CONCRETE MANUAL

PART 2

A Water
Resources
Technical
Publication

NINTH EDITION

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CONCRETE MANUAL

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A Water Resources Technical Publication

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MARCH 3, 1849

A manual for the control
of concrete construction

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Materials Engineering Branch
Research and Laboratory Services Division
Denver Office
1992

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

SI METRIC

PREFACE

The Ninth Edition of the *Concrete Manual* continues a Bureau of Reclamation tradition for providing its technical staff with current information on concrete technology and testing procedures that will help in construction and maintenance of Reclamation's water resources projects throughout the western United States. Unlike previous editions, the Ninth Edition contains two parts. This volume (Part 2) contains standard Reclamation test procedures related to concrete technology and replaces the test designations in the appendix of the Eighth Edition. Part 1, will contain the text on concrete technology.

Evolving from a set of loose-leaf, blue-print instructions, the first tentative edition of the manual was published in 1936. Previous editions to this Ninth Edition have had approximately 153,000 copies distributed throughout the world. The *Concrete Manual* is issued primarily for Bureau of Reclamation staff use; however, it has received widespread acceptance throughout the United States and in many foreign countries.

Since the fundamentals of good concrete practice change little over the years, continued research and construction experience advance the technology to make concrete more versatile, dependable, and economical. This volume (Part 2) presents test procedures that reflect advances in concrete technology. The procedures are published primarily for Reclamation's staff in administering construction and repair specifications and contracts. Some procedures in Part 2 are directly referred to by Bureau of Reclamation specifications. When this is done, these referenced procedures have the full effect of specification requirements. In instances where procedures in Part 2 of the Concrete Manual are at variance with specifications requirements, the specifications take precedence.

The Ninth Edition of the *Concrete Manual* and earlier editions represent the expertise of individuals too numerous to mention. Their contributions are acknowledge since each edition is based upon the technically sound foundation of previous editions.

The Materials Engineering Branch, Research and Laboratory Services Division, Denver Office of the Bureau of Reclamation is responsible for preparing the *Concrete Manual.*

James S. Pierce, Chief of the Materials Engineering Branch, supervised production of the Ninth Edition and made substantial technical contributions. The existence of Part 2, in large part, is due to the relentless efforts of E. F. (Sam) Samuelson (retired Reclamation engineer) of the Materials Engineering Branch, Field Operations Team, who devoted nearly a decade to production, documentation, and review of the test procedures. He enlisted the help of many engineers and technical specialists in the Materials Engineering Branch and throughout the Bureau of Reclamation to ensure the accuracy of the test procedures. Significant contributions were also made by individuals outside Reclamation. Ed Harboe, a retired Reclamation engineer, returned and contributed his more than 40 years of concrete technology experience to the test procedures. Edwin R. Dunstan, Jr., a former Reclamation engineer, and Robert E. Philleo (deceased, U.S. Army Corps of Engineers) wrote several procedures under contracts with Reclamation.

Editorial review of the test procedures was provided by Marlene Johnson, and by technical editors Ron Mohr and Richard Walters of the Denver Office. Typesetting and graphics personnel of the Denver Office assisted in producing all 94 test procedures. Coordination for publication was done by Kathy Bauer. Their assistance and many other individuals, past and present, who contributed to this publication is gratefully acknowledged.

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REFERENCED DESIGNATIONS

INTRODUCTION

The Ninth Edition of the *Concrete Manual*, unlike previous editions, has two parts. Part 1 will contain the text on concrete technology. This volume, Part 2, is a compilation of concrete test procedures currently used by the Bureau of Reclamation.

Part 2 includes many procedures that were not in the Eighth Edition Appendix. A few procedures in the Eighth Edition are outdated; consequently, they were not reproduced in this edition. Some of the previous procedures were combined into a single procedure in this edition; other procedures were modified. While some of the new procedures are based upon previous procedures, attempt is not made to cross reference the procedures in Part 2 (9th ed.) with those in the Eighth Edition (app.).

These test procedures are frequently referenced in Reclamation construction specifications and thereby become a part of a construction contract. If the specifications reference test procedures in *Concrete Manual*, Eighth Edition, those procedures in the Eighth Edition become part of the contract and no attempt should be made to use an updated version in the Ninth Edition for that particular contract. If the specifications reference test procedures in Part 2, Ninth Edition, those procedures become a part of the contract; procedures from previous editions do not apply. Where specifications requirements are at variance with referenced test procedures, the specifications take precedence.

The format presenting the standard Bureau of Reclamation laboratory procedures follows a Modified Decimal Numbering system and a sequence of presentation similar to that used by the American Society for Testing and Materials (ASTM). Each procedure has a four-digit number corresponding to the following categories:

Category	*USBR Series*
Equipment calibration	1000
Equipment specifications	2000
General test methods and definitions	3000
Cement and concrete test methods	4000
Soil test methods	5000
Rock test methods	6000
Drilling and sampling methods	7000
General standards	9000
Accreditation and certification	9000
Equipment (list, inventory)	9100
Laboratory buildings	9200
Quality assurance, documentation, and reporting	9300

For some categories, standards or methods are not yet developed, are under development, or are found in other Reclamation publications such as the *Earth Manual*, Part 2.

Whenever possible, ASTM standards were consulted as a basis for the Bureau of Reclamation procedures; however, these procedures are written in a more detailed step-by-step format. Therefore, this volume serves as a testing handbook as well as a collection of standards. In Part 2, test procedures include examples of Reclamation's data forms and worksheets to illustrate what data are required and where they are to be recorded. Checking data computations is as important as performing the test; the test is not considered complete until the data form has been checked. Checkmarks are not shown on the example data forms so that required data are illustrated neatly and legibly. Instructions for checking, and an example of a typically checked data form, are presented in USBR 9300: Checking, Rounding, and Reporting of Laboratory Data. This document should be reviewed and understood as it is considered part of every test procedure.

A number of procedures for equipment calibration were developed for Reclamation's *Earth Manual*, Part 2. They are noted in the contents as Referenced Designations. Regular calibration and inspection of equipment are as important as adhering to proper testing procedures to ensure acceptable accuracy of results.

Currently, many laboratory tests are performed using computer equipment for running the test, collecting data, and computing and presenting results. In Part 2, the test procedures provide the necessary information for handwritten recording of data and for computing results. Regardless of the methods used, the test procedure requirements are the same. Computerized operations must conform to the test requirements and to the specified accuracies. It is essential that engineers and technicians using computerized operations completely understand the handwritten operations so that the accuracy of results can be confirmed.

Occasionally, references are made to proprietary materials or products. Such references are for clarity only, and must not be construed as an endorsement. The Bureau of Reclamation does not and cannot endorse proprietary products or processes of manufacturers or the services of commercial firms for advertising, publicity, sales, or other purposes.

Each test procedure has a fixed USBR procedure number followed by the year of acceptance or the year of last revision. Revisions will be issued, as required, and the user must ascertain that the latest revision is being used.

Bureau of Reclamation organizational units are noted in the introduction of each test procedure and within the text of others. Recent organizational changes make those references obsolete; all references to the Concrete and Structural Branch should be to the Materials Engineering Branch.

After each test procedure was written, it was checked, validated whenever practical, and extensively reviewed. However, because the procedures are presented in a new format covering both new procedures and revisions to existing procedures, errors and omissions may exist. User comments and suggestions for improvement are invited and should be directed to:

BUREAU OF RECLAMATION
RESEARCH AND LABORATORY SERVICES DIVISION
MATERIALS ENGINEERING BRANCH D-3730
PO BOX 25007
DENVER CO 80225-0007

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1104-92

PROCEDURE FOR
LOAD VERIFICATION OF TESTING MACHINES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1104; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: E4-83a.

1. Scope

1.1 This designation covers the procedure for load (force) verification of tension or compression testing machines using standard calibration devices, and static or quasi-static testing machines, which may or may not have load-indicating systems. This procedure is not intended to be complete purchase specifications for testing machines.

1.2 Testing machines may be verified using elastic calibration devices. This applies to verification of load-indicating systems associated with machine such as a scale, dial, marked or unmarked recorder chart, or digital display. In all cases, the responsible party must designate which load-indicating system is to be verified, and this designation should be included in the report.

2. Applicable Documents

2.1 *ASTM Standards*:
E 4 Standard Practices for Load Verification of Testing Machines[1]
E 74 Standard Methods of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines[2]

3. Terminology

3.1 *Testing Machine*.-A mechanical, load-measuring device for applying a load (force) to a specimen.

3.2 *Load*.-In the case of testing machines, a force measured in units such as pound-force, kilogram-force, or newtons (note 1).

NOTE 1.-A pound-force is that force when acting on a 1-pound mass will give to that mass an acceleration of 32.1740 ft/s^2 (9.80665 m/s^2). Similarly, a newton is that force when acting on a 1-kilogram mass will give to that mass an acceleration of 1 m/s^2 (3.2808 ft/s^2).

3.3 *Accuracy*.-The specified permissible variation from correct value. A testing machine is said to be accurate if indicated load is within specified permissible variation from actual load.

NOTE 2.-In this procedure, the term "accurate," as applied to a testing machine, is used without numerical values. For example, "An accurate testing machine was used for the investigation." The accuracy of a testing machine should not be confused with the sensitivity. For example, a testing machine might be very sensitive; that is, it might indicate quickly and definitely small changes in load, but may be very inaccurate. However, the accuracy of the results is generally limited by the sensitivity.

3.4 *Error*.-The error, or deviation from the correct value, is the difference obtained by subtracting the load indicated by calibration device from load indicated by testing machine.

NOTE 3.-The term "error" shall be used with numerical values. For example, "At a load of 30,000 lbf (133.4 kN), the error of the testing machine was +15 lbf (+0.07 kN)."

3.5 *Percent Error*.-For a testing machine, the percent error is the ratio, expressed as a percent, of the error to correct value of applied load.

3.5.1 The test load, as indicated by testing machine, and applied load, as computed from readings of verification device, shall be recorded at each test point. The error and percent error shall be calculated from these loads as follows:

$$E = A - B \tag{1}$$

$$E_p = \frac{A - B}{B} (100) \tag{2}$$

where:

E = error, in pound force (newtons);
A = load indicated by machine being verified, in pound force (newtons);
B = correct value of applied load as determined by calibration device, in pound force (newtons); and
E_p = percent error.

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[1] *Annual Book of ASTM Standards*, vols. 03.01, 04.02, 07.01, 08.03.
[2] *Annual Book of ASTM Standards*, vol. 03.01.

3.6 *Correction.*–For a testing machine, the correction is the difference obtained by subtracting indicated load from correct value of applied load.

3.7 *Permissible Variation.*–For testing machines, the permissible variation (or tolerance) is the maximum allowable error in the value of the load indicated.

NOTE 4.–It is often convenient to express permissible variation in terms of percentage of error. A numerical value of permissible variation is therefore given in this procedure.

3.8 *Capacity Range.*–For a testing machine, the capacity range is the range of loads for which machine was designed. Some testing machines have more than one capacity range.

3.9 *Verified Loading Range.*–For a testing machine, the verified loading range is the range of indicated loads for which machine gives results within permissible variations specified.

3.10 *Elastic Calibration Device.*–A device used for verifying load readings of a testing machine that consists of an elastic member or members to which loads may be applied; combined with a mechanism or device for indicating the magnitude, or a quantity proportional to magnitude, of deformation under load.

4. Calibration Devices

4.1 When verifying testing machines, use calibration devices over their class A loading ranges only, as determined by ASTM E 74.

4.2 *Proving Rings*:

4.2.1 *Handling.*–Proving rings (fig. 1) are made of high-grade, high-strength, special alloy steel; and are calibrated by NIST (National Institute of Standards and Technology)[3] in accordance with ASTM E 74. These rings have to show certain characteristics under stress or they will not be approved for verification. The rings are very sturdy, and will retain their calibration under adverse conditions. The micrometer dial (fig. 2) on the proving ring should be protected against any treatment that might bend the dial or damage the threads. Never lift a proving ring by the micrometer dial, index posts, or by the mounting for the vibrating reed. Also, never grab the ring with a metal hook or anything that might scratch the surface or change its characteristics. Occasionally, a large proving ring must be handled in a rope sling; if this is necessary, ensure sling does not bear against micrometer dial, vibrating reed, or against any part of internal bosses.

4.2.1.1 Careless handling may cause proving rings to become useless as a verifying instrument; therefore, it is necessary that rings be handled with care. Do not handle rings with bare hands; use a clean cloth or gloves on all handling operations to eliminate possibility of corrosion or other damage to ring surface. The steel ring will rust easily, and should be wiped with an oil cloth after each handling. The dial and index posts are of rust-resistant material. Should ring become rusted, the rust may be carefully removed by hand rubbing with fine emery paper following direction of grinding marks on ring.

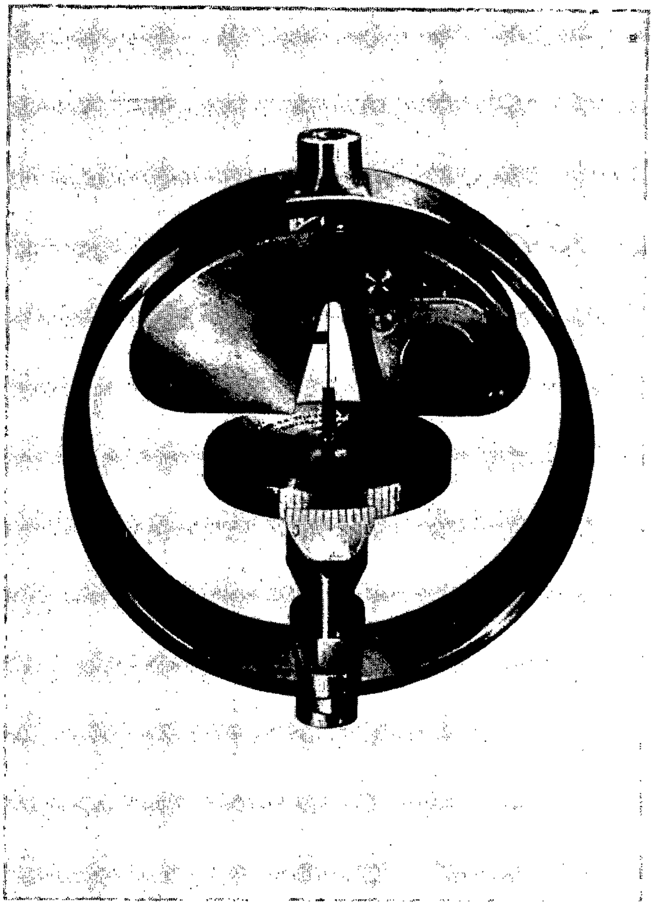

Figure 1. - Proving ring.

4.2.1.2 The external bosses of the proving ring are carefully formed at the factory. The lower boss is flat, and the upper boss is spherical with a radius equal to height of ring. When placing ring on a metal surface, set it down carefully to avoid raising a burr or upsetting the metal of the boss. Never load the upper boss directly against the compression head of the machine; use a mild steel pad between boss and machine head and discard pad when it becomes deformed.

4.2.2 *Calibration.*–The calibration of the proving ring remains practically unchanged under normal service conditions. However, a severe overload will change the calibration and every precaution should be taken to avoid such an overload. If an overload does occur, immediately note the zero-load reading of ring and compare it with zero-load readings taken before overload. If difference in readings exceeds 10 divisions, the calibration may have changed by more than the NIST specifications permit, and ring should be recalibrated.

4.2.2.1 The frequency for recalibrating the proving ring is difficult to establish because the ring does not exhibit any appreciable drift with time, and the main causes of any change are overloads and wear between vibrating reed and spherical tip of the micrometer dial. This wear is dependent on amount of use that ring gets and on how tight the dial is set during use. In a laboratory where ring

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[3] Formerly National Bureau of Standards.

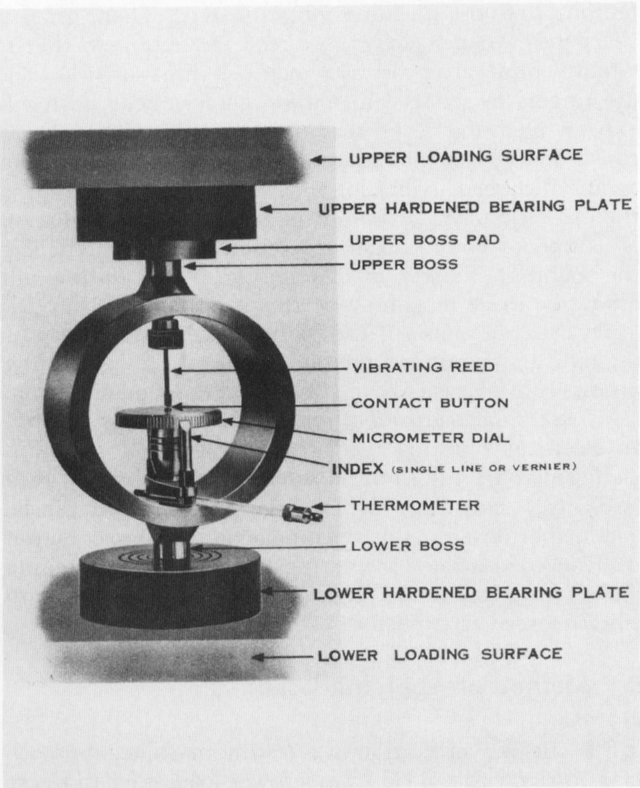


Figure 2. - Mounted proving ring.

is used under careful supervision by only one person a few times a year, 5 or 10 years between calibrations may be satisfactory. However, where ring is in daily use by a variety of personnel, yearly calibrations are advisable.

4.2.2.2 Should ring require repairs, it should be returned to the factory. However, Bureau personnel have replaced the reed with no problems. Rigid requirements have been set by NIST on the performance of proving rings, and any repairs or alterations may cause ring to fail when it is recalibrated.

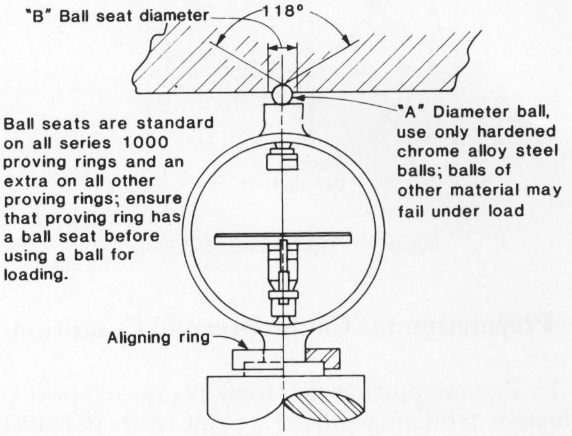
5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Advantages and Limitations of Methods

6.1 *Verification by Elastic Calibration Devices.*-The method of verification of testing machines involves measurement of the elastic strain or deflection under the load of a ring, loop, tension or compression bar, or other elastic device.

6.2 *System Calibration.*-A testing machine must be calibrated as a system with the primary load-sensing and indicating devices in place and operating, refer to figures 3, 4, and 5. If these devices are removed and checked independently of testing machine, such calibrations are not valid.



Diameter, inches(mm)		Capacity	
"A"	"B"	pound mass	kilograms
3/8 (9.5)	11/32 (9)	0-2,000	0-1000
7/16 (11)	11/32 (9)	5,000-6,000	2500-3000
7/16 (11)	3/8 (9.5)	10,000-30,000	5000-15 000
5/8 (16)	1/2 (13)	40,000-60,000	20 000-30 000
7/8 (22)	3/4 (19)	100,000	50 000
1-1/2 (38)	1 (25)	200,000	100 000
1-3/4 (44.5)	1-1/4 (32)	300,000	150 000

Figure 3. - Standard setup for calibrating load cells in a universal calibrating machine.

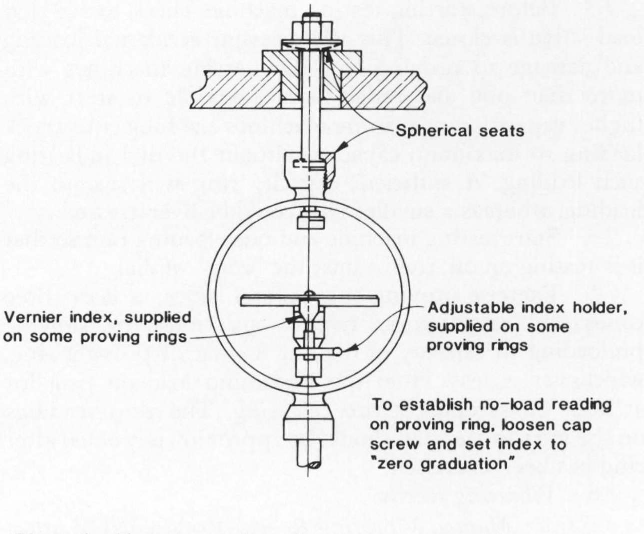


Figure 4. - Typical setup for calibrating a testing machine in tension.

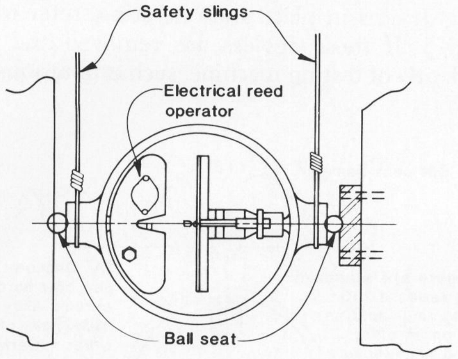


Figure 5. - Typical horizontal setup.

7. Preparation for Calibration and Conditioning

7.1 Remove proving ring from its case and place near calibration position so that ring can reach temperature equilibrium that will prevail during calibration. Standard practice is to set up equipment the afternoon or evening prior to day of calibration. Attach a thermometer to ring by taping bulb of thermometor against side of ring. A magnetic, surface-temperature thermometer will eliminate possibility of tape marring surface of ring.

7.2 The spherical head of the testing machine shall be removed and replaced by a solid head. If a solid head is not available, spherical head should be made as rigid as possible with its bearing surface parallel with upper bearing surface of proving ring. The proving ring is installed by placing it directly upon a hardened bearing block placed on compression table of machine. Another hardened bearing block is placed on top bearing of ring. These bearing blocks are supplied with the proving ring. The 400,000-lbf (1779-kN) proving ring at the Bureau's Denver Office has bearing blocks specially made for this ring because the blocks furnished by the manufacturer were not considered safe.

7.3 Before starting testing machine, check to see that load valve is closed. This will prevent accidental loading and damage to proving ring. On testing machines with more than one dial range, it is advisable to start with higher capacity range. Some machines are subject to shock loading to maximum capacity without the dial indicating such loading. A sufficient capacity ring will sustain the loading, whereas a smaller ring could be overstressed.

7.4 Start testing machine and raise loading ram so that it is resting on oil; then adjust the "zero" of dial.

7.5 Exercise proving ring several times, at least three times and as many as five or six times, by slowing preloading to capacity of dial, or to that of proving ring, whichever is less. Hold the maximum load on ring for at least 20 seconds before releasing. The zero readings on the micrometer dial should be approximately equal after ring has been exercised.

7.6 *Vibrating Reeds*:

7.6.1 *Manual Vibrating Reeds*.–Rotate dial counterclockwise, edge nearest operator to the right, until contact button is almost touching vibrating reed. Then, using a sharpened wooden dowel, set reed in motion so that it vibrates in an arc about 1/2 inch (13 mm) long. Do not use fingers to set reed in motion because body heat will expand reed and make readings unreliable. Continue to rotate dial with one hand until contact button touches the arc in which reed is vibrating and slightly checks or dampens the oscillation. Make the setting such that the oscillation is dampened out in about 2 seconds. Learn to recognize the sound of the reed at this setting so that setting will always be made in same way; this is occasionally difficult to do over the noise of the pump. Observing the top of the reed and forming a mental picture of the dampening process is often easier than remembering sound of setting.

7.6.2 *Electrical Vibrating Reeds*.–If proving ring has an electrical vibrating reed, the instructions for manipulating dial are the same as for a manual vibrating reed (sec. 7.6.1). However, highest degreee of accuracy can be obtained by observing dampening action as contact button is advanced into path of vibrating reed rather than listening for a change in sound. It is not recommended to stop vibrating reed action before taking a reading.

8. Method of Applying Load

8.1 In the verification of a testing machine, approach loads by increasing load from a lower load, refer to figure 6.

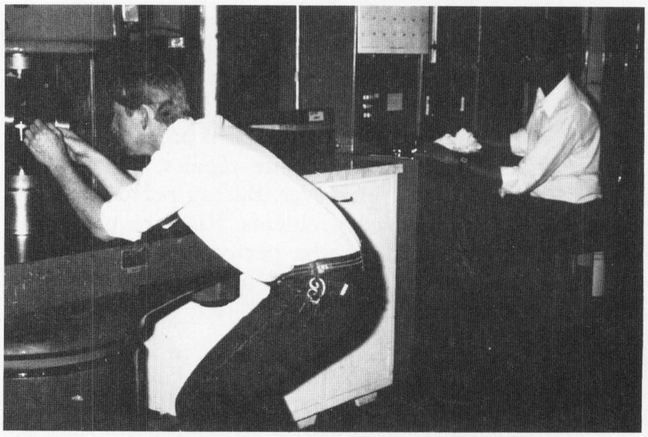


Figure 6. - Calibrating a testing machine in compression.

NOTE 5.–For any testing machine, errors observed at corresponding loads taken initially by increasing load to any given test load and then by decreasing load to that test load, may not agree. Testing machines are usually used under increasing loads; however, if machine is to be used under decreasing loads, machine should be calibrated under decreasing loads as well as under increasing loads. For any particular reading that has overshot desired point of reading, back off load about 10 percent below desired point and then increase to desired setting for the reading. Proving rings tend to retain some deformation if overshot and then lowered to desired point of reading, which causes problems in determining the calibration.

9. Selection of Test Loads

9.1 For any loading range, verify testing machine by using at least five test loads, except for testing machines designed to measure only a smaller number of definite loads, such as some hardness testing machines. The difference between any two successive test loads shall not exceed one-third the difference between maximum and minimum test loads. Report zero-load value of dial, digital display, and all other data after removal of load. Figure 8 shows typical data form.

9.2 If it is desired to establish the lower limit of a verified range lower than 10 percent of capacity of range, verify this lower limit by five successive applications of load, none of which may differ from this lower limit load by more than ±2.5 percent of this load. Only three successive load applications are required for creep machines with fixed-lever ratios of 20:1, nominal, or less.

10. Eccentricity of Loading

10.1 For determining verified loading range of a testing machine, apply all calibration loads so that resultant load is as close as possible to being along axis of testing machine.

NOTE 6.–The effect of an eccentric load on accuracy of a testing machine may be determined by verification readings taken with calibration devices placed so that resultant load is applied at definite distances from axis of machine, and a verified loading range determined for a series of eccentricities.

VERIFICATION BY ELASTIC-CALIBRATION DEVICE

11. Temperature Equalization

11.1 When using an elastic calibration device to verify readings of a testing machine, place device near to, or preferably in, the machine a sufficient length of time before test to assure that response of device is stable.

11.2 During verification, measure temperature of elastic device within ±2 °F or ±1 °C by placing a calibrated thermometer as close to device as possible.

11.3 Elastic calibration devices without an inherent temperature-compensating feature must be corrected mathematically for the difference between ambient temperature and temperature to which calibration is referenced. Temperature-correction coefficients should be furnished, if applicable, by manufacturer of calibration device. For additional information, see paragraph 8.2.2 of ASTM E 74.

11.4 All proving rings are now being calibrated at 73.4 °F (23 °C). Temperature correction is obtained from the equation:

$$D_{73.4} = D_t - 0.00015\,(t - 73.4)\,D_t \qquad (3)$$

$$D_{23} = D_t - 0.00027\,(t - 23)\,D_t \qquad (4)$$

where:

$D_{73.4}$ and D_{23} = ring deflection at 73.4 °F (23 °C),
D_t = ring deflection at monitored temperature, °F (°C),
t = temperature recorded at time of test, and
0.00015 = correction factor for each degree Fahrenheit, and
0.00027 = correction factor for each degree Celsius.

The temperature correction is the amount that must be added or subtracted to deflection to compensate for temperatures other than temperature at which proving ring was calibrated. For temperature correction factors, see table 1 or figure 7, and for an example calculation on determining ring load, see appendix X1.

12. Procedure

12.1 It is standard Bureau practice to average the zero reading and temperature reading before and after each run of five incremental loads. The rings are very sensitive to temperature, and changes in ring readings are very obvious as temperature changes.

Note 7.–The standardizing laboratory shall decide whether or not a zero-load reading is to be taken after each calibration load. Factors such as the stability of the zero-load reading and the presence of noticeable creep under load are to be considered in making this decision. It is pointed out, however, that a lengthy series of incremental loads applied without return to zero reduces the amount of sampling of instrument performance. The operation of removing all load from the instrument permits small readjustments at the load contacting surfaces, increasing the amount of random sampling and thus producing a better appraisal of the performance of the instrument. It is recommended that not more than five incremental loads be applied without return to zero load.

12.2 Minimal maintenance requirements will be realized when establishing initial placement of a testing machine in an environment that is relatively dust free. Calibration procedures are enhanced when machine is placed in a location where temperature is usually constant, and away from open-door drafts.

12.3 Place elastic device in testing machine so that centerline of device coincides with centerline of heads of machine. Record the ASTM E 74, class A verification value that establishes the lowest limit, or load level, allowable for loading range of device, see paragraph 7.5.2.2 of ASTM E 74. Each elastic calibration device is to be used only within its class A loading range, and identified with verification readings for which it is used.

12.4 To ensure a stable zero, flex elastic device from no load to the maximum load at which device will be used. Hold the maximum load on ring for at least 20 seconds before releasing. Repeat as necessary, allowing sufficient time for stability.

Table 1. – Temperature correction factors.

Temperature, °F	Temperature correction factor	Temperature, °C	Temperature correction factor
65.0	1.001260	15.0	1.002160
65.5	1.001185	15.5	1.002025
66.0	1.001110	16.0	1.001890
66.5	1.001035	16.5	1.001755
67.0	1.000960	17.0	1.001620
67.5	1.000886	17.5	1.001485
68.0	1.000810	18.0	1.001350
68.5	1.000735	18.5	1.001215
69.0	1.000660	19.0	1.001080
69.5	1.000585	19.5	1.000945
70.0	1.000510	20.0	1.000810
70.5	1.000435	20.5	1.000675
71.0	1.000360	21.0	1.000540
71.5	1.000285	21.5	1.000405
72.0	1.000210	22.0	1.000270
72.5	1.000135	22.5	1.000135
73.0	1.000060	23.0	1.000000
73.5	0.999985	23.5	0.999865
74.0	0.999910	24.0	0.999730
74.5	0.999835	24.5	0.999595
75.0	0.999760	25.0	0.999460
75.5	0.999685	25.5	0.999325
76.0	0.999610	26.0	0.999190
76.5	0.999535	26.5	0.999055
77.0	0.999460	27.0	0.998920
77.5	0.999335	27.5	0.998785
78.0	0.999310	28.0	0.998650
78.5	0.999235	28.5	0.998515
79.0	0.999160	29.0	0.998380
79.5	0.999085	29.5	0.998245
80.0	0.999010	30.0	0.998110
80.5	0.998935		
81.0	0.998860		
81.5	0.998785		
82.0	0.998710		
82.5	0.998635		
83.0	0.998560		
83.5	0.998485		
84.0	0.998410		
84.5	0.998335		
85.0	0.998260		

12.5 *Follow-the-Load Method.*–The load on the elastic calibration device is followed until load reaches a nominal graduation on load-readout scale of testing machine. Record this load on the elastic calibration device. This method is for calibrating a testing machine in compression with a proving ring having a manually-operated vibrating reed. However, regardless of whether a testing machine, load cell, hydraulic press, or other type of load-measuring system is to be calibrated, the same general method should be followed.

12.5.1 This method is probably the most accurate method available, and is recommended for the minimally experienced operator. However, caution must be exercised because the hydraulic oil in older testing machines, such as the Tinius-Olsen, will heat up with loading and unloading and will refuse to load beyond a certain point.

12.5.2 With head of machine adjusted to be nearly in contact with boss pad, take a no-load reading on proving ring and turn dial to a reading equal to capacity load deflection plus the no-load reading. Allow about five extra divisions for a safety factor. This precaution is necessary to prevent overloading the proving ring because of possible excessive error in load indicator of machine. It is possible to anticipate where setting will be by using ring calibration data and adding or subtracting ring zero. The micrometer can then be moved ahead to minimize danger of bending reed. Testing machines are occasionally hard to hold at a particular setting; therefore, if setting is anticipated, the time required to obtain reading will be lessened.

12.5.3 Zero the load indicator of the testing machine. Then, after carefully centering ring on axis of machine, apply desired load slowly and have machine operator adjust machine during the final part of loading to slowest speed at which machine will continue to load. This may require some skillful manipulation by the operator, depending on type of machine. When machine indicator is within 10 divisions of load to be read, have operator give a signal, such as "ready." Set the vibrating reed in motion and turn dial to the right until a light contact is established. Record the deflection of proving ring at desired load, and then give the operator an "OK" signal, at which time the operator should load the machine to the next desired load. This procedure shall continue for five consecutive loads before returning to zero. After removing load, take and record a no-load reading on proving ring. On large-capacity rings, those with 200,000 lbf (89 kN) and higher capacities, wait 30 to 60 seconds after removal of load to equalize temperature effects.

12.5.4 Do not be concerned that the increasing testing machine load will lightly jam the reed and contact button together because proving ring is designed to be used in this manner. However, never attempt to free reed while it is jammed, either by pushing it aside or by turning the dial. Always slack off the machine load first, and then back the dial off. If this precaution is observed, a jam serious enough to cause the reed to buckle quite noticeably will not damage the instrument.

12.5.5 The average temperature for the two no-load readings taken before and after each run of five incremental readings is used for the temperature correction computation for each load level.

12.5.6 The follow-the-load method is utilized for verification by the CCRL (Cement and Concrete Reference Laboratory) of the NIST, which periodically checks the Bureau of Reclamation's testing machines. The Bureau generally uses five incremental load values with the first one at about 10 to 20 percent of range capacity, the next three at about every 10 to 20 percent after the first, and the last one at maximum capacity, if the machine will allow it (note 8).

NOTE 8.–The factory representatives for the Satec machine use the maximum load capacity. This is not possible to do with all machines because many machines are very unstable at maximum load. Also, using the maximum load requires more accuracy in reading the proving ring; therefore, this method is not recommended for the minimally experienced operator.

12.5.7 After selecting the suitable test load increments, obtain zero readings for both machine and elastic device and apply loads slowly and smoothly during all

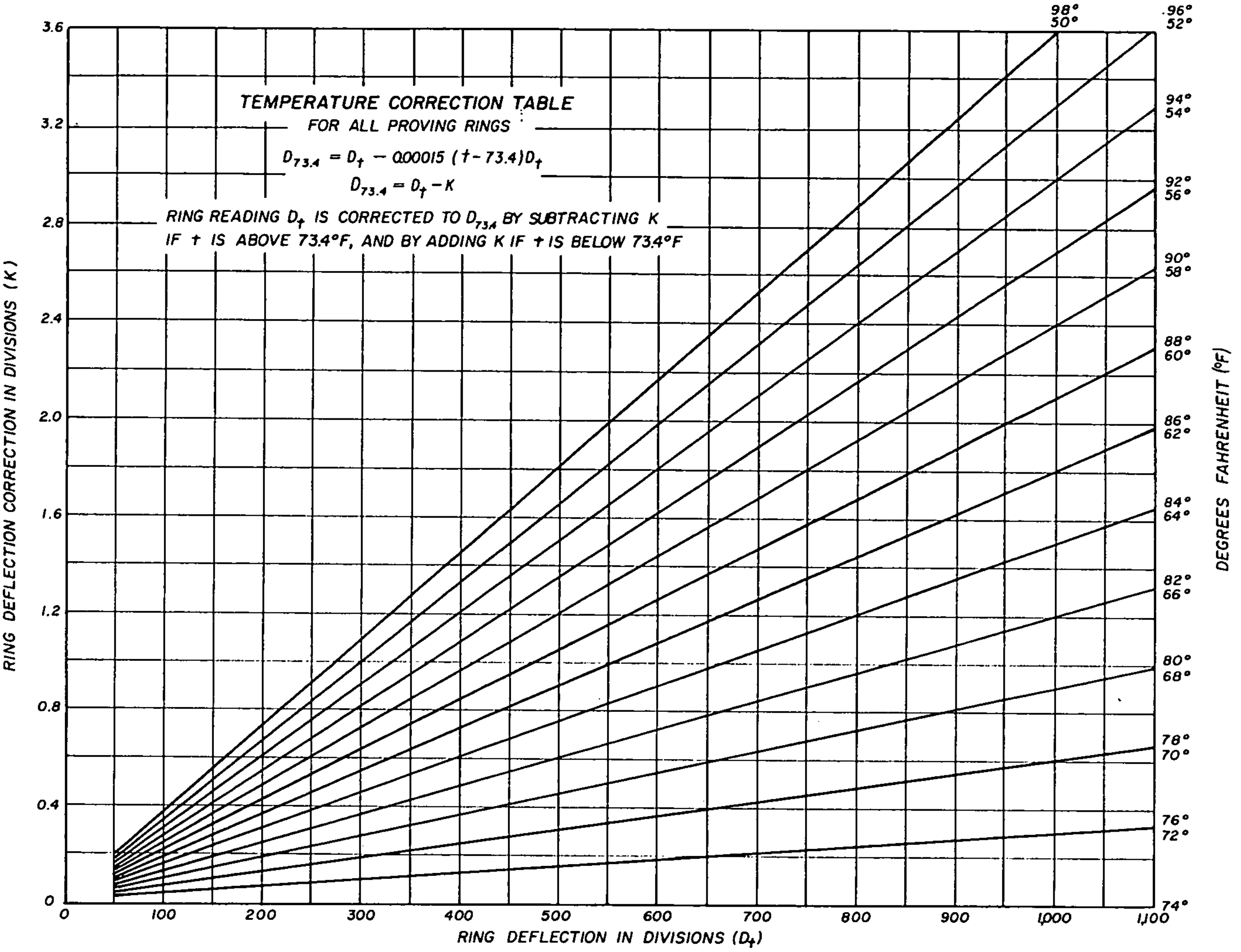


Figure 7a. - Temperature correction graph (inch-pound units).

verification measurements. The technique for applying the loads is as previously discussed. After preloading proving ring, a no-load or zero reading is taken and recorded. Ring is then stressed and a reading obtained for the preselected load values until entire dial has been compassed, after which load is released and another zero reading taken. The two zero readings are averaged for the correction computations. The appropriate method for each calibration must be decided through trial and error to fit particular machine and existing conditions.

12.6 The calibration procedure must assure that use of the maximum load indicator, recorder, or other accessory load devices does not cause testing machine errors to exceed acceptable tolerances of section 13.1.

12.7 Record indicated load of testing machine and applied load from elastic calibration device (temperature corrected as necessary), in addition to the error and percentage of error calculated from readings.

12.8 Under certain conditions, multidevice setups may be used in compression loading. All devices to be loaded in parallel should be the same height (shims may be used), and machine's load axis should be coincidental with load axis of device setup. This is necessary so that a net moment is not applied to testing machine loading member. Multidevice setups are not recommended unless the use of a single calibration device is not practical.

CALCULATION AND REPORT

13. Basis of Verification

13.1 The percent error for loads within loading range of testing machine shall not exceed ±1.0 percent (note 9).

NOTE 9.-The report on verification of a testing machine will state within what verified loading range machine may be used, rather than reporting a blanket acceptance or rejection of machine. For machines that possess multiple-capacity ranges, the verified loading range of each range must be stated.

13.2 When establishing lower limit of a verified loading range below 10 percent of capacity of range, repeated

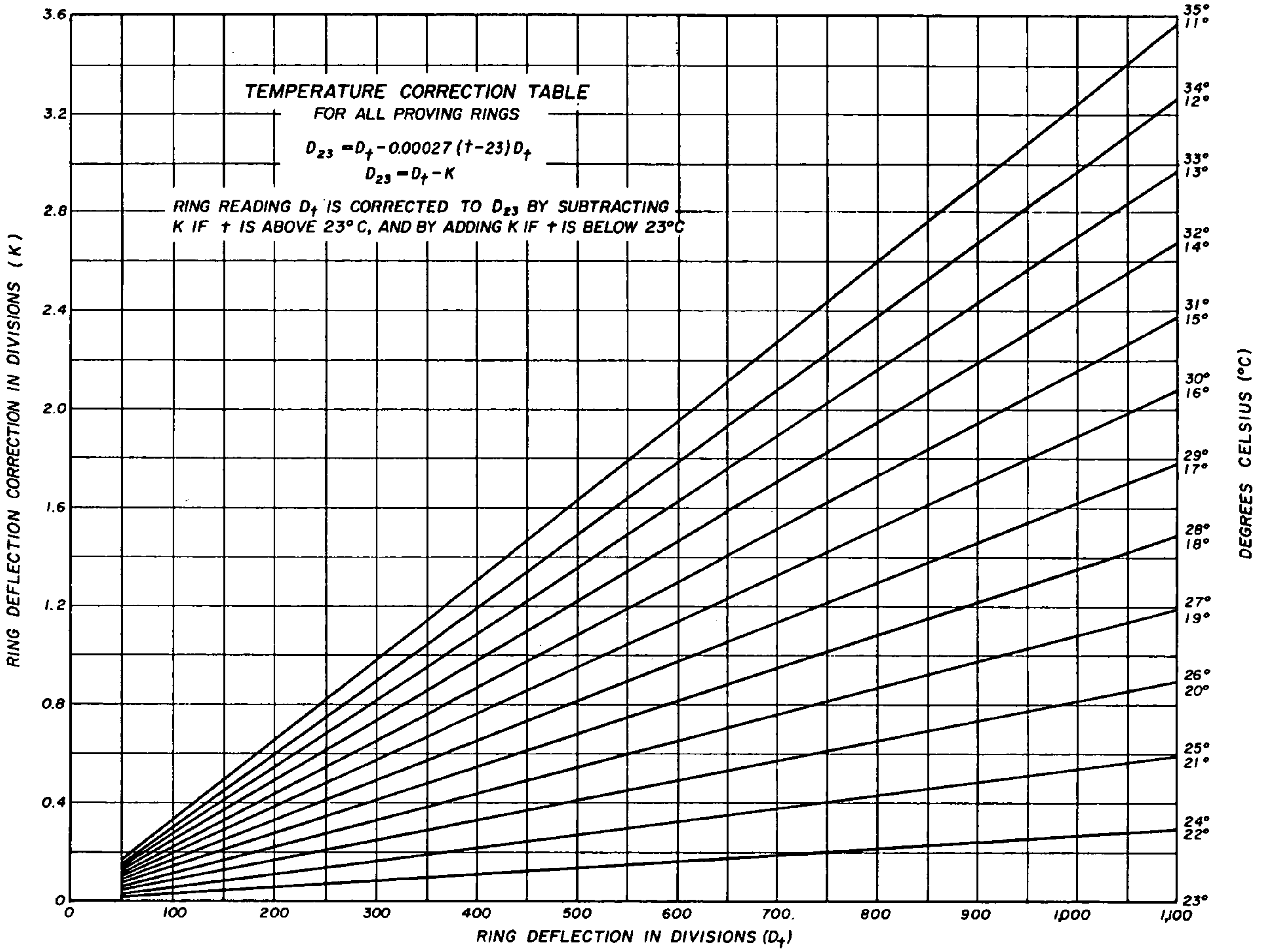


Figure 7b. – Temperature correction graph (SI-metric).

applications of load are required (see sec. 9.2). The algebraic difference between highest and lowest percent error shall not exceed 1.0 (note 10).

NOTE 10.–To establish lower limit of a verified loading range at less than 10-percent capacity of that range, errors for the series of five readings shall not only not exceed 1 percent; but also, no two errors shall differ by more than 1.0 percent. For example, if minimum error in this series is –1.0 percent, maximum error cannot exceed 0.0 percent; if minimum error is -0.5 percent, maximum error cannot exceed +0.5 percent; and if minimum error is 0.0 percent, maximum error cannot exceed +1.0 percent, etc.

13.3 In no case shall verified loading range be stated as including loads below a value that is 100 times the smallest change of load than can readily be estimated on load-indicating apparatus of testing machine (note 11).

NOTE 11.–In a testing machine that has graduations so spaced that estimations can be made to 0.1 of a division, verified loading range could not extend downward to a load less than that corresponding to 10 divisions. If graduations on load-indicating scale can only be estimated to 2 divisions, verified loading range could not extend downward below load corresponding to 200 divisions. On most machines, the smallest load than can be measured is somewhere between these two examples.

13.4 In no case shall verified loading range be stated as including loads outside the range of loads applied during verification test.

13.5 Testing machines may be more or less accurate than the allowable ±1.0 percent error, which is the verification basis in this procedure. Errors more than ±1.0 percent would not comply with this procedure. The specifications may also require or allow a smaller or larger error system.

13.6 *Corrections.*–The indicated load of a testing machine that exceeds the permissible variation shall not be corrected either by calculation or by use of a calibration diagram to obtain values within required permissible variation.

13.7 Figures 8 and 9 show examples of manual and computerized calculations.

14. Time Interval Between Verifications

14.1 It is recommended that testing machines be verified annually, or more frequently if required. In no case shall time interval between verifications exceed 18 months, except for machines used in a long-time test that runs beyond this 18-month period. In such cases, machine shall be verified after completion of test. Calibration of machines with minimal use could be extended by some period of time.

14.2 Testing machines shall be verified immediately after repairs. This includes new or replacement parts or mechanical or electrical adjustments that may in any way affect operation of weighing system or values displayed.

14.3 Verification is also required immediately after a testing machine is relocated, and whenever there is a reason to doubt accuracy of indicated load, regardless of time interval since last verification.

15. Accuracy Assurance Between Verifications

15.1 Some product-testing procedures may require daily, weekly, or monthly spot checks to ascertain that a testing machine is capable of producing accurate load values between machine verifications as specified in section 14.

15.2 Elastic calibration devices must meet class A requirements of ASTM E 74 for the load levels at which spot checks are made.

15.3 Make spot checks at about 20 and 80 percent of a range, unless otherwise agreed upon or stipulated by the Government.

15.4 A testing machine error shall not exceed ±1.0 percent of spot check applied loads. Should errors be greater than ±1.0 percent at any of the spot check load levels, verify the testing machine immediately (see sec. 14.3).

15.5 Maintain a record of spot check tests. Record shall include machine name, serial number, verification date, verification agency, and the minimum class A ASTM E 74 value of calibrating device used to make the spot checks. Also include name of individual making the spot checks.

15.6 Testing machine shall be considered verified up to date of last successful spot check verification (sec. 15.4), provided machine is verified in accordance with section 14 on a regular schedule. Otherwise, spot checks are not permitted.

15.7 When spot checks are made, a clear, concise record must be maintained. The record must also contain documentation of regular verification data and schedule.

16. Report

16.1 Figures 8 and 9 show typical reporting forms. The report should be a clear and complete record on each verification of a testing machine, and shall include:

- Name of calibrating agency.
- Date of verification.
- Testing machine description, serial number, and location.
- Method of verification used.
- Serial number and manufacturer of all devices used for verification.
- Statement of how, by whom, and when calibration of apparatus used in verifying testing machine was made.
- The ASTM E 74, class A value of loading range for each calibration device.
- Temperature of calibration device and a statement that computed loads have been temperature corrected as necessary.
- Statement identifying load-indicating systems that were verified (for testing machines having more than one type of indicating system).
- Testing machine error and percent error for each load-indicating system at each loading point.
- Verified loading range of each load-indicating system of testing machine.
- Statement that verification has been performed in accordance with this test procedure.
- Names of calibration personnel and witnesses (if required).

17. Maintenance

17.1 Testing machines require routine maintenance, and should be checked every few months and before calibration for the following:

17.1.1 *Wiring.*–Ensure that all wiring is in good condition. Using dry air, blow the dust from electronic assemblies every 6 months, where appropriate.

17.1.2 *Lines.*–Check all lines for leaks. Air in system lines causes erratic readings, detected by pulsating or jumping of load hand.

17.1.3 *Oil Reservoir.*–Maintain the oil level 1 to 2 inches (25 to 50 mm) from top of reservoir with ram down (mandatory). Use extra heavy duty oil with a viscocity of 313 to 331 at 100 °F (37.8 °C). Currently, the Bureau uses Kendall R+O AW68 hydraulic oil. Ensure that all openings in oil system are covered to keep foreign matter out of oil, and clean debris around hydraulic piston after each use. For machines equipped with an oil filter, change filter every 6 months. Some machines are adaptable to having a filtering system installed. Perform any lubrication required, where applicable. For additional information, call the Bureau's Denver Office.

17.1.4 *Level Condition.*–If loading cylinder is not level, excessive wear may result or ram may stick and permanently damage machine.

17.1.5 *Load Pacer and Limit Switches.*–The load pacer should be adjusted to Bureau specifications. Limit switches for ram travel and to prevent overload of low-range dial should be adjusted to manufacturer's specifications.

17.1.6 *Maximum Load Hand.*–The friction disk should be adjusted so that drag will not be encountered on load hand.

17.1.7 *Shims.*–Check shims of weighing capsule quarterly, if applicable.

17.1.8 *Exercise Machine.*–No machine should sit idle for too long–exercise occasionally (monthly).

18. Precision and Bias

18.1 The precision and bias for this procedure are not known.

LOAD VERIFICATION OF TESTING MACHINES

Machine Type TINIUS-OLSEN, 300,000 lbf (________kN); Serial No.: D-1750.1, Verified Range: 0 to 50,000 lbf (________kN)
Location: DUCHESNE, UTAH, Calibrated by: K. FORBES & K. ATOR, Date: 10-18-83
Proving Ring 100,000 lbf (________kN), Serial No. 2602, Lower Limit-Class A 8,200 lbf (________kN), Verification Date 1-17-83
*Ring factor is determined by latest calibration of proving ring by National Bureau of Standards.

Incremental Loading	10,000 lbf ~~(kN)~~			20,000 lbf ~~(kN)~~			30,000 lbf ~~(kN)~~			40,000 lbf ~~(kN)~~			50,000 lbf ~~(kN)~~			lbf (kN)		
No-Load Time Frame	Before	After	Avg.	Before	After	Avg.	Before	After	Avg.	Before	After	Avg.	Before	After	Avg.	Before	After	Avg.
Ring Reading (RR)	0.0													0.0	0.0			
Temperature, ~~°F~~ (°C)			25												25			
Temp. Correction Factor (F)	0.999460			0.999460			0.999460			0.999460			0.999460					
Deflection at Avg. Temp. (D)	72.0			144.3			217.2			290.9			364.60					
Defl. Corr. (DC) to ~~73.4 °F~~ (23 °C), (D-RR)(F)	71.96			144.22			217.08			290.74			364.40					
*Ring Factor (RF)	138.827			138.712			138.576			138.433			138.293					
Ring Load, (DC)(RF), lbf ~~(kN)~~	9,990			20,005			30,082			40,248			50,394					
Machine Load, lbf ~~(kN)~~	10,000			20,000			30,000			40,000			50,000					
Error, lbf ~~(kN)~~	10			-5			-82			-248			-394					
Error, percent	0.10			-0.02			-0.27			-0.62			-0.79					
Ring Reading (RR)	0.0													0.0	0.0			
Temperature, ~~°F~~ (°C)			24												24			
Temp. Correction Factor (F)	0.999730			0.999730			0.999730			0.999730			0.999730					
Deflection at Avg. Temp. (D)	72.0			144.1			217.1			290.1			364.1					
Defl. Corr. (DC) to ~~73.4 °F~~ (23 °C), (D-RR)(F)	71.98			144.06			217.04			290.02			364.00					
*Ring Factor (RF)	138.830			138.706			138.574			138.435			138.294					
Ring Load, (DC)(RF), lbf ~~(kN)~~	9,993			19,982			30,076			40,149			50,339					
Machine Load, lbf ~~(kN)~~	10,000			20,000			30,000			40,000			50,000					
Error, lbf ~~(kN)~~	7			18			-76			-149			-339					
Error, percent	0.07			0.09			-0.25			-0.37			-0.68					
Ring Reading (RR)	0.0													0.0	0.0			
Temperature, ~~°F~~ (°C)			23												23			
Temp. Correction Factor (F)	1.000000			1.000000			1.000000			1.000000			1.000000					
Deflection at Avg. Temp. (D)	71.9			144.1			217.0			290.1			364.1					
Defl. Corr. (DC) to ~~73.4 °F~~ (23 °C), (D-RR)(F)	71.90			144.10			217.00			290.10			364.10					
*Ring Factor (RF)	138.832			138.709			138.571			138.435			138.292					
Ring Load, (DC)(RF), lbf ~~(kN)~~	9,982			19,988			30,070			40,160			50,352					
Machine Load, lbf ~~(kN)~~	10,000			20,000			30,000			40,000			50,000					
Error, lbf ~~(kN)~~	18			12			-70			-160			-352					
Error, percent	0.18			0.06			-0.23			-0.40			-0.70					
Average Error, percent	0.12			0.04			-0.25			-0.46			-0.72					

Figure 8. - Sample data and calculation form.

TESTING MACHINE CALIBRATION REPORT

Machine data:
Location: PHOENIX, AZ
Capacity: 300,000 lbf
Range: 300,000 lbf
Verified Range: 0,000 to 300,000 lbf
Calibrated by: MITCHELL

Manufacturer: TINIUS-OLSEN
Serial No.: T-70-269-1

Calib.Date: 6/10/87

Proving Ring Data:
Size: 400,000 lbf
Lower Limit Class A: 41,200 lbf
Verification date: 9/16/85

Serial No.: 5-4944

Average Temp:
Run 1 21.9 deg. C
Run 2 22.2 deg. C
Run 3 22.2 deg. C

Load	Run	Deflection Reading	Corrected Deflection	Machine Reading (lbf)	Proving Ring (lbf)	Machine Error (lbf)	Machine Error (%)
1	1	60.8	60.2	60,000.	59,886.	114.	.19
1	2	60.9	60.3	60,000.	59,932.	68.	.11
1	3	61.0	60.2	60,000.	59,833.	167.	.28
2	1	121.2	120.6	120,000.	119,854.	146.	.12
2	2	121.3	120.7	120,000.	119,895.	105.	.09
2	3	121.8	121.0	120,000.	120,193.	-193.	-.16
3	1	181.7	181.2	180,000.	179,859.	141.	.08
3	2	181.6	181.0	180,000.	179,698.	302.	.17
3	3	182.1	181.3	180,000.	179,995.	5.	.00
4	1	241.4	240.9	240,000.	239,010.	990.	.41
4	2	241.6	241.0	240,000.	239,142.	858.	.36
4	3	242.2	241.4	240,000.	239,539.	461.	.19
5	1	301.5	301.0	300,000.	298,497.	1,503.	.50
5	2	301.4	300.8	300,000.	298,329.	1,671.	.56
5	3	301.7	300.9	300,000.	298,428.	1,572.	.52

OVERALL AVERAGES

Load	Deflection Reading	Corrected Deflection	Machine Reading (lbf)	Proving Ring (lbf)	Machine Error (lbf)	Machine Error (%)
1	60.9	60.2	60,000.	59,884.	116.	.19
2	121.4	120.8	120,000.	119,981.	19.	.02
3	181.8	181.1	180,000.	179,851.	149.	.08
4	241.7	241.1	240,000.	239,230.	770.	.32
5	301.5	300.9	300,000.	298,418.	1,582.	.53

Method of verification is in accordance with ASTM Specification E-4 and the above described machine has been found to be within a tolerance of (+/-) 1%.

Figure 9. – Typical testing machine calibration report.

APPENDIX

X.1 EXAMPLE CALCULATIONS FOR DETERMINING RING LOAD AND TESTING MACHINE ERROR (COMPRESSION CALIBRATION)

(Nonmandatory Information)

Simulated Data:

(1) Average proving ring no-load micrometer reading:

Ring micrometer reading before test load (zero) = 2.5
Ring micrometer reading after test load (zero) = 2.7
Average no-load reading = 2.6

(2) Deflection at t °C ($t = 22.8$ °C for this example):

Ring micrometer reading for test load at 22.8 °C = 436.2
Average no-load reading at 22.8 °C = -2.6
Ring deflection at 22.8 °C = 433.6

(3) Two methods that may be used to determine ring deflection at 23 °C are:

(a) Multiply ring deflection (433.6) by temperature correction factor for 22.8 °C from table 1 (1.000054):
True ring deflection = (433.6) (1.000054) = 433.62

(b) Using equation (4) section 11.4, deflection at 23 °C is:

$$
\begin{aligned}
D_{23} &= D_t - 0.00027(t - 23)\,D_t \\
&= 433.6 - 0.00027\,(22.8 - 23)(433.6) \\
&= 433.6 - 0.00027(-0.2)(433.6) \\
&= 433.6 - (-0.02) \\
&= 433.6 + 0.02 \\
&= 433.62
\end{aligned}
$$

(4) Proving ring load:

True ring deflection = 433.62
Ring factor (from ring calibration data) = 138.158
Proving ring load = (433.62)(138.158) = 59,908 lbf (266.5 kN)

(5) Error of testing machine:

Testing machine reading = 60,000
Load applied to proving ring = 59,908
Error = 92 lbf

$$\frac{92}{59{,}908} = 0.00153, \text{ or } 0.15 \text{ percent error}$$

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 3100-92

PROCEDURE FOR

SAMPLING OF WATER

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 3100; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 3370-82.

1. Scope

1.1 This designation covers the procedure for the sampling of water for chemical, physical, microbiological, and radiological analysis. Three methods are included: (1) Method A for grab samples, (2) Method B for composite samples, and (3) Method C for continuous sampling.

1.2 Definite principles have been established for formulating these sampling methods, which are applicable in most specific cases. If necessary, changes may be made to these methods by mutual agreement of all parties concerned.

2. Applicable Documents

2.1 *ASTM Standards*:

D 1129 Standard Definitions of Terms Relating to Water[1]

D 1193 Standard Specification for Reagent Water[1]

D 3370 Standard Practices for Sampling Water[1]

D 3648 Standard Practices for the Measurement of Radioactivity[2]

D 3694 Standard Practices for Preparation of Sample Containers and for Preservation of Organic Constituents[2]

3. Summary of Procedure

3.1 This procedure includes three different methods for sample collection. The first method is for the collection of a grab sample of water at a specific site representing conditions only at the time of sampling. It is the only method suitable for bacteriological analyses and some radiological tests. The second method is for collection of a composite sample at a specific site, portions of which are collected at varied time intervals. The composite sample may consist of portions collected at various sites or a combination of both site and time variables. The third method provides for a continuous flowing sample, from one or more sampling sites, suitable for onstream analysis.

4. Significance and Use

4.1 The objective of sampling is to obtain, for analysis, a portion of the main body of water that is truly representative. The most critical factors necessary to achieve this are the points, time, and frequency of sampling; and maintenance of integrity of sample prior to analysis.

4.2 Homogeneity of the sampling is frequently lacking, which necessitates multiple-point sampling. If using a most-representative sampling point is impractical, it may be better to determine and understand the interrelationships so that results obtained at a minimum number of points may be extrapolated.

4.3 A totally representative sample should not be an absolute prerequisite to selection of a sampling point. With adequate interpretation, a nonrepresentative sample can yield valuable data about trends and can indicate areas where more representative data would be available. Most samples collected from a single point in a system must be recognized as being nonrepresentative to some degree. Therefore, it becomes important to recognize the degree of representation in the sample and to make it a part of the permanent record. Otherwise, an artificial degree of precision is assigned to data when it is recorded.

4.4 The following general rules are applicable to all sampling methods:

- Sample must represent conditions existing at point taken.
- Samples must be of sufficient volume and taken frequently enough to permit reproducibility of testing requisite for desired objective, as conditioned by method of analysis to be used.
- Samples must be collected, packed, shipped, and manipulated prior to analysis in a manner that safeguards against any change in particular constituents or properties to be examined.

4.5 Sampling of high-purity water requires special consideration. Contact with any material other than original container, including contact with air, subjects sample to possible contamination or alteration.

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[1] *Annual Book of ASTM Standards*, vol. 11.01

[2] *Annual Book of ASTM Standards*, vol. 11.02.

5. Terminology

5.1 For definitions of terms used in this procedure, refer to ASTM D 1129.
5.2 *Sampling*.-Obtaining a representative portion of material concerned.

6. Reagents

6.1 *Purity of Reagents* .-Reagent grade chemicals shall be used and, unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[3] Other grades may be used provided it is first ascertained that reagent is of sufficiently high purity to permit its use without lessening accuracy of determination.
6.2 *Purity of Water*.-References to water in this procedure shall be understood to mean type III reagent water conforming to ASTM D 1193.
6.3 *Acid Dichromate (Cleaning Solution)*.-Prepare a saturated water solution of $Na_2Cr_2O_7$ (sodium dichromate). To 32 mL of this solution, add 1 L of concentrated H_2SO_4 (sulfuric acid, sp. gr. 1.84).

NOTE 1.-*Caution*: This solution is a strong oxidant, and contact with other materials may cause a fire. Solution may also cause delayed burns or external ulcers. KEEP CONTAINER CLOSED. Do not get solution in eyes, on skin, or on clothing; and do not breath dust or mist from the solution. In case of contact, immediately flush skin or eyes with water for 15 minutes and seek medical attention immediately after flushing.

6.4 *Nitric Acid* (1 + 4).-Mix 1 volume of concentrated HNO_3 (nitric acid, sp. gr. 1.42) with 4 volumes of water.

NOTE 2.-*Caution*: This acid is a strong oxidant, and contact with other materials may cause a fire. Acid may also cause delayed burns or external ulcers. KEEP CONTAINER CLOSED. Do not get acid in eyes, on skin, or on clothing. Vapors are extremely hazardous, do not breathe them. Use acid only under a protective hood with an exhaust fan. In case of contact, immediately flush skin or eyes with water for 15 minutes and seek medical attention immediately after flushing.

6.5 *Sodium Thiosulfate* .-Powdered $Na_2S_2O_3$.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.
7.2 Specific precautions with reagents are emphasized in notes 1 and 2 of section 6.
7.3 Specific precautions with regard to radioactive water are discussed in sections 14.3 and 17.3.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

9. Conditioning

9.1 Conditioning for temperature adjustments and purity of containers is covered throughout this procedure.

METHOD A — GRAB SAMPLES

10. Scope

10.1 This method is applicable for sampling water from sources such as wells, rivers, streams, lakes, oceans, reservoirs, pipelines and conduits, processing tanks and vats, steam generators, spray ponds, towers, and filters at atmospheric or higher pressures for chemical, physical, bacteriological, or radiological analyses. A grab sample represents the conditions existing only at the point and time of sampling.

11. Frequency and Duration of Sampling

11.1 A reasonably accurate estimate of the composition of a raw water piped from a large body of water, such as the Great Lakes, and far enough from shoreline to avoid variation from inflowing tributaries and waste discharges may be made by taking individual samples at infrequent intervals, such as biweekly or monthly, and sufficient enough to cover seasonal changes. If samples are taken near the shoreline of such a body of water, take samples at shorter intervals, such as daily, to provide more exact knowledge of the variations in composition. If greater variations or cycles of pollution occur or if closer surveillance of plant intake water is required, take even more frequent samples, such as hourly.
11.2 Water undergoing continuous or intermittent treatment must be sampled with such frequency that adequate control is assured. The interval between samples is directly related to the rate at which critical characteristics can reach intolerable limits.

12. Temperature Adjustment

12.1 When samples above ambient temperature are taken, use cooling coils to adjust sample to about the ambient temperature. Some tests require adjustment to other than ambient temperature, and this adjustment should be carried out when indicated.

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[3] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on testing reagents not listed by the American Chemical Society, see References [1,2], section 37.

13. Particulate Matter

13.1 Samples are usually taken without separation of particulate matter. If constituents are present in colloidal or flocculent suspension, take samples so that these suspensions are present in representative proportions.

14. Volume of Sample

14.1 Consult the specific method of analysis for any given constituent to determine volume of sample required. Frequently, the required volume will vary with concentration level of any given constituent.

14.2 The minimum volume collected should be three to four times the amount determined in section 14.1.

14.3 When sampling highly radioactive water, smaller sample sizes may be desirable to reduce the radiation hazard.

14.4 Some tests require analysis of the entire sample and, for these tests, the volume needed determines the volume collected.

15. Point of Sampling

15.1 *Open Bodies of Water*:

15.1.1 Choose point of sampling with extreme care so that a representative sample of the water to be tested is obtained. Avoid surface scum.

15.1.2 Because of a wide variety of conditions found in streams, lakes, reservoirs, and other bodies of water, it is not possible to prescribe the exact point of sampling. Where water in a stream is mixed so as to approach uniformity, a sample taken at any point in the cross-section is satisfactory. For large rivers or for streams not likely to be uniformly mixed, more samples are desirable and are usually taken at a number of points across entire width and at several depths at each point. When boats are used in sampling, take care to avoid collecting samples where turbulence from oars or a propeller has disturbed characteristics of water. Samples are usually taken at these points and then combined to obtain an integrated sample. Alternatively, test the single grab samples to determine point of highest bacterial density.

15.1.3 Select location of sampling point with respect to information desired and in conformity with local conditions. Allow sufficient distance downstream, with respect to streamflow at time of sampling, from a tributary or source of pollution to permit thorough mixing. If this is not possible, it is better to sample stream above tributary or source of pollution and, in addition, sample tributary or source of pollution. A distance of 1 to 3 miles (1.6 to 4.8 km) below the tributary is usually sufficient.

15.1.4 Collect samples at least 0.5 mile (0.8 km) below dams or waterfalls to allow time for the escape of entrained air. When lakes, reservoirs, or other bodies of water are sampled, it is necessary to avoid nonrepresentative areas such as those created by inlet streams, more stagnant areas, or abrupt changes in shorelines unless determining the effect of such conditions is part of the sampling program.

15.1.5 It is desirable to take a series of samples from any source of water to determine whether differences in composition are likely to exist before final selection of sampling point.

15.2 *Confined Flows*:

15.2.1 Select sampling points in pipelines, conduits, tanks, vats, filters, zeolite and chemical water softeners, deionizing processes, surface condensers, evaporators, or condensate return lines with regard to the piping and configuration of individual piece of equipment containing water to be tested. Also consider the character and changes occurring between inlet and outlet water, and rate of passage through equipment. Ensure that a representative sample is obtained by allowing mixing to take place.

15.2.2 A suitable sampling site may be available in piping immediately downstream from a valve or fitting causing turbulent flow. In this case, sampling line should be flush with interior pipe wall. If adequate turbulence is not available, project sampling line to a distance inside the pipe that will prevent surface sampling. This distance should be 25 percent of pipe diameter to a maximum of 4 inches (102 mm).

15.2.3 When water to be sampled is confined at low or subatmospheric pressure, provide special means to extract sample. A basic arrangement, when physical conditions permit, is the installation of a barometric leg. Equipment for removal of a sample from a line or system operating under vacuum consists of a small positive-displacement pump arranged to discharge into sampling container at atmospheric pressure. The pump should be of such material and construction that sample will not be contaminated. The sample container may also be located between pump and sampling point. With this arrangement, container must be valved off, equalized to atmospheric pressure, and drained into another container.

16. Sample Containers

16.1 Sample containers shall be made of materials that will not contaminate sample, and shall be cleaned thoroughly before use to remove all extraneous surface soil. Chemically-resistant glass and rigid and collapsible plastic containers of polyethylene and polypropylene are suitable. Polypropylene bottles are particularly suited for microbiological samples because they are autoclavable. Plastic containers are not suitable for samples collected for organic analyses.

16.1.1 New, chemically-resistant glass containers shall be conditioned by allowing them to stand full of water for several days. Conditioning may be hastened by a preliminary treatment with dilute hydrochloric acid solution. Only polyethylene containers shall be used for samples where small amounts of hardness, silica, sodium, or potassium are to be determined.

16.1.2 The collection, storage, and subsequent analytical determination in plastic containers will result in erroneous pH values because of the permeability of plastic to gases such as CO_2 (carbon dioxide).

16.1.3 Closures for the sample containers shall be glass stoppers that have been thoroughly washed, or plastic or metal caps with suitable liners. Polytetrafluorethylene (Teflon) or aluminum foil are suitable only as cap liners for samples to be analyzed for organic constituents.

16.1.4 Wash sample containers with soap or biodegradable detergent, if required. Clean with a hot cleaning solution. Rinse bottles that have contained samples with chromate or heavy metals with dilute HNO_3 before a final thorough rinsing with water. Dry by draining.

16.2 For most bacteriological samples, provide wide-mouth sample bottles of at least 10 fluid ounce (300 mL) capacity; however, 4.2-fluid ounce (125-mL) bottles are the most common size for collecting drinking water samples. These bottles may be of borosilicate glass or other material resistant to the solvent action of water. Metal or plastic, wide-mouth, screw caps may be used on the sample bottles. Bottles, caps, and their liners must be capable of withstanding sterilization temperatures, must not produce any compounds by volatilization during sterilizing, and must not impart any toxic or bacteriostatic compounds to water sample.

16.2.1 Dedicate appropriate sample bottles for microbiological use. Wash bottles with a hot detergent water and brush, and rinse well with type III reagent water. Bottles for microbiological samples should not be routinely cleaned with the dichromate solution. If a dichromate or acid cleaning is necessary, rinse well and after final rinse, check pH value to ensure that toxic acids or chromate are not present.

16.2.2 Add $Na_2S_2O_3$ in an amount sufficient to provide a concentration of about 100 mg/L in sample if samples to be taken contain residual chlorine.

16.2.3 Use glass-stoppered or screw-capped bottles and place a strip of aluminum foil between stopper and its seat. Stopper and cover bottle tops and necks with aluminum foil dust covers to protect from contamination. Loosen screw caps slightly to prevent possible rupture of container during sterilization. Sterilize bottles in a hot-air oven at a minimum of 338 °F (170 °C) for at least 1 hour, or autoclave at 250 °F (121 °C) for 15 minutes.

16.3 When organic constituents are to be determined, refer to ASTM D 3694.

17. Sample Collection

17.1 *Chemical and Physical Analyses*:

17.1.1 When sampling streams under pressure, regulate rate of flow in sample line to not less than 500 mL/min after initially flushing line at a rate sufficiently high to remove all sediment and gas pockets. In special cases where dissolved gases are caused to be released from solution by a drop in pressure, please note such on bottle label.

17.1.2 Allow sampling stream to flow until in-line measurements of pH, specific conductance, and temperature are constant before collecting representative samples.

17.1.3 When sampling water from cocks or valves, insert the sample line, or a thoroughly washed glass tube or sulfur-free rubber tube extension of sample line, into sampling bottle so that sample line touches the bottom. Allow a volume of water equal to at least 10 times the volume of sample container to flow into and overflow from the container before sample is taken.

NOTE 3.–If sample is to be tested for constituents that may be absorbed on walls of sample container, do not rinse container and do not allow container to overflow during sample collection. Oil, grease, and polychlorinated biphenyls are typical constituents in this category.

17.1.3.1 If a preservative or additive has been added to sample container, allow sample to free fall into container but do not allow container to overflow.

17.1.4 If contact with air would cause a change in the concentration or in the characteristics of a constituent to be determined, secure sample without contact with air and completely fill container.

17.1.5 For sampling unconfined water at any specific depth, such as in ponds, lagoons, or reservoirs, during which contact with air or agitation of water would cause a change in concentration or characteristics of a constituent to be determined, use a sampling apparatus so constructed that solution at depth to be sampled flows through a tube to bottom of container, and that a volume of sample equal to 4 to 10 times the volume of receiving container passes through the container. Figure 1 shows three types of sampling apparatus that will permit collection of sample at desired depth, or collection of an integrated sample containing water from all points in a vertical section.

17.1.6 When samples are to be shipped, do not completely fill bottles to allow for expansion when bottles are subjected to a change in temperature. An air space

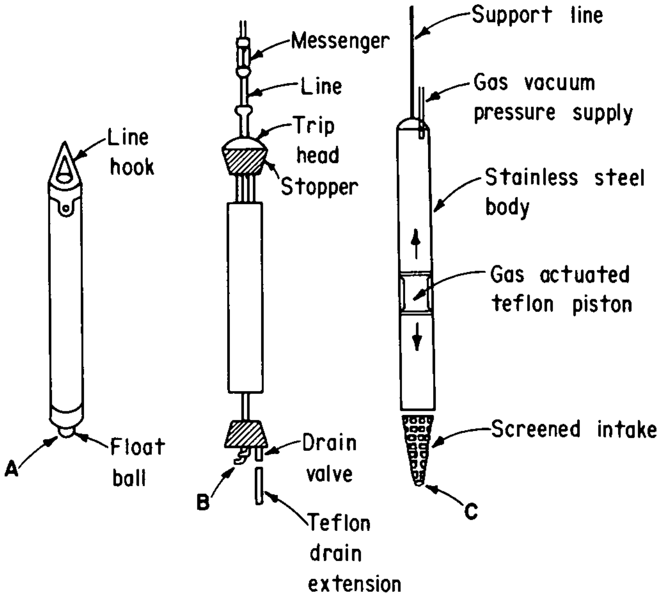

Figure 1. - Sampling devices and recommended application: (A) Teflon bailer (monitoring wells), (B) Kemmerer sampler (lakes), and (C) syringe sampler (ground water).

of about 10 percent usually is sufficient for this purpose; however, this does not protect bottles from cracking or breaking due to freezing. This precaution precludes shipping samples for analysis of constituents as noted in section 17.1.4.

17.1.6.1 An alternative method that provides room for expansion and eliminates contact with air is to use a flexible-plastic sample bottle. Fill bottle completely, compress it to exclude about 10 percent of the contents, and replace cap before pressure is released. However, plastic containers are not suitable for samples for analysis of organic constituents.

17.1.7 When sampling water that is above the ambient temperature, cool water using a cooling coil prior to sampling. Before taking sample, establish a continuous flow of not less than 500 mL/min, and cooled to less than 98.6 °F (37.0 °C). If sample is to be collected for special constituents, the sampling method for the specific test should be used. Calculate recommended minimum purging times for different sizes of sampling lines as follows:

$$t = \left(\frac{D}{3}\right)^2 \qquad (1)$$

where:

t = time in seconds, and

D = inside diameter of sampling line in inches (millimeters).

Approximate purging times for sample lines up to 1 inch (25 mm) in diameter are shown in table 1.

17.1.7.1 Before taking sample, rinse sample container at least three times by filling it to one-fourth its capacity with water to be sampled, shaking, and then emptying.

17.1.7.2 Collect water sample by upward displacement through a tube extending to bottom of container. Allow container to overflow at least five times its volume, and then close container with a stopper previously rinsed with sample water. If analysis cannot be made immediately, containers should be tightly stoppered to prevent atmospheric contamination.

Table 1. - Approximate purging times for sampling lines.[1]

Pipe size inch	Pipe size (mm)	Inside diameter of pipe inch	Inside diameter of pipe (mm)	Purging time in seconds per foot (per meter) of sampling line	
1/8	(3.2)	0.269	(6.8)	5	(16.4)
1/4	(6.4)	0.364	(9.2)	10	(32.8)
3/8	(9.5)	0.493	(12.5)	15	(49.2)
1/2	(12.7)	0.622	(15.8)	25	(82.0)
3/4	(19.0)	0.824	(20.9)	40	(131.2)
1	(25.4)	1.049	(26.6)	60	(196.9)

[1] These purging times provide three to four times the sample line volume.

17.1.7.3 Because concentrations of constituents vary at different water levels, or ratings, and are influenced by amount of water, take all samples when water is at normal operating level unless there is a specific reason for sampling under other conditions. For comparative testing under abnormal conditions, take samples at similar water levels or ratings to avoid dilution or concentration due to changes in amount of water in system.

17.2 *Microbiological Samples*:

17.2.1 When taking a sample from a sample line or tap, allow water to run for at least 5 minutes or long enough to flush, with 6 to 10 times the line's volume, the entire part of the system that has been stagnant for 2 hours or more.

17.2.2. Select a sterile sample bottle containing $Na_2S_2O_3$ if water being sampled contains residual chlorine, has been chlorinated, or contains any free or combined available oxidizing agent intended to sterilize the water. If such sterilizing agents are not present, the thiosulfate may be omitted. In cases where thiosulfate interferes with subsequent examination, such as in the examination for sulfate-reducing bacteria, omit using thiosulfate in sample bottle even if sterilizing agents are present. In this case, if such sterilizing agents are present, examination must be performed as soon as possible.

17.2.3 Remove stopper from sample bottle by grasping the dust cover of the stopper so as not to contaminate stopper by touching it; do not lay it down. Hold bottle at the bottom to avoid touching the neck. Do not rinse bottle with sample. Quickly hold bottle under flowing sample water until about three-fourths full to permit mixing by shaking prior to testing. Replace stopper and promptly crimp dust cover in place over neck of bottle. Take care that stopper and bottle neck are not touched during this operation and that no dust blows into bottle.

17.3 *Sampling Radioactive Water*:

17.3.1 Because of the potential hazards related to working with water containing radioactive nuclides, special handling of radioactive samples may be required. Information on radiological hazards and recommendations on radiation protection have been published by the National Committee on Radiation Protection [3,4][4] Recommendations of the Federal Radiation Council on radiation protection guides have been adopted by all Federal agencies by executive order [5]. Existing standards for protection against radiation are set forth in the Code of Federal Regulations [4]. Special methods and precautionary measures for handling radioactive samples are described in the literature [6, 7].

17.3.2 When sampling process waters where radioactivity levels may be high, such as nuclear reactor cooling waters, follow applicable health-physics regulations. In such cases, the use of suitable protective clothing may be required. Personnel-monitoring devices may be necessary when external radiation levels present a potential hazard. If level of radioactivity in sampling area is

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[4] Numbers in brackets refer to entries in References, section 37.

sufficiently high to introduce a radiation hazard, shielding for sample lines, coolers, and collection devices may be required to minimize exposure. Exercise precautionary measures to prevent contamination and spread of radioactivity by spillage of samples or by leakage or breakage of sampling lines, valves, or containers. In addition, take precautions to prevent release of gaseous or air-borne radioactive substances to minimize exposure to personnel.

17.3.3 If sample containers are to be shipped, shield and pack to comply with regulations for shipping radioactive materials [8].

17.3.4 Procedures for collecting radioactive samples should, in general, follow those described in section 17.1.

17.3.5 When water sampled is under pressure and contains gaseous radioactive substances, the container used should be designed to prevent any disproportionate loss of gases during sampling.

17.3.6 Employ suitable measures to minimize adsorptive losses of radioactivity if this has not already been accomplished during preparation of sample container. When sampling streams or other natural waters, easily adsorbable materials may already be on surfaces of whatever particulate matter is present. In such cases, treatment to prevent adsorption may result in the undesirable transfer of radionuclides from the suspended to dissolved phase.

18. Preservation of Samples

18.1 Add chemical preservatives to samples that are to be used for chemical or physical examination only as specified in specific test methods. Quick freezing has been found to be beneficial in preserving some organic constituents. Note any preservatives added to sample on bottle label.

18.2 Refrigerate or ice samples collected for biological examination immediately after collection. Hold or transport samples at a temperature of not more than 39.2 °F (4.0 °C).

18.2.1 Do not hold samples for microbiological analyses for more than 6 hours from time of collection to analysis. Consider performing a field examination if this time limit cannot be met.

18.2.2 Analyze drinking water samples on the same day they are delivered to laboratory. A specific exception is made for samples mailed or sent by public transportation to control laboratories. These samples are permitted to be held up to 30 hours.

18.2.3 If the conditions in sections 18.2.1 and 18.2.2 cannot be met, note the actual conditions on the examination report.

18.3 Chemical treatment of radioactive samples to prevent biological or algal growth is not recommended and should be avoided unless essential. When necessary, select reagents used to avoid chemical interaction with radioactive species in sample.

18.4 Chemical treatment to retain radioactive species in solution may be used but care is needed in treatment selection, see section 7 of ASTM D 3648.

19. Time Interval Between Collection and Analysis of Samples

19.1 In general, allow as short a time as possible between collection of a sample and its analysis. Under some conditions, analysis in the field is necessary to secure reliable results. The actual time interval that may be allowed between the collection and analysis of a sample varies with the type of examination to be conducted, character of sample, and the time interval allowable for applying corrective treatment. Specify the time interval between collection and analysis of a sample on the examination report.

19.2 Make the determination of dissolved gases, such as oxygen, hydrogen sulfide, and carbon dioxide, at the source except when such constituents may be fixed and determined later as specified in the specific test methods.

19.3 When sampling for radioactivity determinations, note the exact time of sample collection. If short-lived activity is of interest, analysis should be made as soon as practical to minimize loss of activity by radioactive decay. If only long-lived activity is of interest, measurement of radioactivity can often be simplified by allowing sufficient time before analysis for the decay of the short-lived radionuclides.

20. Labeling and Transportation of Samples

20.1 Provide space for the following information on an etched area of the sample bottle, a gummed label, or a cardboard or linen tag securely affixed to container:

- Sample number.
- Date and time of sampling.
- Source of sample.
- Point of sampling (designated in sufficient detail to enable anyone to collect a second sample from identical spot that first sample was taken).
- Temperature and rate of flow of fluid in equipment from which sample was taken.
- Temperature of sample.
- Type and quantity of preservative added.
- Results of field tests made on sample.
- Signature of sampler.

20.1.1 Figure 2 shows a suggested data form.

20.2 Fix stoppers closing the sample containers in place by wire, tape, or cord to prevent leakage in transit. Sample container shall be of such size that when filled with desired amount of sample, a space approximately equivalent to 10 percent of volumetric capacity of container will be available for expansion of the liquid. Exceptions to this are for those constituents noted in section 17.1.4, in which case the method of section 17.1.6.1 may be used.

20.3 The sample shipping container shall be a case having a separate compartment for each sample. Line the compartment around each sample with corrugated paper, felt, or similar material; or hold sample in place with spring clips, foamed plastic, or similar material. Use insulated containers for quick-frozen samples, which are usually shipped with solid carbon dioxide to maintain sample in frozen condition.

20.4 Print addresses of shipper and receiver plainly on outer container, or attach firmly thereon by cards or labels. Attach warning and descriptive labels to outer container, such as "Fragile," "Liquid," "Glass," "Handle With Care," "This Side Up," etc., when applicable. In cold weather, attach the label "Keep From Freezing" to outer container, except for those samples which are intentionally frozen.

METHOD B-COMPOSITE SAMPLES

21. Scope

21.1 Composite sampling is applicable for subsequent chemical and physical analyses; however, this method may not be suitable for radiological examination, particularly for short-lived radionuclides.

21.2 Composite samples are not suitable for bacteriological examination, for constituents noted in section 17.1.4, or for purgeable organics.

22. Sample Collection

22.1 Composite samples may be made by mutual agreement of the interested parties by combining individual grab samples taken at frequent intervals or by using automatic samplers.

22.1.1 Refer to individual test methods for the effect of time interval and temperature prior to analysis [6,7,9].

22.2 Indicate whether volume of sample is proportional to rate of flow. At the end of a definite period, mix composite sample thoroughly so that determinations on a portion of the sample will represent the average for the stable constituents. Variations of unstable constituents may be determined by analysis on individual samples.

23. Frequency and Duration of Sampling

23.1 When sampling process waters, collect composite samples in at least one 24-hour period. If process is cyclic in nature, collect samples during at least one complete process cycle, and identify in accordance with section 20.1. Collect increments for composite samples at regular intervals from 15 to 60 minutes, and in proportion to rate of flow of water. This may be conveniently done by taking a simple multiple in milliliters per minute, gallons per minute, or other unit of flow. Choose a suitable factor to give the proper volume (about 1 gallon or 4 liters) for the composite sample.

23.2 When samples are taken from a stream, composite samples for analysis normally consist of equal quantities of daily samples for a suitable number of consecutive days, 7 days for example.

24. Point of Sampling

24.1 See section 15.

25. Sample Handling

25.1 For information on sample handling, refer to the appropriate sections as follows:

	Section
Volume of Sample	14
Sample Containers	16
Preservation of Samples	18
Time Interval Between Collection and Analysis of Samples	19
Labeling and Transportation of Samples	20

METHOD C — CONTINUAL SAMPLING

26. Scope

26.1 This method is applicable to sampling water from sources such as wells, rivers, streams, lakes, oceans, reservoirs, pipelines and conduits, processing tanks and vats, spray ponds, towers, filters, and steam generators on a continual basis for chemical, physical, or radiological analyses.

27. Apparatus

27.1 The apparatus for this method shall consist of a delivery valve or pump, piping system, flow regulation system, and a waste disposal system.

28. Frequency and Duration of Sampling

28.1 Sampling is essentially on a continuous basis; however, intermittent sampling is possible using sample bypass equipment, although this is seldom used except in measuring variables with a time relationship, such as rate of oxygen uptake. In these cases, deviations from this method shall be handled under descriptions of the specific measurement involved.

29. Single Sample From Multipoint Sampling

29.1 When simultaneous samples from several locations are required, water is drawn continually from each individual source proportionate to flow and mixed into a single sample.

30. Particulate Matter

30.1 The size, quantity, and, in some cases, type of particulate matter often accounts for one or more of the variables to be measured and, in other cases, introduces errors in the analysis if they are disturbed. The water delivery system shall flow fast enough to keep heavier particles in suspension, and the system volume shall be large enough to prevent undesirable filter action through restrictions.

30.2 The sampling system should be sized to maintain a Reynolds number of about 4000 to assure turbulent flow.

31. Point of Sampling

31.1 Selection of sampling points should conform to the applicable paragraphs of section 15.

32. Taking the Sample

32.1 Because pumps employing suction principles disturb the gas-liquid balance, use a submersible-type pump for pumping samples from open bodies of water whenever measurements to be made concern dissolved gases, such as oxygen or carbon dioxide. Pumps, screens, valves, and piping must be selected of corrosion-resistant material to prevent sample from being contaminated by corrosion products and to prevent undue maintenance.

32.2 The debris screens used around the pump intake shall be of sufficient size to preclude a significant pressure drop developing across screens in the event of partial clogging.

32.3 Manufacturers of continual analyzers and samplers will generally specify minimum volume and pressure requirements for proper operation. Sample pump selection must be based on these minimums and on the configuration of the piping.

32.4 The piping system between pump and sample container shall be designed such that pump is operating against lowest practical head.

32.5 Piping system shall be constructed with a continual rise in elevation from pump to point of delivery without reverse bends where sediment and algae could accumulate. To prevent freezing in outdoor installations, remove check valve from pump so that piping will drain in event of power failure.

33. Time Interval Between Collection and Analysis of Sample

33.1 In a continually-operating sampling system, the time interval between system intake and point of sample delivery is a function of flow rate of water and dimensions of intervening pipe. Usually, system dimensions make this time interval so short that its effect on accuracy of determination is negligible. Wherever special precautions should be observed, they will be described in particular method covering that analysis.

33.2 The time response of the system describes its ability to respond to transient conditions in the water source. Time response is defined as time required for system to reach 63.2 percent of total change between state of initial and final equilibrium in response to a step change introduced at input to system.

34. Calculations

34.1 This procedure requires no specific worksheet for calculations. The Bureau's chemistry laboratory in Denver uses a computer program that calculates the test data, performs an error analysis on the results, and then prints out a final report. This program can be used by project offices if the project laboratory has access to a Hewlett-Packard HP-86.

34.2 Figures 3 and 4 consist of two computer printouts. Figure 3 provides backup information in the form of raw data, and figure 4 provides a record of the percent of error in the tests performed.

35. Report

35.1 This procedure requires no specific reporting form. Figures 5, 6, and 7 consist of three computer printouts for reference in reporting the results of the various tests. Figure 5 is a printout of sample background data, figure 6 shows the results of the individual tests performed, and figure 7 is a printout of the stiff diagram (note 4).

NOTE 4.–The stiff diagram has no specific significance other than as a check on at least two of the compounds shown on figure 6.

36. Precision and Bias

36.1 The precision and bias for this procedure have not been established.

37. References

[1] Rosen, Joseph, *Reagent Chemicals and Standards*, 3rd ed., Van Nostrand Co. Inc., New York, NY, 1955.

[2] *United States Pharmacopeia and National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

[3] "Basic Radiation Protection Criteria," NRCP Report No. 39, Jan. 15, 1971.

[4] *Code of Federal Regulations*, Title 10, Part 20, "Standards for Protection Against Radiation," app. B and addenda issued to date.

[5] *Federal Register*, p. 4402, May 18, 1960.

[6] Friedlander, G., J. W. Kennedy, and J. M. Miller, *Nuclear and Radiochemistry*, 2nd ed., John Wiley and Sons, Inc., New York, NY, 1964.

[7] Overman, R. T., and H. M. Clark, *Radioisotope Techniques*, McGraw-Hill Book Co., Inc., New York, NY, 1960.

[8] *Hazardous Material Regulations of the D.O.T.*, Title 49, Parts 170-190, current edition.

[9] Price, W. J., *Nuclear Radiation Detection*, 2nd ed., McGraw-Hill Book Co., Inc., New York, NY, 1966.

Spec. or Solic. No. 4D-C 7513	Structure STREAM AT UPPER END OF RESERVOIR	Sampled by J. ELLIS Date 8-14-85
Project DALLAS CREEK	Item WATER QUALITY Location DALLAS CREEK	Computed by Date
Feature RIDGEWAY DAM-STAGE 2	Station — Offset — Depth SEE DATA to BELOW	Checked by Date

SAMPLING OF WATER

ID No.	Time	Site ID		Depth sampled		Tests desired**			Temp. of source		Rate of flow		Temp. of sample		Preservative added	
		No.	Loc.*	ft	m	WQ	TMf	TMu	°F	°C	ft/s	m/s	°F	°C	Type	Quantity
1	NA	STA. 3	*	SURFACE		✓			NOT TAKEN		NOT MEASURED		NOT TAKEN		NONE ADDED	

Results of any field tests performed: NO TESTS PERFORMED

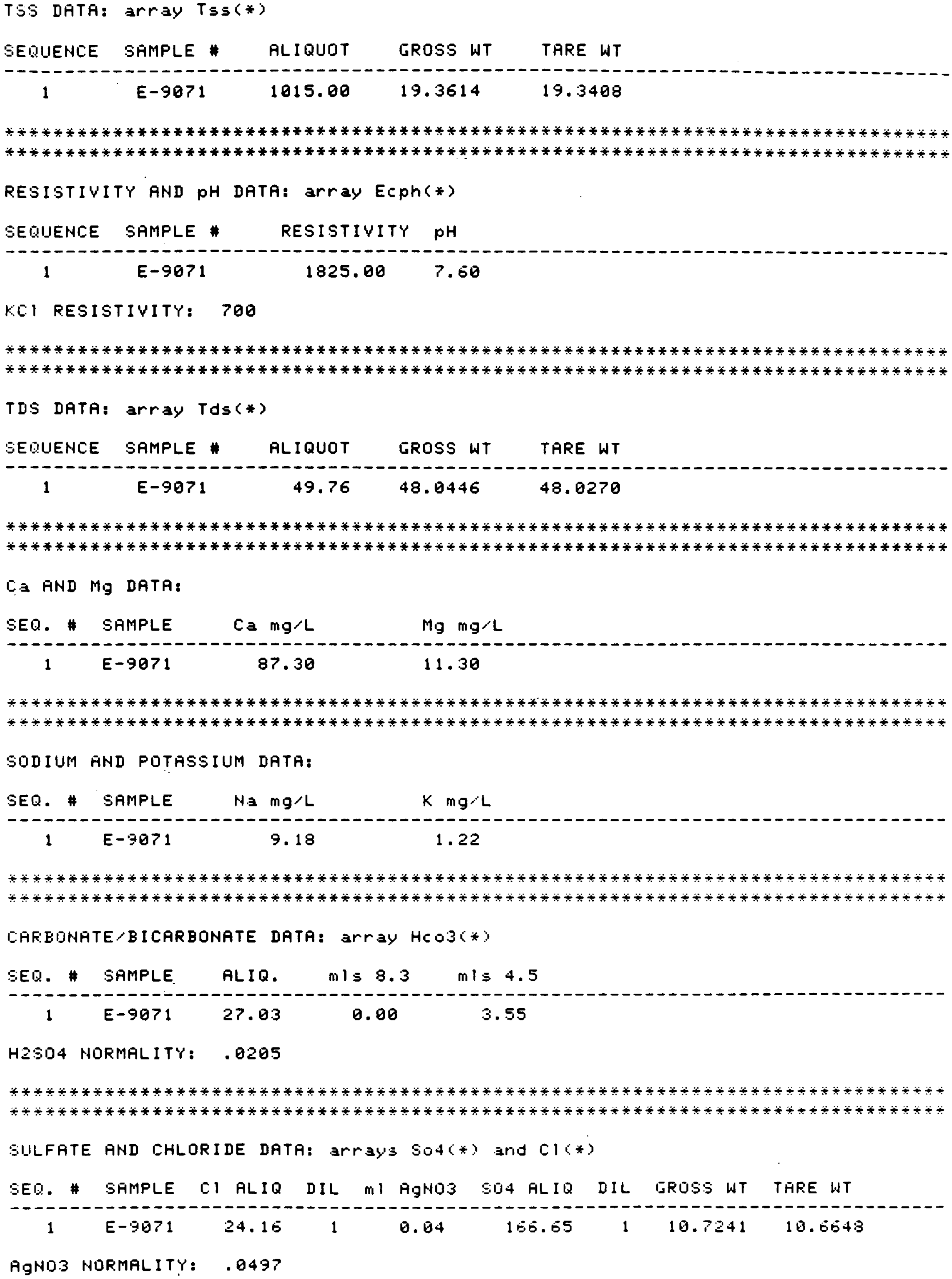
* Location: Point of sampling (designated in sufficient detail so that a second sample could be collected, if necessary, from identical point of first sample): OLD GAUGE SITE (No additional specifics given)

**WQ = Water quality (untreated); includes pH, conductivity, suspended solids, dissolved solids at 221 °F (105 °C), sum of cations and anions, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride; 1.06 quarts (1 L) required.

TM_f = Trace metals, filtered (dissolved), 0.5 mL of HNO_3 added; 0.5 quart (500 mL) required.

TM_u = Trace metals, unfiltered (total metals), 0.5 mL of HNO_3 added; 0.5 quart (500 mL) required.

Figure 2. - Sample data and calculation form.



```
TSS DATA: array Tss(*)

SEQUENCE  SAMPLE #    ALIQUOT    GROSS WT    TARE WT
--------------------------------------------------------------------------------
   1        E-9071     1015.00    19.3614     19.3408

********************************************************************************
********************************************************************************

RESISTIVITY AND pH DATA: array Ecph(*)

SEQUENCE  SAMPLE #     RESISTIVITY  pH
--------------------------------------------------------------------------------
   1        E-9071       1825.00    7.60

KCl RESISTIVITY:  700

********************************************************************************
********************************************************************************

TDS DATA: array Tds(*)

SEQUENCE  SAMPLE #    ALIQUOT    GROSS WT    TARE WT
--------------------------------------------------------------------------------
   1        E-9071       49.76    48.0446     48.0270

********************************************************************************
********************************************************************************

Ca AND Mg DATA:

SEQ. #  SAMPLE     Ca mg/L          Mg mg/L
--------------------------------------------------------------------------------
   1    E-9071       87.30            11.30

********************************************************************************
********************************************************************************

SODIUM AND POTASSIUM DATA:

SEQ. #  SAMPLE     Na mg/L          K mg/L
--------------------------------------------------------------------------------
   1    E-9071       9.18             1.22

********************************************************************************
********************************************************************************

CARBONATE/BICARBONATE DATA: array Hco3(*)

SEQ. #  SAMPLE    ALIQ.    mls 8.3    mls 4.5
--------------------------------------------------------------------------------
   1    E-9071    27.03      0.00       3.55

H2SO4 NORMALITY:  .0205

********************************************************************************
********************************************************************************

SULFATE AND CHLORIDE DATA: arrays So4(*) and Cl(*)

SEQ. #  SAMPLE  Cl ALIQ  DIL  ml AgNO3  SO4 ALIQ  DIL  GROSS WT  TARE WT
--------------------------------------------------------------------------------
   1    E-9071   24.16    1     0.04     166.65    1   10.7241   10.6648

AgNO3 NORMALITY:  .0497
```

Figure 3. – Sample of raw data.

```
                       ION BALANCE ERROR LISTING
---------------------------------------------------------------------------
Project...................Dallas Creek
Sampling date..............8/14/85
---------------------------------------------------------------------------

    SAMPLE                  ERROR PERCENT
---------------------------------------------------------------------------
    E-9071                     -0.07

---------------------------------------------------------------------------
```

Figure 4. – Percent of error for tests performed.

```
                         USBR CHEMISTRY LABORATORY
                      ENGINEERING AND RESEARCH CENTER
                       PO BOX 25007/MAIL CODE D-1523
                          DENVER, COLORADO 80225
                         FTS-776-6201/303-236-6201
                                 1/15/86

---------------------------------------------------------------------------
********************* WATER QUALITY SAMPLE IDENTIFICATION *********************
---------------------------------------------------------------------------

Project........................Dallas Creek
Sampling date..................8/14/85
Number of samples.............. 1
Chemistry lab numbers..........E- 9071 to 9071
Analyst........................R.S./B.F.
Stored under file name.........UC9071
---------------------------------------------------------------------------

SAMPLE  1     E-9071     Sta. #3 Dallas Cr. @ Old Gage Site

---------------------------------------------------------------------------
```

Figure 5. – Sample background data.

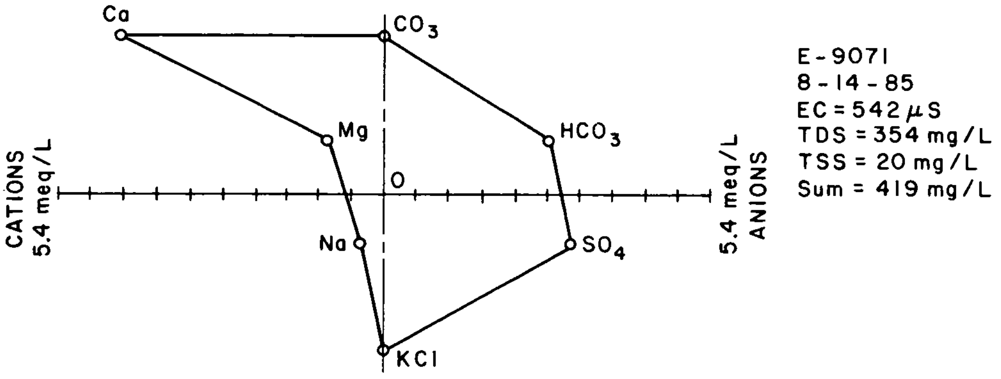
```
                    USBR CHEMISTRY LABORATORY
             REPORT OF MAJOR CATION AND ANION ANALYSES
                             1/15/86
----------------------------------------------------------------------------
PROJECT.............................. Dallas Creek
SAMPLING DATE........................ 8/14/85
----------------------------------------------------------------------------

E- 9071     Sta. #3 Dallas Cr. @ Old Gage Site

pH........................................... 7.60E+00
Conductivity................................. 5.42E+02 microsiemens @ 25
Suspended solids............................. 2.03E+01 mg/L
Dissolved solids-105C........................ 3.54E+02 mg/L
Sum of cations+anions........................ 4.19E+02 mg/L

Calcium.................. 4.36E+00 meq/L  ......... 8.73E+01 mg/L
Magnesium................ 9.30E-01 meq/L  ......... 1.13E+01 mg/L
Sodium................... 3.99E-01 meq/L  ......... 9.18E+00 mg/L
Potassium................ 3.12E-02 meq/L  ......... 1.22E+00 mg/L
Carbonate................ 0.00E+00 meq/L  ......... 0.00E+00 mg/L
Bicarbonate.............. 2.69E+00 meq/L  ......... 1.64E+02 mg/L
Sulfate.................. 3.03E+00 meq/L  ......... 1.45E+02 mg/L
Chloride................. 0.00E+00 meq/L  ......... 0.00E+00 mg/L
----------------------------------------------------------------------------
```

Figure 6. – Results of individual tests.



STATION NO.3 – DALLAS CREEK AT OLD GAUGE SITE

Figure 7. – Stiff diagram.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 3105-92

PROCEDURE FOR

HYDROGEN ION ACTIVITY (pH) OF WATER AND WATER-BASED FLUIDS

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 3105; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 1293-78.

1. Scope

1.1 This designation covers the procedures for determining the hydrogen ion activity (pH) of water and water-based fluids by electrometric measurement using the glass electrode as the sensor (note 1). Two methods are included in this designation: (1) Method A–Precise Laboratory Measurement, covered in sections 9 through 17, and (2) Method B–Routine or Continuous Measurement, covered in sections 18 through 27. Method A covers the precise measurement of pH in water using at least two of seven standard reference buffer solutions for equipment standardization, and also covers the measurement of pH in water-based fluids, such as slurry trench testing. Method B covers the routine measurement of pH in water and is especially useful for continuous monitoring.

NOTE 1.–The pH can be measured either colorimetrically or electrometrically. The colorimetric method is less expensive but suffers from interferences due to color, turbidity, salinity, colloidal matter, and various oxidants and reductants. The indicators are subject to deterioration as are the color standards with which they are compared. Also, no single indicator encompasses the pH range of interest in waters and wastewaters. In poorly buffered liquids, the indicators themselves may alter the pH of the sample unless preadjusted to nearly the same pH as the sample. For these reasons, the colorimetric method is suitable only for rough estimation and is not described in this procedure. For details on the colorimetric method, see references [1,2,3].[1]

Although the hydrogen electrode is recognized as the primary standard, the glass electrode is less subject to interferences and is used in combination with a calomel reference electrode. The glass reference electrode pair produces a change of 59.1 mV per pH unit at 77 °F (25 °C).

2. Applicable Documents

2.1 *USBR Procedure*:

3100 Sampling of Water

2.2 *ASTM Standards*:

D 1067 Standard Test Methods for Acidity or Alkalinity of Water[2]
D 1129 Standard Definitions of Terms Relating to Water[2]
D 1193 Standard Specification for Reagent Water[2]
D 1293 Standard Test Methods for pH of Water[2]
E 380 Standard for Metric Practice[3]

3. Summary of Procedure

3.1 The pH meter and associated electrodes are standardized against two reference buffer solutions which are closest to the anticipated sample pH. The sample measurement is made under strictly controlled conditions and prescribed techniques.

4. Significance and Use

4.1 The pH determination of water is a relatively reliable indication of its acidic or alkaline tendency, it is not a measure of the quantity of acidity or alkalinity in a water sample (refer to ASTM D 1067, app. X1). A pH value less than 7.0 shows a tendency toward acidity while a value greater than 7.0 shows a tendency toward alkalinity. Most natural waters range between 6.0 and 9.0, but there are notable exceptions such as mine drainage water and unbuffered rainwater. The pH measurement is an important consideration in determining the corrosive action of water and assessing water treatment practices for industrial processes.

5. Terminology

5.1 The term "pH" in this procedure is defined in accordance with ASTM D 1129 as follows: pH is the negative logarithm to the base 10 of the conventional hydrogen ion activity. The pH of an aqueous solution is derived from the electromotive force E of the cell:

$$\text{glass electrode} \mid \text{solution} \parallel \text{reference electrode}$$

---

[1] Numbers in brackets refer to entries in References, section 28.

[2] *Annual Book of ASTM Standards*, vol. 11.01.

[3] *Annual Book of ASTM Standards*, vol. 14.02

where double vertical lines represent a liquid junction when electrodes are immersed in the solution in the diagrammed position, and the electromotive force E_s obtained when electrodes are immersed in a reference buffer solution. For use in the operational definition given below, the sign of the measured potential difference indicated by many pH meters must be reversed because the electrode configuration used with these meters is:

reference electrode ‖ solution | glass electrode

With assigned pH of reference buffer designated as pH_s, and E and E_s expressed in volts:

$$\mathrm{pH} = \mathrm{pH}_s + \frac{(E - E_s)\,F}{2.3026\,RT} \tag{1}$$

where:

F = Faraday constant
R = gas constant
T = absolute temperature, 5/9 (°F + 459.67) or °C + 273.15

Values of the factor $F/(2.3026\ RT)$ at different temperatures are given in table 1. See section X1.1 of appendix X1 for additional comment on the definition of pH.

Table 1. - Values of factor in equation (1) at different temperatures.[1]

Temperature		$\frac{F}{2.3026\,RT}$, volts^{-1}
°F	(°C)	
32	(0)	18.4512
41	(5)	18.1195
50	(10)	17.7996
59	(15)	17.4907
68	(20)	17.1924
77	(25)	16.9041
86	(30)	16.6253
95	(35)	16.3555
104	(40)	16.0944
113	(45)	15.8414
122	(50)	15.5963
131	(55)	15.3587
140	(60)	15.1282
149	(65)	14.9045
158	(70)	14.6873
167	(75)	14.4764
176	(80)	14.2714
185	(85)	14.0722
194	(90)	13.8784
203	(95)	13.6899

[1] Values were calculated using a precise value of logarithmic conversion factor (2.302585) and values of the fundamental constants:
F = 96 487.0 C/eq
R = 8.31433 J/(K·mol)
T = 5/9 (°F ± 459.67) or °C ± 273.15

5.2 For definitions of other terms used in this procedure, refer to ASTM D 1129. For an explanation of the metric system including units, symbols, and conversion factors, see ASTM E 380.

6. Purity of Reagents

6.1 Reagent grade chemicals shall be used in all tests, except as specifically noted for preparation of reference buffer solutions. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available [4]. For suggestions on testing of reagents not listed in [4], see [5,6]. Other grades may be used, provided it is ascertained that reagent is of sufficiently high purity to permit its use without lessening accuracy of determination.

6.2 Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to ASTM D 1193, Type I. The water used for reference buffer solutions shall be prepared as specified for each standard buffer solution. Precautions shall be taken to prevent contamination of water with traces of material used for protection against carbon dioxide. The pH of the carbon dioxide-free water shall be between 6.5 and 7.5 at 77 °F (25 °C).

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all of the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices, and to determine the applicability of regulatory limitations prior to use.

8. Sampling

8.1 Collect sample in accordance with USBR 3100.

METHOD A-PRECISE LABORATORY MEASUREMENT OF pH

9. Application

9.1 Method A covers the precise measurement of pH in water under strictly controlled laboratory conditions.

10. Interferences

10.1 The glass electrode reliably measures pH in nearly all aqueous solutions and is not usually subject to solution interference from color, turbidity, colloidal matter, oxidants, or reductants.

10.2 The true pH of an aqueous solution or extract is affected by temperature. The electromotive force between the glass and reference electrode is a function of temperature as well as pH. The temperature effect can be compensated for automatically in many instruments, or can be manually compensated for in most other instruments. The temperature compensation corrects for the effect of water temperature on the instrument, including electrodes, but does not correct for temperature effects on chemical system being monitored. The compensation also does not adjust the measured pH to a common temperature; therefore, the temperature should be reported for each pH measurement. Temperature effects are discussed further in section X1.2 of appendix X1.

10.3 The pH response of most glass electrodes is imperfect at both ends of the pH scale. The indicated pH value of highly alkaline solutions, as measured with the glass electrode, will be too low. This interference can be minimized by selection of the proper glass electrode for measurements in highly alkaline solutions.

10.4 The indicated pH value of strong aqueous solutions of salts and strong acids having a pH less than 1, will often be higher than the true pH value. This is termed negative error, and the pH indicated is somewhat greater than the true pH.

10.5 A few substances sometimes dispersed in water appear to poison the glass electrode. A discussion on this subject is given in section X1.4 of appendix X1.

11. Apparatus

11.1 *Laboratory pH Meter.*-Table 2 shows the most important characteristics of four typical pH meters commercially available. Each type of meter, with its associated glass and reference electrodes, is permissible. The choice depends on desired precision of measurement.

11.2 *Glass Electrode.*-The pH response of the glass electrode shall conform to requirements of sections 13.1 through 13.5. If glass electrode is used outside electrode compartment of meter, the lead wire shall be shielded. Measurements at pH values greater than 10.0 shall be made with a high-alkalinity type electrode to lessen the possibility of sodium ion errors. Proper care of the electrode is essential when not in use (note 2).

NOTE 2.-New glass electrodes and those that have been stored dry shall be conditioned and maintained as recommended by manufacturer. It is necessary to keep immersible ends of electrodes in water between measurements. For prolonged storage, glass electrodes may be allowed to become dry, but the junction and filling openings of reference electrodes should be capped to decrease evaporation. Ideally, glass electrodes should be stored as recommended by manufacturer, and reference electrodes should be stored in a saturated potassium chloride solution.

11.3 *Reference Electrode.*-A calomel, silver-silver chloride or other reference electrode of constant potential shall be used. There are two basic types of reference electrodes, the flowing and nonflowing liquid junction-type electrodes. The flowing, liquid junction-type unit shall be used for Method A determinations; this unit ensures that a fresh liquid junction is formed for each measurement. The internal elements of the reference and glass electrodes should be matched. If a saturated calomel electrode is used, some potassium chloride crystals shall be contained in the saturated potassium chloride solution. If the reference electrode is of the flowing junction type, design of the electrode shall permit a fresh liquid junction to be formed between the solution of potassium chloride and the buffer standard or tested water for each measurement, and shall allow traces of the solution to be washed from outer surfaces of electrodes. To ensure the desired slow outward flow of reference electrode solution, solution pressure inside the liquid junction should be kept somewhat in excess of that outside the junction. In nonpressurized applications, this

Table 2. - Laboratory pH meters.

	Type I	Type II	Type III	Type IV
Range:				
Normal	0-14	0-14	0-14	0-14.000
Expanded	-	2 pH units	1.4 pH units	-
Scale division	0.1	0.01	0.01	0.001 digital
Accuracy	±0.05	±0.01	±0.007	±0.002
Repeatability	±0.02	±0.005	±0.002	±0.002
Temperature compensation:				
Manual or automatic	Yes	Yes	Yes	Yes
Range:				
°F	32-212	32-212	32-212	32-212
°C	0-100	0-100	0-100	0-100
Smallest graduation:				
°F	3.6	3.6	3.6	3.6
°C	2	2	2	2
Slope compensator	-	Yes	Yes	Yes

requirement can be met by maintaining the inside solution level higher than the outside water level. If the reference electrode is of the nonflowing junction type, these outward flow and pressurization considerations do not apply. The reference electrode and junction shall perform satisfactorily as required in the standardizing procedure described in sections 13.1 through 13.5. Proper care of the reference electrode is essential when it is not in use. Further discussion on reference electrodes is given in section X1.3 of appendix X1.

11.4 *Temperature Compensator.*-The thermocompensator is a temperature-sensitive resistance element immersed in the water sample with the electrodes. The thermocompensator automatically corrects for change of slope of glass electrode (with change of temperature), but does not correct for actual changes in the pH of the water sample with temperature. The automatic thermocompensator is not required if the water temperature is essentially constant and the analyst chooses to use the manual temperature compensation feature of the pH meter.

11.5 *Stirrer and Stir Bar.*-The stirrer shall be a small laboratory-type mechanical stirrer having a glass agitator, or with a magnetic stirring unit having an inert plastic-coated impeller. The stir bar may come in different sizes.

12. Reagents

12.1 *Reference Buffer Solution.*-The pH values of the reference buffer solutions measured at several temperatures are listed in table 3. Table 4 identifies each buffer salt by its NIST (National Institute of Standards and Technology) number and provides a recommended drying procedure prior to use. Keep the five reference buffer solutions with a pH less than 9.5 in bottles of chemically resistant glass. Keep calcium hydroxide solutions in plastic bottles that are nonporous to air (if obtainable). Keep all reference buffer solutions well stoppered and replace them at a shelf age of 3 months, or sooner if a visible change is observed.

12.1.1 *Borax Reference Buffer Solution.*-This solution has a pH_s of 9.18 at 77 °F (25 °C), and is prepared by dissolving 3.80 grams of sodium tetraborate decahydrate, $Na_2B_4O_7 \cdot 10H_2O$, in water and diluting to 1 liter.

12.1.2 *Calcium Hydroxide Reference Buffer Solution.*-This solution has a pH_s of 12.45 at 77 °F (25 °C), and is prepared with pure calcium hydroxide, $Ca(OH)_2$, from well-washed calcium carbonate, $CaCO_3$, of low-alkali grade by slowly heating carbonate in a platinum dish at 1832 °F (1000 °C) and calcining for at least 45 minutes at that temperature. After cooling, stir the calcined product slowly into water, heat resultant suspension to boiling, cool, and then filter through a funnel having a fritted-glass disk of medium porosity. Collect the solid from filter, dry in an oven at 230 °F (110 °C), and then crush to a uniform and fine granular state. Vigorously shake a considerable excess (about 3 g/L) of the fine granular product with water at 77 °F (25 °C) in a stoppered plastic bottle that is essentially nonporous to gases. Allow gross excess of solid to settle, and then filter the solution with suction through a fritted-glass funnel of medium porosity. The filtrate is the reference buffer solution. Contamination of the solution with atmospheric carbon dioxide renders it turbid and indicates need for replacement.

12.1.3 *Phosphate Reference Buffer Solution.*-This solution has a pH_s of 6.86 at 77 °F (25 °C), and is prepared

Table 3. - Reference buffer solutions (pH_s values)[1].

Temperature		Solution						
°F	(°C)	Tetroxalate	Tartrate	Phthalate	Phosphate	Borax	Sodium bicarbonate-sodium carbonate	Calcium hydroxide
32	(0)	1.67	-	4.00	6.98	9.46	10.32	13.42
41	(5)	1.67	-	4.00	6.95	9.39	10.25	13.21
50	(10)	1.67	-	4.00	6.92	9.33	10.18	13.00
59	(15)	1.67	-	4.00	6.90	9.28	10.12	12.81
68	(20)	1.68	-	4.00	6.88	9.23	10.06	12.63
77	(25)	1.68	3.56	4.00	6.86	9.18	10.01	12.45
86	(30)	1.68	3.55	4.01	6.85	9.14	9.97	12.29
95	(35)	1.69	3.55	4.02	6.84	9.11	9.93	12.13
104	(40)	1.69	3.55	4.03	6.84	9.07	9.89	11.98
113	(45)	1.70	3.55	4.04	6.83	9.04	9.86	11.84
122	(50)	1.71	3.55	4.06	6.83	9.02	9.83	11.71
131	(55)	1.72	3.55	4.07	6.83	8.99	-	11.57
140	(60)	1.72	3.56	4.09	6.84	8.96	-	11.45
158	(70)	1.74	3.58	4.12	6.85	8.92	-	-
176	(80)	1.77	3.61	4.16	6.86	8.89	-	-
194	(90)	1.79	3.65	4.19	6.88	8.85	-	-
203	(95)	1.81	3.67	4.21	6.89	8.83	-	-

[1] For a discussion on how these values were assigned, see reference [7].

Table 4. - National Institute of Standards and Technology materials for reference buffer solutions.

NIST Standard sample designation	Buffer salt[1]	Drying procedure
187-b	Borax (sodium tetraborate decahydrate)	Drying not necessary (this salt should be oven dried)
186-II-c	Disodium hydrogen phosphate	2 hours in an oven at 266 °F (130 °C)
186-I-c	Potassium dihydrogen phosphate	2 hours in an oven at 266 °F (130 °C)
185-e	Potassium hydrogen phthalate	2 hours in an oven at 230 °F (110 °C)
188	Potassium hydrogen tartrate	Drying not necessary
189	Potassium tetroxalate dihydrate	Should not be dried
191	Sodium bicarbonate	Should not be dried
192	Sodium carbonate	2 hours in an oven at 527 °F (275 °C)

[1] The buffer salts listed can be purchased from Office of Standard Reference Materials, National Institute of Standards and Technology, Washington, DC 20234.

by dissolving 3.39 grams of potassium dihydrogen phosphate, KH_2PO_4, and 3.53 grams of anhydrous disodium hydrogen phosphate, Na_2HPO_4, in water and diluting to 1 liter.

12.1.4 *Phthalate Reference Buffer Solution.*-This solution has a pH_s of 4.00 at 77 °F (25 °C), and is prepared by dissolving 10.12 grams of potassium hydrogen phthalate, $KHC_8H_4O_4$, in water and diluting to 1 liter.

12.1.5 *Tartrate Reference Buffer Solution.*-This solution has a pH_s of 3.56 at 77 °F (25 °C), and is prepared by shaking vigorously an excess (about 75 g/L) of potassium hydrogen tartrate, $KHC_4H_4O_6$, with 100 to 300 mL of water at 77 °F in a glass-stoppered bottle. Filter, if necessary, to remove suspended salt, and then add a crystal of thymol (about 0.1 g) as a preservative.

12.1.6 *Tetroxalate Reference Buffer Solution.*-This solution has a pH_s of 1.68 at 77 °F (25 °C), and is prepared by dissolving 12.61 grams of potassium tetroxalate dihydrate, $KHC_2O_4 \cdot H_2C_2O_4 \cdot 2H_2O$, in water and diluting to 1 liter.

12.1.7 *Sodium Bicarbonate-Sodium Carbonate Reference Buffer Solution.*-This solution has a pH_s of 10.01 at 77 °F (25 °C), and is prepared by dissolving 2.092 grams of sodium bicarbonate, $NaHCO_3$, and 2.640 grams of sodium carbonate, Na_2CO_3, in water and diluting to 1 liter.

12.2 *Other Buffer Solutions.*-A buffer solution of composition identical to one of the previously mentioned solutions, but of a buffer material or solution source other than that specified, may be used as a working standard in this method provided that such a solution is first checked against the corresponding reference buffer solution, using procedures of this method, and is found to differ by not more than 0.02 pH unit.

12.3 *Commercial Buffer Solutions.*-Commercially available prepared buffer solutions should be adequate for the standardization in Method A. These solutions usually have pH values near 4, 7, and 10; the exact pH and working temperature to be provided by the distributor. The pH buffer is susceptible to contamination from atmospheric carbon dioxide, and frequently used or partially filled bottles are particularly vulnerable to this contamination.

13. Standardization of Assembly

13.1 For standardization of the assembly, first turn on analyzer and allow for thorough warm up. Then, bring assembly into electrical balance in accordance with manufacturer's instructions. Wash glass and reference electrodes and sample cup with three changes of water or by using a flowing stream from a wash bottle. Form a fresh liquid junction if a sleeve-type reference junction is used. Note temperature of water to be tested. If temperature compensation is to be manual, adjust temperature dial of meter to correspond to temperature of water to be tested and allow time for all buffers, solutions, and electrodes to equilibrate thermally.

13.2 If anticipated pH of solution to be tested is less than 10.0, select two reference buffer solutions with pH_s values that bracket the anticipated value, see table 3. Warm or cool reference solutions as necessary to match within 3.6 °F (2 °C) the temperature of solution to be tested. Fill sample cup with first reference buffer solution and immerse electrodes. If pH meter is of the zero-null type, set dial of meter to equal the pH_s value of reference buffer solution at temperature of buffer, as shown in table 3, or as interpolated from table 3. Engage operating button and rotate standardization knob or asymmetry potential knob until meter is brought to balance. If pH meter is of the direct-reading type, engage operating button, turn range switch (if provided) to proper position, and rotate asymmetry potential knob until reading corresponds to temperature (corrected pH_s value) of reference buffer solution. Empty sample cup and repeat, using successive portions of reference buffer solution. Repeat procedure until two successive readings are obtained, without adjusting the asymmetry potential knob, that do not differ from pH_s value of buffer solution by more than 0.02 pH unit. If temperature of electrode differs appreciably from that of solution to be tested, use several portions of solution and immerse electrodes deeply to assure that both the electrodes and the solution are at the desired temperature. If a flowing-junction reference electrode is used, the level of potassium chloride solution in reference electrode must always be kept higher than that of solution being measured. To reduce effects of thermal lag, keep temperature of electrodes, reference buffer solutions, and wash water as close to that of water sample as possible.

13.3 Wash electrodes and sample cup three times with water. Place second reference buffer solution in sample cup, and measure pH_s by reading dial or by adjusting balance point, depending on type of pH meter. Adjust slope control until reading corresponds to the temperature corrected value of second reference buffer solution. Do not change setting of asymmetry knob in either case. Use additional portions of second reference buffer solution, as before, until two successive readings do not differ by more than 0.02 pH unit. The assembly shall be judged to be operating satisfactorily if pH reading obtained from second reference buffer solution agrees with its assigned pH_s value within 0.05 unit for Type I meters or within 0.03 for Type II, III, or IV meters (table 2).

13.4 If anticipated pH of test solution is greater than 10.0, use the high-alkalinity type electrode and observe manufacturer's instructions. Use sodium bicarbonate and sodium carbonate reference buffer solution for initial standardization of assembly. If temperature of measurement is below 140 °F (60 °C), use calcium hydroxide reference buffer solution as second standard. Because the pH_s of this second solution changes significantly with temperature, note temperature of solution to the nearest 1.8 °F (1 °C) and use this reading to obtain applicable pH_s by interpolation of data in table 3. Judge assembly to be operating satisfactorily if reading obtained for second reference solution does not differ from assigned pH_s value by more than 0.1. If temperature of measurement is above 140 °F (60 °C) and the pH is greater than 10.0, standardize assembly with borax solution alone; however, prior to doing so, ensure correct functioning of high-alkalinity electrode with two more alkaline reference solutions at some temperature below 140 °F.

13.5 If only an occasional pH determination is made, standardize assembly each time it is used. For a long series of measurements, supplemental interim checks at regular intervals are recommended. Since commercially available pH assemblies exhibit different degrees of measurement stability, conduct these checks at 30-minute intervals unless it is ascertained that less frequent checking is satisfactory to ensure performance requirements of sections 13.2 and 13.3. If assembly is in continuous use under flowing conditions, standardize daily using two reference buffer solutions to check proper functioning of electrodes. More frequent checking may be required to ensure acceptable performance.

14. Procedure

14.1 Standardize assembly with two reference buffer solutions as described in sections 13.2 and 13.3, and then wash electrodes with three changes of water or by using a flowing stream from a wash bottle. Place water sample in a clean glass beaker provided with a thermometer. Equip beaker with a small laboratory-type mechanical stirrer having a glass agitator, or with a magnetic stirring unit having an inert plastic-covered impeller. If measurement is made outside electrode compartment of pH meter, avoid use of electric motors for operation of stirring equipment that generate an electrical signal or heat the water sample because of possible interference with pH measurement. Operate stirrer during period of pH measurement at a rate to prevent splashing and to avoid loss or gain of acid or basic gases by interchange with the atmosphere. When necessary, stir briskly enough to intermix the phases of a nonhomogeneous water sample. Stop stirrer during period of measurement if streaming potentials are noted. Insert electrodes and determine a preliminary pH value. Since this value may drift somewhat, it should be considered an estimated value. Measure successive portions of water sample until readings on two successive portions differ by no more than 0.03 pH unit, and show drifts of less than 0.02 unit in 1 minute. Two or three portions will usually be sufficient if water is well buffered. Record pH and temperature of sample.

14.2 Measure pH of slightly buffered waters (that are in equilibrium with air) essentially as described in 14.1, but measure pH of successive portions, with agitation, until readings for two successive portions differ by no more than 0.1 pH unit; six or more portions may be necessary to accomplish this. Take special precautions if sample is not in equilibrium with the carbon dioxide of the atmosphere protecting the sample from exposure to the air during measurement. Make measurements with externally mounted electrodes in a wide-mouth flask that has been flushed with carbon dioxide-free air. Measurement of unbuffered or slightly buffered samples is more reliably made in flow-type cells as described in section 23.2. Section X1.5.3 of appendix X1 describes additional precautions that should be taken if electrical conductivity of sample is less than about 13μS/in (5μS/cm).

15. Calculation

15.1 Most pH meters are calibrated in pH units, and the pH of the sample is obtained directly by reading meter scale. See note 3 regarding the documentation of calculations.

NOTE 3.–The Bureau's chemistry laboratory in Denver uses a computer program that calculates the test data, performs an error analysis on the results, and then prints out a final report. The report includes a listing of sample descriptions and assigned laboratory numbers, an error analysis, and a tabulated report of test results including stiff diagrams. This program can be used by project offices if project laboratory has access to a Hewlett-Packard HP-86 computer.

16. Report

16.1 Report temperature of measurement to the nearest 1.8 °F (1 °C). Report pH of test solution to nearest 0.01 pH unit when pH measurement lies between 1.0 and 12.0; report to nearest 0.1 unit when measurement is less than 1.0 or greater than 12.0. See note 3, and utilize the computer printouts shown on figures 5 and 6 of USBR 3100.

17. Precision and Bias

17.1 Under the strict conditions set forth in this method, the precision is 0.05 pH unit. To attain this precision, the condition of the instrumentation and the technique for standardization and operation is extremely important. When the pH is less than 1.0 and greater than 12.0, the precision is 0.1 pH unit.

17.2 The bias for method A is not currently known.

METHOD B-ROUTINE OR CONTINUOUS MEASUREMENT OF pH

18. Application

18.1 Method B is used for the routine measurement of pH in the laboratory and the measurement of pH under various process conditions.

19. Summary of Method

19.1 A direct standardization technique is employed in this method for routine batch samples. Two buffers are used to standardize the assembly under controlled parameters; however, the conditions are somewhat less restrictive than those in Method A. An indirect standardization procedure is used on flowing systems, where grab samples are removed periodically to compare a monitored pH value of the system with the reading on the laboratory pH meter.

20. Interference

20.1 See section 10 and appendix section X1.4.

21. Apparatus

21.1 *Laboratory pH Meter.*-See section 11.1.

21.2 *Glass Electrode.*-See section 11.2.

21.3 *Reference Electrode.*-See section 11.3.

21.4 *Temperature Compensator.*-See section 11.4.

21.5 *Stirrer and Stir Bar.*-See section 11.5.

21.6 *Process pH Measurement Instrumentation.*-Instruments used for process pH measurements are generally more substantially built than those used for more accurate measurements in the laboratory. The characteristics of three types of process pH analyzers are shown in table 5. Each of these analyzers is satisfactory for process pH measurements. The choice of analyzer is generally based on how closely characteristics of analyzer match requirements of application. These requirements may include an analyzer signal that can drive external devices, or provision for pH measurement in one or more specific span ranges.

21.6.1 *Electrode Chamber.*-For process pH measurements, electrodes and thermocompensator are mounted in an electrode chamber. One style of chamber (flow-through type) completely encloses electrodes, and sample is piped to and from chamber in a flow-through configuration. Commercially available chambers generally can tolerate temperatures as high as 212 °F (100 °C) over a pH range from 0 to 14. Flow-through style chambers are available for service to about 150 lbf/in^2 (1034 kPa). Another style of chamber (immersion type), suitable for measurement in open streams or tanks, shields but does not completely enclose electrodes. Immersion-style chambers are available for use at depths to about 100 feet (30 m).

Table 5. - Remote measurement of pH.

	Type I	Type II	Type III
Range:			
Normal	0-14	0-14	0-14
Expanded	Any 2 pH or wider units	Any 2, 4, 5, 7, 10, or 14 pH units	Any 2, 5, or 10 pH units
Signal to recorder	To 1000 mV	To 50 mA	To 5000 mV, 4 to 20 or 10 to 50 mA
Accuracy	±0.02	±0.005 to 0.04, dependent upon span	±0.02
Temperature compensation:			
Manual or automatic	Yes	Yes	Yes
Range:			
°F	32-212	32-212	32-212
°C	0-100	0-100	0-100
Stability per 24-hour period	0.005 pH unit	0.005 pH unit	±0.02 pH unit

21.6.2 *Signal Transmission.*–The glass electrode is a high-impedance device from which only an extremely small current can be drawn. Shielded cable must be used to connect electrode to pH analyzer. The signal can frequently be transmitted up to about 1000 feet (305 m) with no loss in accuracy if manufacturer's recommendations are followed carefully. The signal can usually be amplified for transmission over even greater distances.

21.6.3 *pH Meter Associated With Remote Measurement.*–Usually a different style instrument is used to indicate or display remote pH measurements. Table 5 shows the characteristics of three types of suitable meters.

21.7 Tables 6 and 7 list various meters and electrodes.

22. Reagents

22.1 See section 12.

23. Standardization of Assembly

23.1 For standardization of the assembly, first turn on analyzer and allow for thorough warm up. Then, bring assembly into electrical balance in accordance with manufacturer's instructions. Wash electrodes, thermocompensator, and sample cup with three changes of water or by using flowing stream from a wash bottle. Form a fresh liquid junction if a sleeve reference electrode junction is used. If manual temperature compensation is to be used, note temperature of water sample and adjust temperature dial of meter to correspond.

23.2 *Direct Standardization*:

23.2.1 Select two reference buffer solutions that have a pH_s value as close as possible to anticipated pH of water sample, providing it is less than 10.0. Warm or cool reference solution to within 3.6 °F (2 °C) of temperature of water sample. Fill sample cup with first reference buffer solution and immerse electrodes. Engage operating button, turn range switch (if present) to proper position, and rotate asymmetry potential knob until reading of dial corresponds to known pH_s of reference buffer solution. Repeat procedure using successive portions of reference buffer solution until two successive instrument readings are obtained which do not differ from pH_s value of buffer solution by more than 0.02 unit. It is important that this final standardization be accomplished without changing setting of asymmetry potential knob.

23.2.2 If anticipated pH of test solution is greater than 10.0, use the high-alkalinity type of electrode and observe manufacturer's instructions.

23.2.3 If only an occasional pH determination is made, standardize assembly each time it is used. For a long series of measurements, supplement initial and final standardizations by interim checks at regular intervals. Since commercially available pH assemblies exhibit different degrees of measurement stability, conduct these checks at 30-minute intervals unless it is ascertained that less frequent checking is satisfactory to ensure performance.

23.2.4 Repeat standardization using second buffer solution.

23.3 *Indirect Standardization*:

23.3.1 Indirect standardization is to be used when it is not convenient or practical to remove electrodes from flowing stream or container on which the pH is being determined. Use of a laboratory pH meter or an additional analyzer is required.

23.3.2 Standardize laboratory pH meter or additional process analyzer as described in section 23.2.

23.3.3 Collect a grab sample of impounded or flowing water, or the water diverted from process for pH measurement, from immediate vicinity of electrodes if an immersion style electrode chamber is to be used; or from discharge if flow-through style electrode chamber is to be used. Measure pH of grab sample immediately using standardized laboratory pH meter or additional process analyzer. Adjust standardization control on process analyzer until reading corresponds to pH of grab sample. Repeat grab sampling, analyzing, and adjusting procedure until two successive readings are obtained that differ by no more than 0.05 pH unit or within an acceptable accuracy. This indirect standardization method cannot be used when pH of water being tested fluctuates by more than 0.05 pH unit. The standardization must be accomplished in the shortest possible time if pH is fluctuating. It is absolutely essential that grab sample be representative of water in contact with electrodes of analyzer being standardized. The integrity of grab sample must be maintained until its pH has been measured by standardized meter, and its temperature must remain constant.

23.3.4 Indirect standardization is a one-point calibration and does not establish proper response of electrodes over a pH range.

24. Procedure

24.1 *Routine pH Determination of Batch Sample.*–Standardize assembly as described in section 23.2, and wash electrodes with three changes of water or by using a flowing stream from a wash bottle. Place water sample in a clean glass beaker and determine temperature. Equip beaker with a small laboratory-type mechanical stirrer having a glass agitator or with a magnetic stirring unit having an inert, plastic-coated impeller. Operate stirrer during period of pH measurement at a rate to prevent splashing and to avoid loss or gain of acid or basic gases by interchange with the atmosphere. When necessary, stir briskly enough to intermix phases of a nonhomogeneous water sample. Insert electrodes and determine a preliminary pH value (reading may drift). Measure successive portions of water sample until readings on two successive portions differ by no more than 0.05 unit. Two portions will usually be sufficient if water is well buffered. Record pH and temperature of sample.

24.2 *Continuous Determination of pH.*–Select electrodes and electrode chamber to suit physical and chemical characteristics of process water. Locate a submersion style electrode chamber so that fresh representative sampling is provided continuously across electrodes. Agitation may be required to improve homogeneity. Process pH measurements generally have automatic temperature compensation. The pH value is usually displayed continuously and can be noted at any specific time. Record successive pH values frequently to provide a permanent record.

24.3 *Continuous Determination of pH of High-Purity Water.*–The analyzer used to determine the pH of high-purity water must have a high-impedance differential input to minimize environmental effects. Use a metallic electrode chamber to shield electrodes, and to electrically isolate it from all stray a-c fields. Pay particular attention to grounding and the use of metallic connectors, as recommended by equipment manufacturer. Place reference electrode upstream of glass electrode to impart the small amount of electrolyte essential to the sensing of the pH of water sample. One successful flow pattern uses a bottom inlet, a full chamber, and a top overflow; flow rate and pressure are held constant; and discharge is to atmospheric pressure. Follow manufacturer's instructions closely.

25. Calculation

25.1 Most pH meters are calibrated in pH units, and the pH of the sample is obtained directly by reading meter scale. See note 3 regarding the documentation of calculations.

26. Report

26.1 Report temperature of measurement to nearest 1.8 °F (1 °C). Report pH value to nearest 0.1 pH unit. See note 3 regarding preparation of report.

27. Precision and Bias

27.1 Because of the wide variability in measurement conditions and the changeable character of the pH of many process waters, precision of this method is probably less than that of Method A; however, a precision of 0.1 pH unit should be attainable under controlled conditions.

27.2 The bias for method B is not currently known.

28. References

[1] Clark, W. M., *The Determination of Hydrogen Ions*, 3rd ed., Williams & Wilkins Co., Baltimore, MD, 1928.

[2] Kolthoff, I. M., *Acid-Base Indicators*, 4th ed., Macmillan Co., New York, NY.

[3] *Simplified Procedures for Water Examination, Manual M12*, American Water Works Association, New York, NY, 1964.

[4] "Reagent Chemicals, American Chemical Society Specifications," American Chemical Society, Washington, D C.

[5] Rosen, Joseph, *Reagent Chemicals and Standards*, 3rd ed., Van Nostrand Co. Inc., New York, NY, 1955.

[6] *United States Pharmacopeia* and *National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

[7] Bates, R. G., "Revised Standard Values for pH Measurements from 0 to 95 °C," *Journal of Research*, JRM5B, vol. 66A, p. 179, National Bureau of Standards, 1962.

Table 6. – Various types of pH meters.[1]

Table of pH and Specific Ion Meters

Model	Readout		Reading Divisions Normal		Reading Divisions Expanded		Power		Reproducibility	VWR
	Meter	Display	pH	MV	pH	MV	Battery	Line	pH	Cat. No.
VWR Digital										
Mini 55		Digital	0.1				X	X	±0.02	34100-630
VWR Digital										
Mini 49		Digital	0.1				X	X	±0.05	34100-607
VWR Mini pH	X		0.1		0.2		X		±0.05	34100-505
VWR Phase IV		Digital	0.01				X		±0.01	34100-651
Beckman										
Zeromatic™ IV	8″	Digital	0.03	3				X	±0.07	34101-370
Beckman										
Model pHI 20		Digital	0.01	1.0				X	±0.01	34101-086
Model pHI 21		Digital	0.01	1.0				X	±0.01	34101-097
Model pHI 31		Digital	0.01	1.0				X	±0.01	34101-100
Model pHI 40		Digital	0.01	1.0				X	±0.01	34101-326
Model pHI 44		Digital	0.01	1.0				X	±0.01	34101-348
Model pHI 45		Digital	0.01	1.0				X	±0.01	34101-359
Model pHI 70		Digital	0.01	1.0				X	±0.01	34101-439
Model pHI 71		Digital	0.01	1.0				X	±0.001	34101-450
Monitor™II pH/mV	X		0.05	5			X		±0.1	34101-701
Monitor™II pH/mV O_2/°C	X		0.05	5			X		±0.1	52448-653
Corning Model 3	2½″		0.2	12			X		±0.1	34103-503
Corning Model 4	2″		0.01	–			X	X	±0.01	34103-150
Corning										
Model 5	5½″		0.1	10	–	–	–	X	±0.05	34103-300
Model 610	5½″		0.1	70	0.01	–	X	X	±0.05	34103-558
Model 620	5½″		0.1		–		X		±0.05	34103-605
Corning Model 3D		Digital	0.01	1			X		±0.02	34103-128
Corning										
Model 120		Digital	0.01	1				X	±0.01	34103-183
Model 140		Digital	0.01	1				X	±0.01	34103-219
Model 145		Digital	0.01	1				X	±0.01	34103-220
Model 150		Digital	0.001	0.1				X	±0.001	34103-230
Model 155		Digital	0.001	0.1				X	±0.001	34103-310
Orion										
Model 399 A/F	18 cm		0.1	10	0.02		X	X	±0.004	34104-153
Model 399 A/L	18 cm		0.1	10	0.02				±0.004	34104-200
Orion										
Model 201		Digital	0.05	-			X		±0.025	34104-029
Model 211		Digital	0.005	-			X	X	±0.005	34104-040
Model 231		Digital	0.01	-			X		±0.005	34104-051

Table 6. - Various types of pH meters.[1]- (Continued)

Table of pH and Specific Ion Meters

Model	Readout		Reading Divisions				Power		Reproducibility	VWR
			Normal		Expanded					
	Meter	Display	pH	MV	pH	MV	Battery	Line	pH	Cat. No.
Orion Model 301		Digital	0.2	20 20				X	±0.1	34104-109
Orion										
Model 407 A/F	18 cm		0.1	10	0.02		X	X	±0.004	34104-459
Model 407 A/L	18 cm		0.1	10	0.02				±0.004	34104-506
Orion Model 501		Digital	0.01	1				X	±0.01	34104-222
Orion										
Model 601A		Digital	0.01	1				X	±0.01	34104-266
Model 611A		Digital	0.01	1				X	±0.01	34104-288
Orion Model 701A		Digital	0.01	1	0.001	0.1		X	±0.01	34104-313
Orion Model 811		Digital	0.001		0.1			X	±0.001	34104-299
Orion Model 901		Digital	0.001	0.1				X	±0.001	34104-324

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[1] Data for this table were taken from VWR Scientific 1984-85 catalogue.

Table 7. - Types of electrodes.[1]

Standard Glass Body and Epoxy Body Models

pH Electrodes

Type	pH range	Temp. range	Body L cm (inches)	Tip Diameter cm (inches)	Lead L m (inches)	Connector	Orion No.	Cat. No.
Research Grade Glass Body Ag AgCl	0-14	0 to 90 °C	12 (4.7)	1.2 (0.47)	1 (39)	Standard	910100	13-641-763
HF-Resistant Polymer Body For acid fluorides	0-4	0 to 40 °C	11 (4.3)	1.2 (0.47)	1 (39)	Standard	930100	13-641-784

Reference Electrodes

Type	pH range	Temp. range	Reference junction	Body L cm (inches)	Tip Diameter cm (inches)	Lead L m (inches)	Connector	Corning No.	Cat. No.
Double Junction Epoxy Body For ISE tests Ag AgCl	0-14	0 to 100 °C	Sleeve	11 (4.3)	1.2 (0.47)	1 (39)	Pin	900200	13-641-900
Single Junction Epoxy Body Ag AgCl	0-14	0 to 100 °C	Sleeve	11 (4.3)	1.2 (0.47)	1 (39)	Pin	900100	13-641-898

Combination Electrodes

Type	pH range	Temp. range	Reference junction	Body L cm (inches)	Tip Diameter cm (inches)	Lead L m (inches)	Connectors	Orion No.	Cat. No.
Standard Glass Body Models									
Research Grade Ag AgCl	0-14	0 to 90 °C	Ceramic	14 (5-1/2)	1.2 (0.47)	1 (39)	Standard/pin	910200	13-641-764
Lab Field Grade Rugged Bulb	0-12	0 to 90 °C	Ceramic	14 (5-1/2)	1.2 (0.47)	1 (39)	Standard/pin	910400	13-641-681
Epoxy Body Models									
RX Series Refillable Ag AgCl	0-14	0 to 90 °C	Glass Fiber	12 (4.7)	1.2 (0.47)	1 (39)	Standard/pin	915500	13-641-700
							BNC	915600	13-641-701
GX Series Gel-filled Ag AgCl	0-12	0 to 80 °C	Wick	11 (4.3)	1.2 (0.47)	1 (39)	Standard/pin	910500	13-641-689A
							BNC	910600	13-641-689B
							Mini Phone/pin	910700	14-641-689C
Redox Platinum Ag AgCl		0 to 80 °C	Sleeve	13.9 (5-1/2)	1.2 (0.47)	1 (39)	Standard/pin	967800	13-641-905

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[1] Data for this table were taken from the 1986 Fisher catalogue.

APPENDIX

X1. MISCELLANEOUS NOTES ON GLASS ELECTRODE MEASUREMENTS AND EQUIPMENT
(Nonmandatory Information)

X1.1 Definition of pH

X1.1.1 The term pH historically has referred to the hydrogen ion activity of a solution, and has been expressed as the logarithm to the base 10 of the reciprocal (negative logarithm) of the activity of hydrogen ions at a given temperature:

$$pH = \frac{\log 1}{H^+} = -\log (H^+) \qquad (1)$$

where:

H^+ = activity of hydrogen ions.

Although equation (1) is helpful in giving theoretical meaning to the term pH and can be used as an approximate definition, it may not be rigorously related to empirical pH measurements. The definition given in section 5.1 has gained wide acceptance.

X1.2 Temperature Effects

X1.2.1 Effects of temperature on electrometric pH measurements are primarily from two categories: (1) temperature effects that are common to all electrometric measurements, and (2) variations of sample pH with temperature. The first category includes the effect of temperature on the factor $F/2.3026\ RT$ that occurs in equation (1) of section 5.1. Values of this factor for various temperatures are given in table 1. The first category also includes variations of glass electrode asymmetry potential and reference electrode liquid junction potential with temperature. If pH measurement is made in accordance with sections 14 and 24, effects of these potentials will be negligible. For the second category because of changes in activity coefficients and equilibrium constants with temperature, the pH of a sample will change with temperature. These changes are independent of method of measurement. In general, rate of change of pH with temperature is not constant, and change may be positive or negative. The data in table 3, showing changes in pH_s of buffer solutions with temperature, are typical examples.

X1.3 Reference Electrodes

X1.3.1 When making pH measurements with the glass electrode, the reference electrode used to complete the cell assembly simply functions as a source of reproducible potential. The absolute value of the reference electrode potential is of no consequence because of the way measurements are made. Both saturated calomel and silver-silver chloride electrodes have proven to be satisfactory reference electrodes. For measurements at normal room temperatures, either of these electrodes is satisfactory, and both are recommended. The silver-silver chloride is recommended for measurements at elevated temperatures because its potential is more stable than that of the saturated calomel electrode. Depending on environmental conditions, other electrodes may serve satisfactorily as reference electrodes.

X1.3.2 If a saturated electrode is used under significantly changeable temperature conditions, care must be taken to be sure that sufficient solid potassium chloride is present at all temperatures to ensure solution saturation throughout, both in free solution in electrode tube and in solution permeating electrode element. The electrode must be given 5 or 10 minutes to accommodate itself to a new temperature condition before a pH measurement is made. If temperature falls appreciably, crystallization of potassium chloride may cause plugging of liquid junction, which can result in high resistance and false or erratic potential at the junction. Any such accumulation of potassium chloride should be removed by aqueous washing.

X1.3.3 Reference electrodes of the unsaturated type have been used preferentially in continuous mechanized pH monitoring where the temperature is likely to fluctuate. The selected potassium chloride concentration is frequently saturated at the lowest temperature of use; e.g., about 3.3 normal concentration for 32 °F (0 °C). Such a reference electrode has the advantage of being free from annoying effects caused by variable solubility; however, considerable care must be taken to prepare the required concentration and to maintain prescribed value under plant operating conditions. Follow instrument manufacturer's recommendations on choosing and maintaining reference electrodes. Changing an electrode from saturated to unsaturated type (or vice versa) by changing concentration of potassium chloride may produce drifting potentials for weeks or even months.

X1.3.4 Reference electrodes are available with various ways to establish the liquid junction. These include, but are not limited to, dependence on porosity of wood, fibrous materials, glass-encased noble metal, ground-glass sleeves, ceramic frits, and nonflowing polymeric bodies.

X1.4 Faulty Glass Electrode Response and Restorative Techniques

X1.4.1 *Detecting Faulty Electrodes.*-The pH measuring assembly is standardized with two reference buffer solutions (sec. 13.2) to verify linearity of response of electrode combination at different pH values. Standardization also detects a faulty glass or reference electrode, or an incorrect temperature compensator. The faulty electrode is indicated by failure to obtain a reasonably correct value for the pH of second reference buffer solution after meter has been standardized with first solution. A cracked glass electrode will often yield pH readings that are essentially the same for both standards, and should be discarded. Even though a normal glass electrode responds well to moderate pH changes, it is not necessarily a perfect pH measuring device and may fail the rigid requirements of section 13.2 if, for example, the pH span is made as great as 5 pH units (phthalate to borax).

X1.4.2 *Imperfect pH Response.*-The pH response of the glass electrode may be impaired by a few coating substances, such as certain oily materials or even some particulates. When a faulty condition is disclosed by the check with two reference buffer solutions, electrode can frequently be restored to normal by an appropriate cleaning procedure.

X1.4.3 *Glass Electrode Cleaning Techniques.*-Where emulsions of free oil and water are to be measured for pH, it is absolutely necessary that electrodes be cleaned thoroughly after each measurement. This may be done by washing with soap or detergent and water, followed by several rinses with water. Then, the lower third of the electrodes should be immersed in HCl (1 + 9) to remove any film that may have formed on them. Rinse electrodes again by washing in several changes of water before returning them to service. Process pH analyzers used for continuous measurement may be provided with an ultrasonic cleaner to lessen or even eliminate the need for manual cleaning.

X1.4.4 Thorough cleaning with a suitable solvent may be necessary after each measurement if sample contains sticky soaps or suspended particles. If this fails, a chemical treatment designed to dissolve the particular deposited coating may prove successful. After final rinsing of electrode in cleaning solvent, immerse lower third of electrode in HCl (1 + 9) to remove possible residual film. Wash the electrode thoroughly again in several changes of water before subjecting it to standardization procedure.

X1.4.5 If an electrode has failed to respond to cleaning techniques, try a more drastic treatment as a last resort. This treatment, which will limit the life of electrode and should be used only as an alternative to discarding it, is immersing it in chromic acid cleaning solution for several minutes (longer if necessary). Chromic acid is particularly effective in cleaning foreign substances from surface of glass; however, it also has a dehydrating effect on the glass. Consequently, allow an electrode so treated, after thoroughly rinsing, to stand in water overnight before using it for measurements. Finally, if electrode fails to respond to chromic acid cleaning, it may be subjected to mild etching in an ammonium bifluoride solution. Immerse electrode for about 1 minute in a 20-percent solution of ammonium bifluoride (NH_4HF_2) and water in a polyethylene cup. The bifluoride actually removes a portion of the bulb glass and should be used only as a last resort, and then only infrequently. Follow treatment by thorough rinsing and conditioning as is recommended for a new electrode. The electrode manufacturer may have additional suggestions specific to a particular product.

X1.4.6 Techniques for cleaning flow-cell electrodes include the use of ultrasonics, brushes, and high-velocity submerged jets.

X1.5 Special Measurement Techniques

X1.5.1 *Measurements on Alkaline Waters.*-Although the high-alkalinity electrode exhibits a much lower sodium ion error than an ordinary glass electrode, the high-alkalinity electrode can still introduce an appreciable error when sodium ion content and pH or temperature of water are unusually high. Corrections may, in some instances, be applied to the measurement if suitable data are available from electrode manufacturer.

X1.5.2 Carbon dioxide from the air tends to react with alkaline water and change its pH. Make all measurements with alkaline waters or buffer solutions as quickly as possible, with the water exposed to air no longer than absolutely necessary.

X1.5.3 *Measurement of Static Solutions of Low Conductivity.*-When the sample electrical conductivity is lower than about 13μS/in (5μS/cm), the electrical resistance of water path between glass and reference electrodes may become high enough to cause measuring difficulties. If placing junction of reference electrode as close as possible to pH responsive bulb of glass electrode does not correct difficulties, the electrode pair should be protected from electrostatic charges by surrounding nonconducting cell with a grounded metallic shield. Using a metallic connector at the inlet and outlet, electrically connected externally to the chamber, can also be helpful.

X1.5.4 *Measurement of Flowing Solutions of Low Conductivity.*-When making measurements on flowing samples having an electrical conductivity lower than about 13μS/in (5μS/cm), take precautions to avoid difficulties from streaming potentials. If available, observe special precautions recommended by instrument manufacturer. Preferably, make the flow chamber of a conductive material such as stainless steel and ground it. Because streaming potential increases with flow velocity, it is advisable to adjust sample flow rate at a value not exceeding that needed to keep flow cell properly flushed. This can be done by conveying sample water to flow cell through a short line leading from a constant-head overflow chamber. Provide the line to the cell with a suitable flow-controlling means.

X1.5.5 *Magnetic Stirring.*-Do not use magnetic stirring in those instances where it may affect pH measurement.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 3110-92

PROCEDURE FOR

TURBIDITY OF WATER

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 3110; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 1889-81.

1. Scope

1.1 This designation covers procedures for determination of turbidity of industrial water and industrial waste water. Measurements of both relative and absolute turbidity are employed. Three turbidity methods are included: (1) Jackson Candle, (2) Nephelometric, and (3) Absolute.

2. Applicable Documents

2.1 *USBR Procedures*:
3100 Sampling of Water
2.2 *ASTM Standards*:
D 1129 Standard Definitions of Terms Relating to Water[1]
D 1192 Standard Specification for Equipment for Sampling Water and Steam[1]
D 1193 Standard Specification for Reagent Water[1]
D 1889 Standard Test Methods for Turbidity of Water[1]

3. Terminology

3.1 The term "turbidity" in these procedures is defined in accordance with ASTM D 1129 as follows:

3.1.1 *Turbidity.*-The reduction of transparency of a sample due to presence of particulate matter.

3.1.2 *Jackson Candle Turbidity.*-An empirical measure of turbidity in a special apparatus based on measurement of depth of a column of water sample that is just sufficient to extinguish image of a burning standard candle observed vertically through sample.

3.1.3 *Nephelometric Turbidity.*-An empirical measure of turbidity based on measurement of light-scattering characteristics (Tyndall effect) of particulate matter in sample (note 1).

NOTE 1.-The measurement of nephelometric turbidity is accomplished by measuring intensity of scattered light at 90° to incident beam of light. Numerical values are obtained by comparison with light-scattering characteristics of a known or an arbitrarily chosen material in an equivalent optical system. Comparison may also be made between transmitted light effect and scattered light effect.

3.1.4 *Absolute Turbidity.*-The fractional decrease of incident monochromatic light through sample, integrating both scattered and transmitted light (note 2).

NOTE 2.-For the small amount of scattering experienced in essentially colorless solutions, absolute turbidity of a 0.4-inch (10-mm) layer corresponds to the extinction coefficient in the equation expressing Lambert's law.

3.2 For definitions of other terms used in these procedures, refer to ASTM D 1129.

4. Reagents and Materials

4.1 *Reagent Water.*-Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to ASTM D 1193.

4.2 *Chemicals.*-Chemicals used in these procedures are discussed in sections 14.1 and 17.1.

5. Precautions

5.1 These test procedures may involve hazardous materials, operations, and equipment, and do not claim to address all safety problems associated with their use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling

6.1 The sample tubes used must be of clear, colorless glass; and must be kept meticulously clean, both inside and out. Tubes should be discarded when they become scratched or etched. Tubes must not be handled at all where the light strikes them; they should be provided with sufficient extra length or with a protective case so that they may be handled properly.

6.2 Collect sample in accordance with applicable methods of USBR 3100 and ASTM D 1192.

6.3 Turbidity should preferably be determined on same day that sample is taken. When longer storage is unavoidable, samples may be stored in the dark up to 24 hours. For even longer storage, treat each liter of sample with 1 gram of mercuric chloride; however, prolonged

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[1] *Annual Book of ASTM Standards*, vol. 11.01.

storage is not recommended. All samples should be vigorously shaken before examination.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

7.2 Specific calibration for equipment for the nephelometric turbidity method is cited in section 16.

JACKSON CANDLE TURBIDITY

8. Application

8.1 The Jackson candle turbidity method is suitable for measurement of light scattering, by turbid waters, but is not sufficiently sensitive for measurement of turbidity of well water, filtered water, or clarified effluent samples. The range of applicability of the method is shown in table 1.

8.2 The standard instrument for determining turbidity has been, for many years, the Jackson candle turbidimeter. However, because the lowest turbidity value which can be measured on this instrument is 25 units and because method is dependent upon operator's ability to visually judge point at which candlelight is indiscernible, the candle turbidimeter is generally being discarded in favor of photoelectric methods [1].[2]

NOTE 3.–Equipment available to measure turbidity or suspended solids in the very low range, less than 3 JTU (Jackson turbidity units), are the particle-size counter and the plugging index monitor. For measuring JTU's greater than 3, use the silt density index monitor by Millipave, a hydrometer, or various filter weighing techniques.

NOTE 4.–City water supplies frequently measure between 1 and 2 JTU, well below the range of either the Jackson or nephelometric turbidity methods.

9. Summary of Method

9.1 The Jackson candle method is an empirical measure of turbidity based on measurement of depth of sample, in a special graduated vessel, that is just sufficient to extinguish the image of a burning standard candle observed vertically through sample.

10. Apparatus

10.1 *Jackson Candle Turbidimeter.*[3]–This instrument consists of a graduated glass tube, a standard candle, a light shield surrounding glass tube, and a support for candle and tube. The glass tube and candle shall be supported in a vertical position so that centerline of tube passes through centerline of candle, top of support being 3 inches (76 mm) below bottom of tube. The glass tube shall be graduated either in turbidity units or in inches (millimeters). The relationship between these units of measure is shown in table 1. The glass tube shall have a flat, polished glass bottom. The candle shall be made of beeswax and spermaceti, gauged to burn within the limits of 114 to 126 grains (7.4 to 8.3 g) per hour. The support shall have a spring or other device to keep top of candle pressed against top of support.

Table 1. - Graduation of Jackson candle turbidimeter.

Depth of liquid		Turbidity, JTU[1]	Depth of liquid		Turbidity, JTU
inch	(mm)		inch	(mm)	
0.09	(2.3)	1000	0.40	(10.3)	210
.10	(2.6)	900	.42	(10.8)	200
.11	(2.9)	800	.44	(11.4)	190
.12	(3.2)	700	.47	(12.0)	180
.14	(3.5)	650	.50	(12.7)	170
.15	(3.8)	600	.53	(13.5)	160
.16	(4.1)	550	.56	(14.4)	150
.18	(4.5)	500	.60	(15.4)	140
.19	(4.9)	450	.65	(16.6)	130
.21	(5.5)	400	.70	(18.0)	120
.22	(5.6)	390	.76	(19.6)	110
.23	(5.8)	380	.84	(21.5)	100
.23	(5.9)	370	.88	(22.6)	95
.24	(6.1)	360	.93	(23.8)	90
.25	(6.3)	350	.98	(25.1)	85
.25	(6.4)	340	1.03	(26.5)	80
.26	(6.6)	330	1.10	(28.1)	75
.27	(6.8)	320	1.16	(29.8)	70
.27	(7.0)	310	1.24	(31.8)	65
.28	(7.3)	300	1.33	(34.1)	60
.29	(7.5)	290	1.43	(36.7)	55
.30	(7.8)	280	1.55	(39.8)	50
.32	(8.1)	270	1.70	(43.5)	45
.33	(8.4)	260	1.88	(48.1)	40
.34	(8.7)	250	2.11	(54.0)	35
.35	(9.1)	240	2.41	(61.8)	30
.37	(9.5)	230	2.84	(72.9)	25
.39	(9.9)	220			

[1] Jackson turbidity units.

11. Procedure

11.1 Make observations in a darkened room, with glass tube enclosed in nonreflective material. It is allowable to substitute an alternate light source for the standard candle, but instrument must then be calibrated, using a number of samples, with both the standard candle and alternate light source.

11.2 Make the turbidity test by pouring sample suspension into glass tube until image of candle flame is no longer visible when viewed through column of liquid. A 400-mL beaker and a glass stirring rod may be conveniently used for transferring water to graduated tube.

11.3 The turbidity of sample is measured in terms of the amount of sample required in calibrated tube above

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[2] Numbers in brackets refer to entries in References, section 27.

[3] This apparatus is available as a complete unit from laboratory supply houses.

candle to cause flame to be visible. The sample of water is shaken thoroughly, and about 200 mL poured into the 400-mL beaker, stirring vigorously with a glass rod to prevent settling of suspended solids. Then, about 1/2 inch (13 mm) of the water to be tested is placed in glass tube, candle lighted, and water from beaker poured slowly into tube. The water in the beaker should be stirred frequently during this process. Pouring should be very slow when flame image becomes only faintly visible, and should be stopped when image disappears. The removal of 1 percent of the suspension (water and suspended solids) should make the image visible again. The glass tube is then removed from the base and turbidity read. The reading should be carefully checked, remembering that turbidity values increase toward bottom of glass. Samples having a turbidity of more than 1,000 JTU's should be diluted with one or more equal amounts of clear water until turbidity falls below 1,000 units. The turbidity of original sample is then computed from reading made on diluted sample. For example, if reading on diluted sample is 500 JTU's and amount of original sample in dilute sample is one part in six, turbidity of original sample is 3,000 units.

NOTE 5.-Take care to keep glass tube clean both inside and outside. An occasional rinsing of tube with weak hydrochloric acid is advisable. Accumulations of dirt inside and soot and moisture outside the tube will seriously interfere with reliability of results. To obtain reasonably consistent results, candle flame must be maintained (as close as possible) at a standard size and spacing. This requires frequent trimming and adjusting. Do not keep candle lit for more than a few minutes at a time or flame size will increase.

11.4 Figure 1 shows the approximate white-light relationship between the Jackson candle turbidity and nephelos standards using No. 325 (45-μm) mesh diatomaceous earth,[4] suspended in water, settled for 24 hours, and supernatant suspension pipetted out. This relationship will vary with different materials of suspension, size of particles in suspension, and wavelength of light used for nephelos determination.

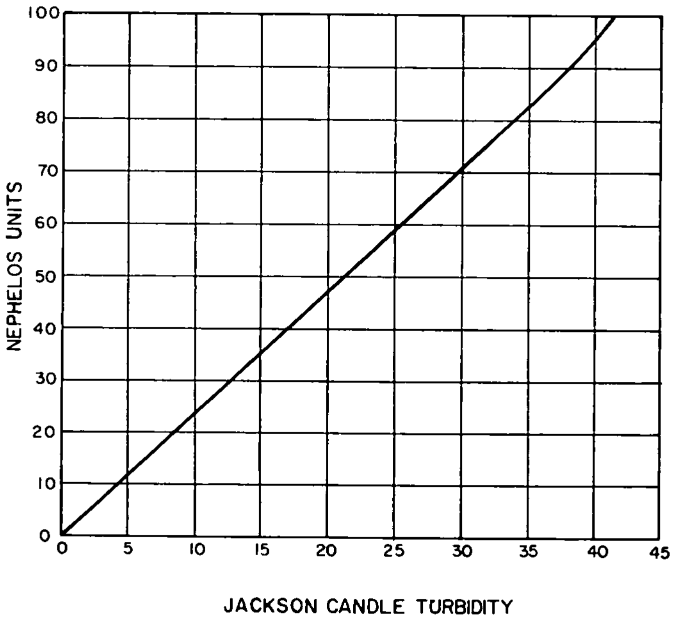

Figure 1. - Relationship between nephelos units and Jackson candle turbidity for No. 325 (45-μm) mesh diatomaceous earth.

12. Report

12.1 Report turbidity as the JTU's between 25 and 1,000.

12.2 With present instrumentation, the use of the Jackson candle turbidimeter is practically obsolete; therefore, no reporting form for this data has been devised.

NOTE 6.-The JTU is an arbitrary number and is not in terms of parts per million or milligrams per liter.

NEPHELOMETRIC TURBIDITY

13. Application

13.1 The nephelometric turbidity method covers the measurement of relative turbidity and is also applicable to the measurement of low turbidity.

14. Summary of Method

14.1 Nephelometric turbidity instruments measure scattered light at 90° or at 90° and 270° angles to the incident beam. These instruments cannot be calibrated accurately in terms of absolute turbidity, except in the case of fluids having uniform size particles that are less than about one-fifth of the wavelength of incident light, see figures 2 and 3. Nephelos standards have been prepared by thoroughly mixing suitable amounts of finely divided TiO_2 (titanium dioxide) into partially polymerized polystyrene. Alternatively, a suspension of formazine has been used as a turbidity standard, formed by reacting hydrazine sulfate and hexamethylene tetramine under carefully controlled conditions [2]. Calibrated commercial standards in sealed tubes are available.

15. Apparatus

15.1 *Nephelometer or Calibrated Slit Turbidimeter*

16. Calibration

16.1 Using nephelometric turbidity standards, obtain readings with at least three separate standards to calibrate instrument.

16.2 No specific calibration worksheets or instructions are provided with this procedure because the supplier of the turbidimeter used will provide complete instructions on calibration and standardization.

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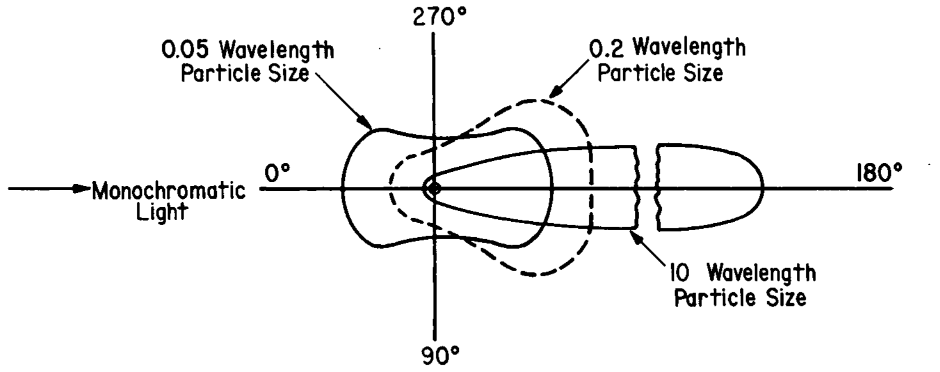
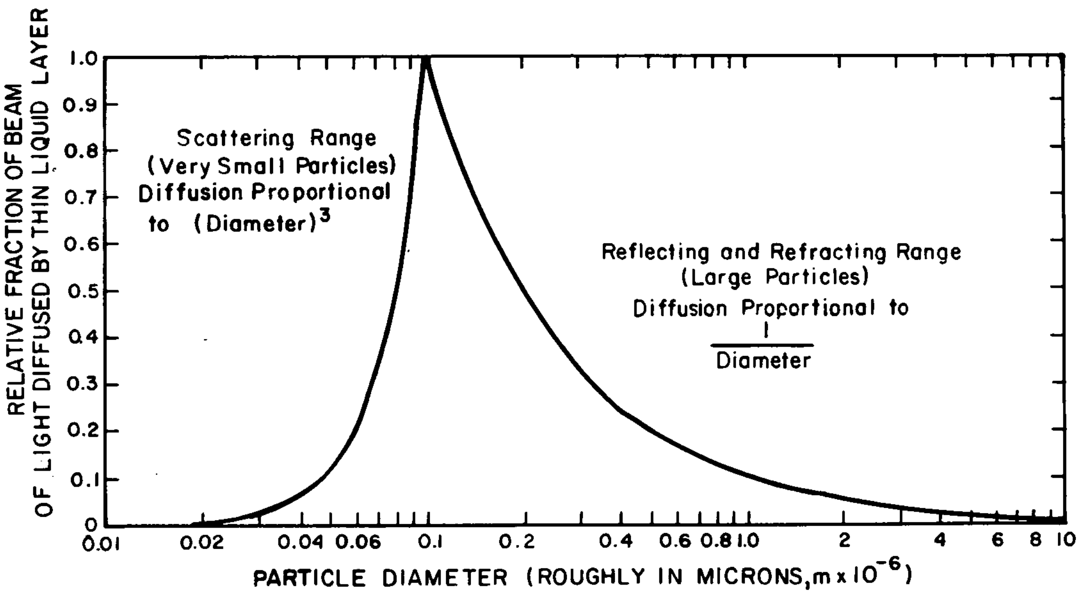
[4] Dicalite Speed plus diatomaceous earth, No. 325 (45-μm) mesh has been found satisfactory for this purpose.



Note-Typical polar diagram of total scattered light for suspensions of approximately uniform size particles of various dimensions. The ratio of particle size dimension to incident wavelength results in a particular shape polar diagram for scattered light.

Figure 2. - Rayleigh's light-scattering observations for uniform small-size particles.



NOTE-The nature of the relation between diameter of particles in supension and diffusion of a beam of 0.47-µm blue light by a thin layer of suspension (constant percentage by mass of particle material).

Figure 3. - Relationship between particle diameter and light diffusion.

17. Procedure

17.1 *Reagent Preparation*:

17.1.1 *Turbidity-Free Water*.-Pass distilled water through a membrane filter having a pore size no greater than 100 millimicrometers, discarding first 200 mL collected. Use the filtered water if it shows a lower turbidity than the distilled water. Otherwise, use the distilled water.

17.1.2 *Stock Turbidity Solutions and Suspensions*.-Prepare the following solutions and suspension monthly:

Solution 1.-Dissolve 1.00 gram of hydrazine sulfate, $(NH_2)_2\ H_2SO_4$, in distilled water and dilute to 100 mL in a volumetric flask.

Solution 2.-Dissolve 10.00 grams of hexamethalene tetramine, $(CH_2)_6N_4$, in distilled water and dilute to 100 mL in a volumetric flask.

Stock Turbidity Suspension.-In a 100-mL volumetric flask, mix 5.0 mL of solution 1 with 5.0 mL of solution 2. Allow mixture to stand 24 hours at 77 ±5.4°F (25±3 °C), then dilute to the mark and mix. The turbidity of this suspension is 400 units.

17.1.3 *Standard Turbidity Suspension*.-Dilute 10.00 mL of stock turbidity suspension to 100 mL with turbidity-free water. The turbidity of this suspension is defined as 40 units. Prepare new suspension weekly.

17.1.4 *Dilute Turbidity Standards*.-Dilute portions of standard turbidity suspension with turbidity-free water as required. Prepare new suspension weekly.

17.2 *Calibration.*-Calibrate instrument in accordance with manufacturer's instructions, running at least one standard in each range to be used. Turbidities less than 40 units are read directly from instrument scale or from appropriate calibration scale. For measurement of turbidities over 40 units, sample is diluted with turbidity-free water until turbidity falls between 30 and 40 units. The turbidity is then calculated as follows:

$$\text{NTU} = \frac{(A)\,(B + C\,)}{C} \qquad (1)$$

where:

NTU = nephelos turbidity units,
A = turbidity units found in diluted sample,
B = volume of dilution water used, and
C = sample volume taken in dilution.

17.2.1 Refer to section 16.2.

17.3 *Instruments Using Nephelometric Standards.*-First balance instrument system physically and electrically in accordance with manufacturer's instructions. Then, replace standards by sample in an optically identical tube and record reading. The straight-line relationship for Tyndall effect for small amounts of scattered 90° or 90° and 270° light produces proportional readings for nephelometric turbidity standards up to about 100 nephelos units. Therefore, nephelometric turbidity of sample can be calculated as turbidity of calibrated standard times ratio of readings.

17.4 *Instruments Using Transmitted Light From Calibrated Slit As Reference.*-Follow manufacturer's instructions in detail. This type of turbidimeter uses a fixed ratio of scattered light to transmitted light intensity. A calibrated slit adjusts quantity of light for transmission from single light source until observer matches final intensity of light for different paths. The instrument uses a special cell for the sample.

17.4.1 For all calibrated slit instruments, estimate midpoint of interval of uniform-light intensity for the two fields by rotating dial in one direction only towards higher values. This eliminates errors caused by lost motion in mechanism.

17.5 Turbidity measuring equipment manufactured by Monitek and Hach have been found to be excellent nephelometric type units.

18. Calculations

18.1 Calculate nephelometric turbidity, in nephelos units, as follows:

$$\text{NTU} = DE \qquad (2)$$

where:

NTU = nephelos turbidity units,
D = instrument reading of scattered light, and
E = nephelos units per unit of instrument reading.

18.2 No specific forms with typical data are included because most turbidimeters are of the direct readout type.

19. Report

19.1 Report results in NTU's. No typical reporting form is included with this procedure because field laboratories will generally report turbidities along with results of other water quality determinations to satisfy local requirements.

ABSOLUTE TURBIDITY

20. Application

20.1 The absolute turbidity method covers the measurement of both scattered and transmitted light. The method using the integrating-sphere apparatus is not subject to a particle size limitation.

21. Summary of Method

21.1 An integrating-sphere type of absolute turbidity instrument measures all of the scattered light. For most industrial water problems, particle size is greater than one-fifth the wavelength of light; therefore, backscattering is much less than 90° or forward-scattering, see figures 2 and 3. The apparatus shown on figure 4 is arranged to give the summation of most of the scattered light for such suspensions and solutions. From this summation, the approximate absolute turbidity can be calculated.

22. Apparatus

22.1 Instruments for measuring absolute turbidity are commercially available or can be constructed for particular needs. The best instrument for a particular problem will depend on the average size of light-scattering particles in the suspension, see figures 2 and 3. If particle size averages one-twentieth the wavelength of light, an instrument as shown on figure 5 should be used to determine absolute turbidity.

22.2 To determine approximate absolute turbidity where particle size is sufficiently large to neglect backscattering, a simplified integrating-sphere instrument can be constructed [3].[5]This instrument (fig. 4) has eliminated many interference problems by mounting test cell at outer surface of sphere and integrating only the forward and side-scattered light. If test cell is mounted internally in sphere to integrate all scattered light, many corrections must be applied because sample cell cannot be made infinitely small relative to size of sphere. The external sample cell results in more uniform reflected light within sphere. Because the sensitive surface of the barrier-layer photocells are illuminated diffusely, difficulties caused by variations in sensitivity or different parts of their sensitive surfaces are thus reduced.

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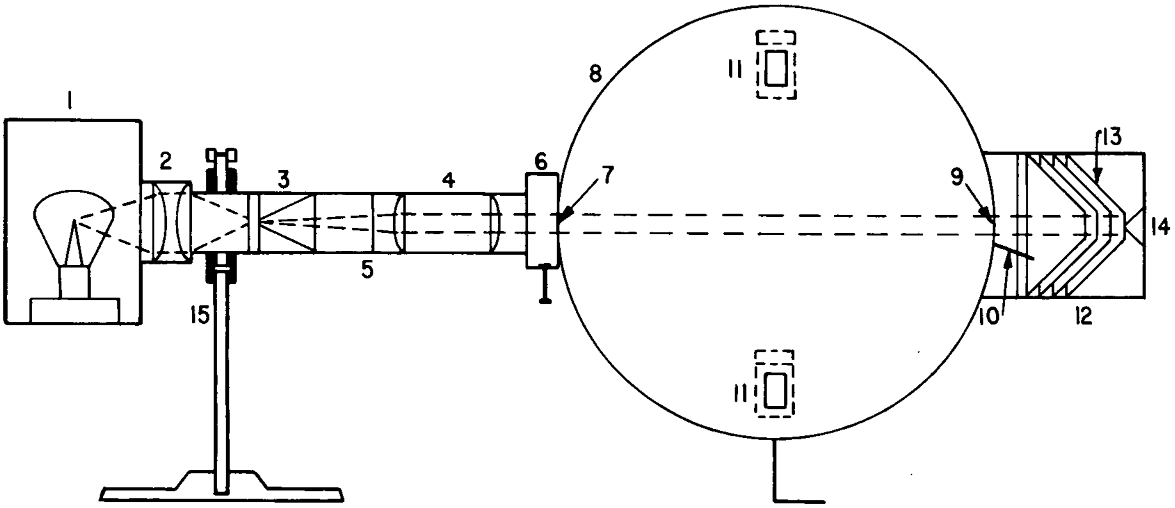
[5] Beckman makes an absolute turbidity unit that has been found to be excellent.



1. Light source
2. Condenser lenses
3. Diaphragm
4. Lens system, focusing
5. Lens tube
6. Specimen holder
7. Inlet hole
8. Integrating sphere
9. Exit hole
10. Exit flap
11. Photocells
12. Light trap
13. Light trap cones
14. Polished central chromium plated cone
15. Adjustable support for lens tube

Figure 4. – Diagrammatic full section of a sphere turbidimeter.

23. Procedure

23.1 After instrument has been properly adjusted and calibrated, obtain one galvanometer deflection for total light flux with the exit-light-reflecting flap closed to integrate both transmitted and scattered light. Then, obtain a second galvanometer reading with exit flap open to allow transmitted light to leave sphere. The second reading is usually made with a shunt setting for higher sensitivity.

24. Calculations

24.1 Calculate absolute turbidity with instrument shown on figure 4, and express result as a percentage decrease, as follows:

$$T_A = \frac{(100)\,(G_2 S_1 - T)}{G_1 S_2} \qquad (3)$$

where:

T_A = absolute turbidity,
G_1 = first galvanometer reading,
G_2 = second galvanometer reading,
S_1 = shunt factor for G_1 reading,
S_2 = shunt factor for G_2 reading, and
T = previously determined instrument error including determined scattered light from sample cell.

24.2 Refer to section 18.2.

25. Report

25.1 Report calculated absolute turbidity and corresponding wavelength and bandwidth of incident light, filter number, light source, and solution temperature.

25.2 Refer to section 19.1.

26. Precision and Bias

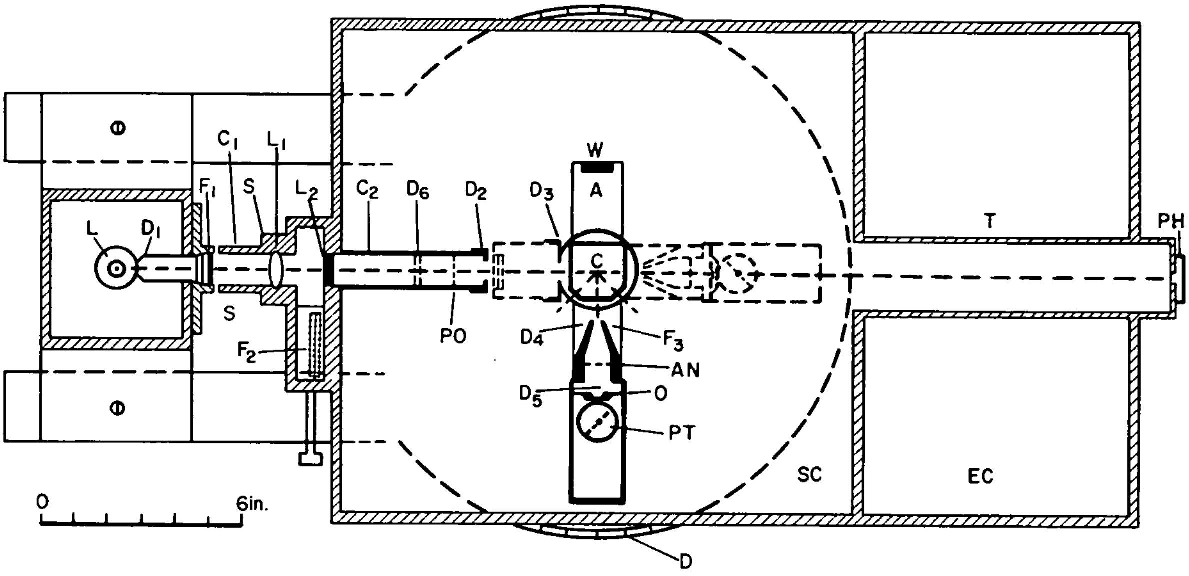
26.1 The precision and bias for this procedure have not been established.

27. References

[1] "Standard Methods for Examination of Water and Wastewater," part 163, 13th ed., American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, DC, 1971.

[2] Chevalier, P., "Formazine Standard for Turbidity," Brasserie, 152, pp. 132-133, 1959.

[3] Barnes, R. B., and C. R. Stock, "Apparatus for Transmission Turbidity of Slightly Hazy Materials," *Analytical Chemistry*, ANCHA, vol. 21, No. 1, pp. 181-184, January 1949.



OPTICAL SYSTEM

A — Rotatable arm attached to disk
AN — Analyzer
C — Semioctagonal cell
C_1 — Shutter collimating tube
C_2 — Scattering beam collimating tube
D — Graduated disk
D_1 — Lamp diaphragm.
D_2 — Removable collimating tube diaphragm
D_3 — Cell table diaphragm
D_4 — Nosepiece diaphragm
D_5 — Cathode diaphragm
D_6 — Collimating tube diaphragm
EC — Electrical compartment
F_1 — Monochromatic filter
F_2 Neutral filters

F_3 — Location of filters used for correcting for fluorescence
L — Mercury lamp
L_1 — Achromatic lens
L_2 — Planocylindrical lens
O — Opal glass depolarizing diffusor (Required for 931A photomultiplier tube but not for 1P21 tube)
PH — Covered peephole
PT — Photomultiplier tube
PO — Demountable polarizer
S — Photographic shutter
SC — Scattering compartment
T — Light-trap tube
W — Working standard

Figure 5. - Schematic diagram of instrument used for measuring absolute turbidity, dissymmetry, and depolarization of liquids.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 3115-92

PROCEDURE FOR

PARTICULATE, DISSOLVED, OR TOTAL MATTER IN WATER

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 3115; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 1888-78.

1. Scope

1.1 This designation covers the procedures for the determination of particulate, dissolved, or total matter in water, which are sometimes referred to as the suspended, dissolved, or total solids.

1.2 The procedures actually cover the determination of (1) constituents of water that can be removed by filtration, and (2) the residue on evaporation to dryness of either filtered or unfiltered samples and, as a result, these procedures do not always measure water components as defined. Separation of particulate matter by filtration requires precise definition of the filtering medium because some materials that are in no way dissolved, such as certain colloids, may not be removed by the filter used. Also, an evaporation residue will usually differ in composition from the particulate and dissolved matter present in the water.

1.3 When particulate matter is determined separately (when sample is filtered and residue quantitatively assessed), a glass fiber medium in a Gooch crucible is prescribed. Consequently, when reporting results of these tests, the filtration medium must be stated. All buoyant floating particles, or large particulate agglomerations, that cannot be dispersed throughout the sample by vigorous shaking need not be considered as fundamental constituents of the water under examination, and may be excluded from the test portion.

1.4 The procedures include steps for the determination of volatile and fixed matter in the dry residue from evaporation; however, do not include water constituents that are (1) volatile at boiling temperature, or (2) normally classified as "oily matter," which are extractable with organic solvents or volatile at drying temperature of residues. For determination of the latter, refer to ASTM D 3921.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
3100 Sampling of Water

2.2 *ASTM Standards*:

D 1129 Standard Definitions of Terms Relating to Water[1]
D 1193 Standard Specifications for Reagent Water[2]
D 1888 Standard Test Methods for Particulate and Dissolved Matter, Solids, or Residue in Water[1]
D 3921 Standard Test Method for Oil and Grease and Petroleum Hydrocarbons in Water[3]

3. Summary of Procedure

3.1 Total matter is determined by evaporation of an appropriate aliquot, or the particulate and dissolved matter are separated by filtration and individually assessed. The particulate matter is dried, and the mass determined. Dissolved matter is determined by evaporation of a portion of filtered sample. Volatile and fixed matter are determined by ignition of total matter residue at a temperature of 1112 °F (600 °C).

4. Definitions

4.1 The terms "particulate matter," "dissolved matter," "total matter," and other terms related to water constituents determined in these procedures are defined in accordance with ASTM D 1129 as follows:

4.1.1 *Particulate Matter.*-That matter, exclusive of gases, existing in the nonliquid state, which is dispersed in water to give a heterogeneous mixture.

4.1.2 *Dissolved Matter.*-That matter, exclusive of gases, which is dispersed in water to give a single phase of homogeneous liquid.

4.1.3 *Total Matter.*-The sum of the particulate and dissolved matter.

4.1.4 *Volatile Matter.*-That matter which is changed under conditions of the test from a solid or a liquid state to the gaseous state.

4.1.5 *Fixed Matter.*-Residue remaining after ignition of total matter.

4.2 For definitions of other terms used in these procedures, refer to ASTM D 1129.

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[1] *Annual Book of ASTM Standards*, vol. 11.01.

[2] *Annual Book of ASTM Standards*, vols. 02.05, 05.05, 06.03, 09.01, 10.01, 10.02, 10.03, 10.05, 11.01, 15.09.

[3] *Annual Book of ASTM Standards*, vol. 11.02.

5. Interferences

5.1 Some evaporation residues readily absorb moisture; therefore, rapid mass determination is essential to this procedure. Some residues contain materials, such as ammonium carbonate, that decompose below 217 °F (103 °C); others contain liquids, such as glycerol and sulfuric acid, that will remain as a liquid residue at 217 °F with or without solution of salts that might also be present.

5.2 Rapid mass determination of ignited residues is also important because of possible moisture absorption. There is also the possibility of interference from carbonates, organic matter, nitrite and nitrate nitrogen, water of hydration, chlorides, and sulfates, which may be decomposed either completely or in part when ignited at 1112 °F (600 °C). No single temperature is known that will eliminate all these interferences; however, reasonably reproducible results should be obtained at the prescribed 1112 °F.

5.3 Because the water being sampled is, of necessity, in contact with the sample container and tubing, it is important, especially in the case of glass, that the possible precipitation of cations or absorption of substances originally present in the water, on these surfaces, be recognized.

5.4 Too much residue on the filter or in evaporating dish will entrap water and may require prolonged drying.

6. Apparatus

6.1 *Evaporating Dishes.*-Porcelain dishes with 90- to 100-mL capacity. Vycor or platinum dishes may be substituted, and smaller size dishes may be used if required.

6.2 *Filter Discs.*-Glass-fiber filter discs either 2.2 or 4.7 cm, without organic binder, Reeve Angel type 934-A or 984-H, Gelman type A, or equivalent.

6.3 *Filter Holder, Membrane Filter Funnel, or Gooch Crucible Adapter*

6.4 *Suction Flask.*-A 500-mL flask.

6.5 *Gooch Crucible.*-A 25-mL crucible is required if a 2.2-cm filter is used.

6.6 *Drying Oven.*-Capable of 217 to 221 °F (103 to 105 °C).

6.7 *Desiccator.*-A desiccator containing calcium sulfate desiccant (Anhydrite).

6.8 *Analytical Balance.*-A balance with 200-gram capacity, capable of determining a mass to 0.0001 gram.

6.9 *Steam Bath*

6.10 *Muffle Furnace.*-Capable of 1112 °F (600 °C).

6.11 *Volumetric Cylinder.*-A 100-mL capacity cylinder.

6.12 *Volumetric Pipets*

7. Reagents and Materials

7.1 *Purity of Reagents*:

7.1.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[4] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.1.2 Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to ASTM D 1193.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8.2 Specific precautions for sampling and testing are covered in section 5.

9. Sampling

9.1 Collect sample in accordance with USBR 3100.

9.2 Because of the low concentration of total matter in some waters and the possible effects of aeration on others, sampling shall be carried out in a manner that reduces atmospheric exposure to a minimum.

9.3 Large, floating particles or submerged agglomerates (nonhomogenous materials) should be excluded from test sample.

9.4 Floating oil and grease, if present, should be included in sample and dispersed by a blender device before aliquoting.

9.5 Samples shall be analyzed as soon as practicable.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

10.2 Balances or scales shall be calibrated in accordance with USBR 1012.

10.3 Ovens shall be calibrated in accordance with USBR 1020.

10.4 Muffle furnaces must be checked using a certified thermometer.

11. Procedures

11.1 Select a volume of sample sufficient to yield an evaporation residue of about 25 mg if only the matter content is to be determined, or about 100 mg if evaporation residue is to be analyzed.

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[4] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on testing reagents not listed by the American Chemical Society, see references [1,2] in section 15.

11.2 If both particulate and dissolved matter are to be determined, proceed in accordance with sections 11.3 and 11.4; if only total matter is desired, follow the procedure starting with 11.5.

11.3 *Particulate Matter.*-This water component, also called "suspended solids," is separated by filtration using a glass-fiber filter.

11.3.1 *Preparation of Glass-Fiber Filter Disc.*-Place disc on membrane filter apparatus, or insert into bottom of a suitable Gooch crucible. While vacuum is applied, wash disc with three successive 20-mL volumes of distilled water. Remove all traces of water by continuing to apply vacuum after water has passed through. Remove filter from membrane filter apparatus, or both crucible and filter if Gooch crucible is used, and dry in an oven at 217 to 221 °F (103 to 105 °C) for 1 hour. Remove to desiccator and store until needed. Determine mass immediately before use.

11.3.2 Assemble filtering apparatus and begin suction. Shake sample vigorously, and rapidly transfer 100 mL to membrane filter funnel assembly using a 100-mL volumetric cylinder. If suspended matter is low, a larger volume may be filtered.

11.3.3 Carefully remove filter from membrane filter funnel assembly. Alternatively, remove crucible and filter from crucible adapter. Dry for at least 1 hour at 217 to 221 °F, cool in a desiccator, and determine mass. Repeat drying cycle until mass loss is less than 4 percent of previous mass, or 0.5 mg, whichever is less.

11.3.4 Record mass of particulate matter determined from the difference between final and initial masses of test filter as the "mass of particulate matter."

11.4 *Dissolved Matter.*-This water component, also called "dissolved solids" on filtration, passes through a glass-fiber filter and remains after evaporation and drying at 217 to 221 °F.

11.4.1 *Preparation of Evaporating Dishes.*-Heat the clean dish to 1112 °F (600 °C) for 1 hour in a muffle furnace, cool in a desiccator, and store until needed. Determine mass immediately before use.

11.4.2 Transfer a measured aliquot of filtered sample obtained in 11.3.2 to the dish with predetermined mass, and evaporate to dryness on a steam bath or in a drying oven.

11.4.2.1 Select an aliquot of sample sufficient to contain a residue of at least 25 mg. To obtain a residue capable of having its mass determined, successive aliquots of sample may be added to the same dish.

11.4.2.2 If evaporation is performed in a drying oven, temperature should be lowered to about 208 °F (98 °C) to prevent boiling and splattering of sample.

11.4.3 Dry evaporated sample for at least 1 hour at 217 to 221 °F, cool in a desiccator, and determine mass. Repeat drying cycle at 217 to 221 °F, cooling, desiccating, and determining mass until loss of mass is less than 4 percent of previous mass, or 0.5 mg, whichever is less.

11.4.4 Record mass of residue determined from the difference between final and initial dish masses as the "mass of dissolved matter."

11.5 *Total Matter.*-The total matter, also called "total solids," is the sum of the particulate and dissolved matter in the sample.

11.5.1 Prepare evaporating dishes as in section 11.4.1.

11.5.2 Transfer a measured portion of the well-mixed sample to an evaporating dish of predetermined mass, and evaporate to dryness on a steam bath or in a drying oven.

11.5.2.1 If evaporation is performed in a drying oven, temperature should be lowered to about 208 °F to prevent boiling and splattering of sample.

11.5.3 Dry evaporated sample for at least 1 hour at 217 to 221 °F, cool in a desiccator, and determine mass. Repeat drying cycle until mass loss is less than 4 percent of previous mass, or 0.5 mg, whichever is less.

11.5.4 Record mass of residue determined from the difference between final and initial dish masses as the "mass of total matter."

11.6 *Volatile Matter.*-This is the component lost from the total matter residue upon ignition of the residue at 1112 °F in a muffle furnace.

11.6.1 *Precautions.*-This test is subject to many errors due to loss of water of crystallization, loss of volatile organic matter prior to combustion, incomplete oxidation of certain complex organics, and decomposition of mineral salts during combustion. The results should not be considered an accurate measure of organic carbon in the sample; however, the results may be useful in the control of plant operations. The principal source of error in the determination is the failure to obtain a representative sample.

11.6.2 Ignite residue obtained for the determination of total matter at 1112 °F (600 °C) in a muffle furnace for 30 minutes, cool in a desiccator, and determine mass.

11.6.3 Record the difference between the masses of total matter and ignited matter residues as the "mass of volatile matter."

11.7 *Fixed Matter.*-This is the residue that remains after ignition of the total matter residue.

11.7.1 Record the difference in masses between the total and volatile matter, as determined in 11.5 and 11.6, as the "fixed matter."

12. Calculations

12.1 Calculate the result of each specific determination as follows:

$$M = \frac{M_x}{V} (1000) \qquad (1)$$

where:

M = matter, in milligrams per liter;
$M_x = M_1$ = grams of total matter,
$= M_2$ = grams of particulate matter,
$= M_3$ = grams of dissolved matter,

= M_4 = grams of volatile matter,
= M_5 = grams of fixed matter; and
V = liters of sample used.

12.2 When particulate and dissolved matter have been separately determined, total matter can be calculated by adding the values of M_2 and M_3.

12.3 Since glass-fiber filtration is used for the removal of particulate matter, it is mandatory that this be stated when reporting either particulate or dissolved matter.

12.4 Figures 1 and 2 show suggested worksheets for recording data and sample calculations.

13. Report

13.1 Figure 3 shows a suggested reporting form for all matter determined in accordance with this procedure. A computer printout, figure 6 of USBR 3100, is another way of reporting this data.

14. Precision and Bias

14.1 No statement can be made concerning the precision of this procedure because the precision is influenced by both the nature and amount of entrained matter and by the effects of drying and ignition on actual composition.

14.2 The bias for this procedure has not been established.

15. References

[1] Rosen, Joseph, *Reagent Chemicals and Standards,* 3rd ed., Van Nostrand Co. Inc., New York, NY, 1955.

[2] *United States Pharmacopeia and National Formulary XV,* 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

Spec. or Solic. No. DC-7612	Structure PECOS RIVER	Tested by B. FROST	Date 7-6-86
Project BRANTLEY	Item WATER QUALITY Location 1,000 FT. D/S DAM AXIS	Computed by B. FROST	Date 7-6-86
Feature BRANTLEY DAM	Station — Offset — Depth SURFACE to 2 FT.	Checked by F. HELLER	Date 7-6-86

TOTAL, VOLATILE, AND FIXED MATTER

Sample I.D.	Unfiltered aliquot, (V), L (liters)	Dish No.	Dish mass, g		Total matter		Dish mass, g Ignited (IGN)	Volatile matter		Fixed matter	
			Initial (I)	Final (F)	M_1, g	M, mg/L		M_4, g	M, mg/L	M_5, g	M, mg/L
333	0.100	5	30.1624	30.1932	0.0308	308	30.1930	0.0002	2	0.0306	306

Total Matter

M_1 (g) = F - I

$$M\text{(mg/L)} = \frac{M_1}{V}(1000)$$

Volatile Matter

M_4 (g) = F - IGN

$$M\text{(mg/L)} = \frac{M_4}{V}(1000)$$

Fixed Matter

M_5 (g) = IGN - I

$$M\text{(mg/L)} = \frac{M_5}{V}(1000)$$

Figure 1. – Sample data and calculation form for total, volatile, and fixed matter.

Spec. or Solic. No. DC-7612	Structure PECOS RIVER	Tested by B. FROST Date 7-6-86
Project BRANTLEY	Item WATER QUALITY Location 1,000 FT. D/S DAM AXIS	Computed by B. FROST Date 7-6-86
Feature BRANTLEY DAM	Station — Offset — Depth SURFACE to 2 FT.	Checked by F. HELLER Date 7-6-86

PARTICULATE AND DISSOLVED MATTER

Sample I.D.	Aliquot (V), L (liters)		Container No.		Mass, g (grams)				Particulate matter		Dissolved matter	
					Initial (I)		Final (F)		M_2, g	M, mg/L	M_3, g	M, mg/L
	Unfiltered	Filtered	Filter	Dish	Filter	Dish	Filter	Dish				
333	0.100	0.097	A	X	11.8795	31.0864	11.8810	31.1148	0.0015	15	0.0284	293

Particulate Matter

$$M_2(\text{g}) = \text{F} - \text{I}$$

$$M(\text{mg/L}) = \frac{M_2}{V}(1000)$$

Dissolved Matter

$$M_3(\text{g}) = \text{F} - \text{I}$$

$$M(\text{mg/L}) = \frac{M_3}{V}(1000)$$

Filtering Media GLASS FIBER

Figure 2. - Sample data and calculation form for particulate and dissolved matter.

Spec. or Solic. No. DC-7612	Structure PECOS RIVER	Tested by B. FROST	Date 7-6-86
Project BRANTLEY	Item WATER QUALITY Location 1,000 FT. D/S DAM AXIS	Computed by B. FROST	Date 7-6-86
Feature BRANTLEY DAM	Station —— Offset —— Depth SURFACE to 2 FT.	Checked by F. HELLER	Date 7-6-86

PARTICULATE, DISSOLVED, VOLATILE, FIXED, AND TOTAL MATTER IN WATER

Sample Identification	Matter, mg/L				
	Particulate[1]	Dissolved[1]	Volatile	Fixed	Total
333	15	293	2	306	308

[1] Separation by GLASS FIBER

Figure 3. – Sample reporting form.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 3120–92

PROCEDURE FOR

SULFATE ION IN WATER

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 3120; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 516-82.

1. Scope

1.1 This designation covers the procedure for determining the sulfate ion in water and waste water. Four methods are given as follows:

	Sections
Method A (Gravimetric Method)	8-14
Method B (Turbidimetric Method)	15-23
Method C (Volumetric Method)	24-34
Method D (Ion Chromatography)	35-44

1.2 Method A is the primary measure of the sulfate ion in all water. Methods B and C are less time consuming than Method A; however, they are frequently more liable to interference; they are particularly useful in the lower sulfate ion range, below 20 p/m or mg/L. Method D is the current method of determination used by the Bureau, and covers the range from 1 to 300 p/m or mg/L.

2. Applicable Documents

2.1 *USBR Procedures*:

3100 Sampling of Water

4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens

4191 Time-of-Setting of Hydraulic Cement by Vicat Needle

4227 Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

4908 Length Change of Hardened Concrete Exposed to Alkali Sulfates

2.2 *ASTM Standards*:

D 516 Standard Test Methods for Sulfate Ion in Water[1]

D 859 Standard Test Methods for Silica in Water[1]

D 1129 Standard Definitions of Terms Relating to Water[1]

D 1193 Standard Specification for Reagent Water[1]

D 1339 Standard Test Methods for Sulfite Ion in Water[1]

E 60 Standard Practice for Photometric Methods for Chemical Analysis of Metals[2]

E 275 Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers[3]

3. Significance

3.1 *Sulfate Attack on Hardened Concrete*.–For the degree of attack on hardened concrete by soils and waters containing various sulfate concentrations, refer to table 1. This table also recommends various types of cementitious materials to minimize the effects of sulfates. For determining the effect of alkali sulfates on hardened concrete, see USBR 4908.

3.2 *Detrimental Effects of Sulfates in Water for Mixing Concrete*:

3.2.1 In concrete construction, proposed mixing water suspected of having detrimental amounts of sulfate should be analyzed. Hard and very bitter waters are likely to contain high sulfate concentrations. Water from wells and streams in the arid Western States often contains dissolved mineral salts, chlorides, and sulfates, and should be regarded with suspicion. The purest available water should be used for mixing and curing. However, a concentration of 3,000 p/m (parts per million) or 3000 mg/L of dissolved sulfates has no detrimental effect when used for mixing or curing.

3.2.2 Researchers have found that the use of mixing water containing considerable amounts of soluble sulfate may result in a delayed reduction of compressive strength of the concrete. In one series of tests, 1.0 percent sulfate, 10,000 p/m or mg/L, in the mixing water produced no significant reduction in the 28-day compressive strength. However, after 1 year (1 month standard moist curing followed by 11 months outdoor storage), compressive strength of concrete made with 10,000 p/m sulfate-bearing mix water and Type V cement declined by 10 percent. For a similar concrete made with Type I cement, compressive strength at 1 year was 15 percent below the strength of the control concrete mixed with tap water.

3.2.3 If water with a sulfate concentration in excess of 3,000 p/m must be considered for use as mixing water, additional tests should be performed. Time-of-set studies, in accordance with USBR 4191, should be performed for general information during construction. Compressive strength studies, in accordance with USBR 4109, should be performed for 24 hours' through 1 year's age and at any intermediate time frame as desired. A reduction in strength in excess of 10 percent of control mix should be considered as a failure. Volume stability (length change)

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[1] *Annual Book of ASTM Standards*, vol. 11.01.

[2] *Annual Book of ASTM Standards*, vol. 03.05.

[3] *Annual Book of ASTM Standards*, vol. 14.01.

Table 1. – Attack on concrete by soils and waters containing various sulfate concentrations.

Relative degree of sulfate attack	Percent water-soluble sulfate (as SO_4) in soil samples	mg/L sulfate (as SO_4) in water samples
Negligible	0.00 to 0.10	0 to 150
Positive[1]	0.10 to 0.20	150 to 1500
Severe[2]	0.20 to 2.00	1500 to 10 000
Very severe[3]	2.00 or more	10 000 or more

[1] Use Type II cement.

[2] Use Type V cement, or approved combination of portland cement and pozzolan which has been shown by test to provide comparable sulfate resistance when used in concrete.

[3] Use Type V cement plus approved pozzolan which has been determined by tests to improve sulfate resistance when used in concrete with Type V cement.

studies, in accordance with USBR 4227, should be performed for 7 days' through 2 years' age and at any intermediate time frame as desired. An expansion in excess of 0.04 percent at 6 months' age should be regarded with suspicion. An expansion in excess of 0.1 percent at 1 year's age indicates remedial action must be taken. An expansion in excess of 0.2 percent at 1 year's age should be expected to cause rapid, intense, and readily recognizable expansive deterioration of the concrete. An expansion in excess of 0.5 percent at any age should be considered as a complete failure.

3.3 *Detrimental Effects of Sulfates in Water for Curing Fresh Concrete.*–Test data on the effect of impurities in curing water on quality of concrete are minimal. A concentration of 3,000 mg/L of dissolved sulfates should not be harmful; however, curing water should be free from organic matter or other impurities that might stain surface of concrete.

4. Terminology

4.1 For definitions of terms used in this procedure, refer to ASTM D 1129.

5. Purity of Reagents

5.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[4] Other grades may be used, provided it is first ascertained that reagent is of sufficiently high purity to permit its use without lessening accuracy of determination.

5.2 Unless otherwise indicated, references to water shall be understood to mean Type II reagent water conforming to ASTM D 1193. In addition, reagent water used for these methods shall be sulfate free.

6. Precautions

6.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 Picric acid, as discussed in note 2 following section 12.3, is a hazardous material.

7. Sampling

7.1 Collect sample in accordance with USBR 3100.

METHOD A-GRAVIMETRIC METHOD

8. Scope

8.1 This method is applicable to all types of water and waste water, and is directly applicable to samples containing about 20 to 100 p/m (20 to 100 mg/L) of the sulfate ion (SO_4^{-2}). This method can be extended to higher or lower ranges by adjusting sample size.

9. Summary of Method

9.1 Sulfate ion is precipitated and the mass determined as barium sulfate after removal of silica and other insoluble matter.

10. Interferences

10.1 Sulfites and sulfides may oxidize and precipitate with the sulfate. Turbidity caused by silica or other insoluble material would interfere if allowed to be present; however, removal of such interference is provided for in this method.

10.2 Other substances tend to be occluded or adsorbed on the barium sulfate, but they do not significantly affect precision and accuracy of method.

11. Reagents

11.1 *Ammonium Hydroxide* (sp. gr. 0.90).–Concentrated NH_4OH (ammonium hydroxide).

11.2 *Barium Chloride Solution* (118 g/L).–Dissolve 118 grams of $BaCl_2 \cdot 2H_2O$ (barium chloride) in water and dilute to 1 liter.

11.3 *Hydrochloric Acid* (sp. gr. 1.19) (1 + 9).–Mix 1 volume of HCl (hydrochloric acid) with 9 volumes of water.

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[4] *Reagent Chemicals, American Chemical Society Specifications*, Am. Chemical Soc., Washington, DC. For suggestions on testing reagents not listed by American Chemical Society, see references [1,2] section 45.

11.4 *Hydrofluoric Acid* (48 to 51 percent).-Concentrated HF (hydrofluoric acid).

11.5 *Methyl Orange Indicator Solution* (0.5 g/L).-Dissolve 0.05 gram of methyl orange in water and dilute to 100 mL.

11.6 *Nitric Acid* (sp. gr. 1.42).-Concentrated HNO_3 (nitric acid).

11.7 *Picric Acid.*-Saturated aqueous solution.

11.8 *Silver Nitrate Solution* (100 g/L).-Dissolve 10 grams of $AgNO_3$ (silver nitrate) in water and dilute to 100 mL.

11.9 *Sulfuric Acid* (sp. gr. 1.84).-Concentrated H_2SO_4 (sulfuric acid).

12. Procedure

12.1 Filter sample, if turbid, using a fine, ashless paper (note 1). Wash beaker and filter thoroughly with hot water.

NOTE 1.-Silica may be removed before applying this method by dehydration with HCl or $HClO_4$ (perchloric acid) in accordance with respective procedures in ASTM D 859. In this case, ignition described in section 12.5 need not be done in a platinum crucible.

12.2 Measure into beaker a quantity of clear sample containing sulfate ion equivalent to 10 to 50 mg of $BaSO_4$ (barium sulfate). Adjust volume by evaporation or dilution with water to about 200 mL. Adjust acidity of sample to methyl orange end point and add 10 mL excess of HCl (1 + 9).

12.3 Heat acidified solution to boiling and slowly add to it 5 mL of hot $BaCl_2$ solution (note 2). Stir sample vigorously while adding $BaCl_2$ solution. Keep temperature just below boiling until liquid has become clear and precipitate has settled out completely. In no case shall this settling period be less than 2 hours.

NOTE 2.-Faster precipitation and a coarser precipitate can be obtained by adding 10 mL of saturated picric acid solution and boiling sample 5 minutes before adding $BaCl_2$.

12.4 Filter the suspension of $BaSO_4$ on a fine, ashless, filter paper and wash precipitate with hot water until washings are substantially free of chlorides, as indicated by testing last portion of washings with an $AgNO_3$ solution (note 3). Avoid excessive washing. If any $BaSO_4$ passes through filter, pour filtrate through paper a second time (note 4).

NOTE 3.-Do not attempt to obtain a completely negative test for chloride. Discontinue washing when no more than a faint opalescence is produced in test.

NOTE 4.-If filtrate is poured through paper a second time, $AgNO_3$ must not be present in filtrate.

12.5 Place filter paper and contents in a platinum crucible with a predetermined mass, and char and consume paper slowly without flaming (note 1). Ignite residue at about 1472 °F (800 °C) for 1 hour, or until it is apparent that all carbon has been consumed.

12.6 Add a drop of H_2SO_4 and a few drops of HF, and evaporate under a hood to expel silica as SiF_4 (silicon tetrafluoride). Reignite at about 1472 °F, cool in a desiccator, and determine mass of crucible containing $BaSO_4$.

13. Calculation

13.1 A typical calculation form is shown on figure 1. Calculate concentration of sulfate ion as follows:

$$\text{Sulfate, p/m or mg/L} = \frac{M\,(411{,}500)}{S} \qquad (1)$$

where:

M = grams of $BaSO_4$, and
S = milliliters of sample.

14. Precision and Bias

14.1 Results of this method are precise to 1.0 percent of amount of sulfate ion present.

14.2 The bias for this method is not known.

METHOD B-TURBIDIMETRIC METHOD

15. Scope

15.1 This method is intended for rapid routine or control tests for the sulfate ion in industrial water where extreme accuracy and precision are not required. This method is directly applicable over the range of 10 to 100 p/m (10 to 100 mg/L) of the sulfate ion.

16. Summary of Method

16.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. A glycerin solution and a sodium chloride solution are added to stabilize the suspension and minimize interferences. The resulting turbidity is determined by a photoelectric colorimeter or spectrophotometer and compared to a curve prepared from standard sulfate solutions.

17. Interferences

17.1 Insoluble suspended matter in sample must be removed. Dark colors that cannot be compensated for in the procedure interfere with measurement of suspended $BaSO_4$ (barium sulfate).

17.2 Although other ions normally found in water do not appear to interfere, formation of the barium sulfate suspension is very critical. This method is more suitable as a control procedure where concentration and type of impurities present in the water are relatively constant. Determinations that are in doubt should be checked by Method A, in some cases, or by procedure suggested in note 7.

18. Apparatus

18.1 *Photometer.*-A filter photometer or spectrophotometer suitable for measurements between 350 and 425

Spec. or Solic. No. 4D-C7513	Structure RESERVOIR	Tested by J. ELLIS Date 8-14-85
Project DALLAS CREEK	Item SULFATE DETERMINATION Location STREAM AT UPPER END OF RESERVOIR	Couputed by J. ELLIS Date 8-14-85
Feature RIDGEWAY DAM - STAGE 2	Station ~ Offset ~ Depth SURFACE to ~	Checked by F. HELLER Date 8-14-85

SULFATE ION IN WATER

METHOD A							METHOD B				
Sample No.	*S* Size of Sample, mL	Filtered Sample, grams	Crucible Tare, grams	Mass of Filter Paper, Residue, and Crucible; grams	*M* Mass of $BaSO_4$, grams	SO_4^{-2} $\frac{M(411{,}500)}{S}$ p/m or mg/L	*A* ☐ Added Std. Sulfate Solution, mL	Photometer Reading Blank	Photometer Reading Sample	*B* SO_4^{-2} From Calibrated Curve, p/m or mg/L	SO_4^{-2} *B* - *A*, p/m or mg/L
/	150	NOT TURBID	10.0055	10.0435	0.0380	104.2	← NO DATA AVAILABLE →				

Figure 1. – Typical calculation form for methods A and B.

nm; preferable wavelength range being 380 to 400 nm. The cell for the instrument should have a light path through sample of about 40 mm, and should hold about 50 mL of sample. Filter photometers and photometric practices prescribed in this method shall conform to ASTM E 60; spectrophotometers shall conform to ASTM E 275.

19. Reagents

19.1 *Barium Chloride.*–Crystals of $BaCl_2 \cdot 2H_2O$ (barium chloride) screened on the No. 20 to No. 30 mesh (850 to 600 μm).

19.2 *Glycerin Solution* (1 + 1).–Mix 1 volume of glycerin with 1 volume of water (note 5).

NOTE 5.–A stabilizing solution containing sodium carboxymethyl cellulose (10 g/L) may be used instead of glycerin solution.[5]

19.3 *Sodium Chloride Solution* (240 g/L).–Dissolve 240 grams of NaCl (sodium chloride) in water containing 20 mL of concentrated HCl (hydrochloric acid, sp. gr. 1.19), and dilute to 1 liter with water. Filter solution if turbid.

19.4 *Sulfate, Standard Solution* (1 mL = 0.100 mg SO_4^{-2}).–Dissolve 0.1479 gram of anhydrous Na_2SO_4 (sodium sulfate) in water and dilute to 1 liter in a volumetric flask. Standardize by the procedure prescribed in section 12.

20. Calibration

20.1 Follow procedure in section 21, using appropriate amounts of standard sulfate solution prepared in accordance with section 19.4, and prepare a calibration curve showing sulfate ion content in parts per million (milligrams per liter) plotted against corresponding photometer readings (note 6). Prepare standards by diluting with water 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, 40.0, and 50.0 mL of standard sulfate solution to 50-mL volumes in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 4.0, 10.0, 20.0, 30.0, 40.0, 60.0, 80.0, and 100.0 p/m or mg/L, respectively.

NOTE 6.–A separate calibration curve must be prepared for each photometer, and a new curve must be prepared if it is necessary to change cell, lamp, or filter, or if any other alterations to instrument or reagents are made. Check curve with each series of tests by running two or more solutions of known sulfate concentrations.

20.2 The Bureau has never performed the sulfate ion determination by the turbidimetric method; therefore, no typical calibration curves are included.

21. Procedure

21.1 Filter sample if turbid, and adjust temperature to between 59 and 86 °F (15 and 30 °C).

21.2 Pipet 50 mL or less of clear sample containing between 0.5 and 5 mg of sulfate ion into a 200-mL beaker (note 7). Dilute to 50 mL with water if required, and add 10.0 mL of glycerin solution (note 5) and 5.0 mL of NaCl solution.

NOTE 7.–The solubility of $BaSO_4$ is such that difficulty may be experienced in determination of sulfate concentrations below about 10 p/m or mg/L. This can be overcome by concentrating the sample or by adding 5 mL of standard sulfate solution (1 mL = 0.100 mg of SO_4^{-2}) to sample before diluting to 50 mL.This will add 0.5 mg of SO_4 to the sample, which must be subtracted from final result.

21.3 Fill a 40-mm sample cell with sample solution; wipe with a clean, dry cloth; and place in cell compartment. Set colorimeter to zero absorbance (100 percent transmission) for a blank. This compensates for any acid-insoluble matter that has not been filtered out, for any color present, or both.

21.4 Pour sample solution from cell back into beaker and add, while stirring, 0.3 gram of barium chloride (note 8). Continue gently stirring solution for 1 minute, let stand for 4 minutes, and stir again for 15 seconds. Fill sample cell as before and immediately take a reading with photometer.

NOTE 8.–Stirring should be at a constant rate in all determinations. The use of a magnetic stirrer has been found satisfactory for this purpose.

21.5 If interferences are suspected, dilute sample with an equal volume of water and redetermine sulfate concentration. If value so determined is one-half that of undiluted sample, interferences may be assumed to be absent.

22. Calculation

22.1 Convert photometer readings obtained with sample to parts per million (milligrams per liter) of the sulfate ion using calibration curves described in section 20.

22.2 The Bureau has never performed the sulfate ion determination by the turbidimetric method; therefore, no typical data are provided; however, a suggested calculation form is shown on figure 1.

23. Precision and Bias

23.1 The precision of this method depends on interferences present and the skill of the analyst. When no interfering substances are present, a careful analyst can obtain a precision of 5 percent of the sulfate ion or 2 mg/L, whichever is greater.

23.2 The bias for this method is not known.

METHOD C–VOLUMETRIC METHOD

24. Scope

24.1 This method is intended for the rapid volumetric determination of a wide range of sulfate ion concentrations

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[5] The following commercial reagents have also been found to be suitable: Colloresine LV, obtainable from General Aniline and Film Corp., New York, NY, or from Irwin Dyestuff Corp., Ltd., Montreal, Canada; or Hercules CMC-70 Premium Low, obtainable from Hercules Inc., Wilmington, DE.

in industrial water. The method can be used directly for routine or control tests for the sulfate ion in certain industrial waters and, when extended by use of ion-exchange and microtechnique, for the accurate determination of the sulfate ion over the range of 5 to 1,000 p/m (5 to 1000 mg/L). For additional information on this method, see reference [3] section 45.

25. Summary of Method

25.1 Sulfate ion is titrated in an alcoholic solution under controlled acid conditions with a standard barium chloride solution using thorin as indicator. Under controlled conditions of titration, end point is relatively sharp; indicator changing from yellow to a stable pink color.

26. Interferences

26.1 Both cations and anions may cause coprecipitation errors with barium sulfate precipitate. Potassium, iron, aluminum, phosphate, flouride, and nitrate are the worst offenders. Most metallic ions also seriously interfere by forming colored complexes with the thorin indicator, especially in alcohol-water mixtures.

26.2 Interference by cations is eliminated by ion exchange. However, chromium and zirconium may form varying quantities of anion complexes with the sulfate ion under certain conditions.

26.3 Fluorides and nitrates cause no serious interference up to concentrations of 2 and 50 mg/L, respectively.

26.4 Ortho and metaphosphates interfere when present in excess of about 2 mg/L. In industrial water, such as boiler water, orthophosphate is removed by precipitation with magnesium carbonate and filtration.

26.5 Sulfite interference is eliminated by determining sulfate equivalent of sulfite and subtraction of this sulfate from determined sulfate content. Sulfides also interfere but can usually be removed by precipitation as zinc sulfide.

26.6 Chlorides obscure the pink end point if present in concentrations greater than 1000 mg/L when sulfate present is low (about 5 mg/L). The noninterfering concentration of chloride increases with increasing sulfate content.

26.7 Chromium present as chromates and dichromates is converted by treatment with hydrogen peroxide to the cation, Cr^{+3}, which is then removed by ion exchange.

27. Apparatus

27.1 *Titration Assembly*.–For high accuracy and determination of low sulfate ion concentrations, a microburet reading to 0.01 mL is necessary. Efficient magnetic stirring improves speed and convenience of titration.

27.2 *Ion Exchange Column*.–A suitable continuous flow column may be prepared by pouring 30 cm of a washed, wet resin, No. 20- to No. 25-mesh (850- to 710-µm) size, into a glass column of 9- to 10-mm inside diameter and 500±5 mm in length, the top of which widens to a reservoir of 50- to 55-mm inside diameter and 100±5 mm in length.

27.2.1 Resin is held on a suitable screen or filter plug, and flow is controlled by a length of 2-mm bore capillary tubing joined to bottom of column. This tubing is bent into a U-shape, rises to about 13 mm above resin bed, and then makes a U-bend downward for about 50 to 70 mm.

27.2.2 Other designs of exchange columns are suitable, such as a small glass column using only 25 mm of washed resin, No. 100- to No. 200-mesh (150- to 75-µm) size; 65- to 70-mm total length; and 15-mm inside diameter widening to a reservoir cup 50 to 55 mm in length and 30- to 35-mm inside diameter. This column is useful for very small samples which must be washed through the bed with water. Correction must be made for amount of wash water used.

27.3 The exchange columns shall be regenerated when about two-thirds exhausted. Regeneration shall be carried out by passing HCl (1 + 4) through resin column and by thorough washing with water. If resin column shows no visual change as exhaustion proceeds, it is advisable to regenerate after one or two samples have passed through column.

28. Reagents

28.1 *Alcohol*.–Ethyl alcohol (95 percent)[6], isopropyl alcohol, or methyl alcohol.

28.2 *Ammonium Hydroxide* (sp. gr. 0.90) (1 + 99).–Mix 1 volume of NH_4OH (ammonium hydroxide) with 99 volumes of water.

28.3 *Barium Chloride, Standard Solution* (1 mL = 0.500 mg SO_4^{-2}).–Dissolve 1.221 grams of barium chloride in 1 liter of water that has been adjusted to a pH of 3.8 to 4.0 with dilute HCl. Standardize solution in accordance with section 29 against standard sodium sulfate solutions that have been passed through ion-exchange resin.

28.4 *Hydrochloric Acid* (1 + 4).–Mix 1 volume of concentrated HCl (sp. gr. 1.19) with 4 volumes of water.

28.5 *Hydrochloric Acid* (1 + 99).–Mix 1 volume of HCl (sp. gr. 1.19) with 99 volumes of water.

28.6 *Hydrogen Peroxide* (30 percent).–Concentrated H_2O_2 (hydrogen peroxide).

28.7 *Iodine, Standard Solution* (1 mL = 0.480 mg SO_4^{-2}).–Dissolve 10 grams of KI (potassium iodine) in 100 mL of water, add 1.27 grams of iodine crystals, and stir until solution is complete. Dilute to 1 liter with water and store in a dark bottle. Standardize against 0.01 normal sodium thiosulfate solution.

28.8 *Ion-exchange Resin*.–A cationic exchange resin,[7] No. 20- to No. 25-mesh (850- to 710-µm) or No. 100- to No. 200-mesh (150- to 75-µm).

28.9 $MgCO_3$ (*Magnesium Carbonate*)

28.10 *Phenolphthalein Indicator Solution* (5.0 g/L).–Dissolve 0.5 gram of phenolphthalein in 50 mL of 95 percent ethyl alcohol.[6] Dilute to 100 mL with water.

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[6] Specially denatured ethyl alcohol conforming to Formula No. 3A or 30 of U.S. Bureau of Internal Revenue may be substituted for 95 percent ethyl alcohol.

[7] Commercial resins Dowex 50 X 8 and Amberlite IR-120 have been found to be satisfactory for this purpose.

28.11 *Potassium Dichromate.*-Heat $K_2Cr_2O_7$ (potassium dichromate)[8]in a platinum crucible to a temperature just above its fusion point, 745 °F (396 °C), taking care to exclude all dust and organic matter. After cooling, crush fused salt to a powder in an agate mortar and preserve in a glass-stoppered bottle.

28.12 *Potassium Iodide.*-The potassium iodide[8] should not yield a blue color when 1 gram is dissolved in freshly boiled reagent-grade deaerated water treated with 5 drops (0.25 mL) of 1.0 normal sulfuric acid and 1 mL of freshly prepared starch solution.

28.13 $NaHCO_3$ (*Sodium Bicarbonate*)[8]

28.14 Na_2CO_3 (*Sodium Carbonate*)[8], anhydrous.

28.15 *Sodium Thiosulfate, Standard Solution* (0.01 *N*).-Using a 1000-mL volumetric flask, dissolve 2.482 grams of sodium thiosulfate[8] in about 800 mL of water that has just been boiled and cooled. Invert flask at frequent intervals until solid is dissolved. Stabilize solution by dissolving in it, in the same manner, 1 gram of Na_2CO_3 and dilute to 1 liter with the boiled water. Standardize against $K_2Cr_2O_7$ as described in section 28.15.1.

28.15.1 Dissolve 2 grams of KI and 2 grams of $NaHCO_3$ in 300 mL of water in a 500-mL Erlenmeyer flask and add concentrated HCl (sp. gr. 1.19) slowly, while swirling flask, until carbon dioxide gas evolution ceases. Add 10 mL excess of HCl, mix, and then dissolve 0.010 gram of dried $K_2Cr_2O_7$ in the solution. Wash down inside of flask with a small amount of water without agitating flask, and allow to stand for 10 minutes. Titrate with the $Na_2S_2O_3$ solution, using starch solution as indicator, until color just changes from blue to the green color of chromic salt.

28.15.2 Calculate as follows:

$$N = \frac{\text{grams of } K_2Cr_2O_7 \text{ (1000)}}{\text{equiv. mass of } K_2Cr_2O_7 \text{ (49.04) } (S)} \qquad (2)$$

where:

N = normality of thiosulfate in equivalents per liter; and

S = milliliters of $Na_2S_2O_3$ required.

28.16 *Starch Indicator.*-Make a paste using 1 gram of Arrowroot starch or soluble iodometric starch with cold water. Pour paste into 100 mL of boiling water and boil for several minutes. Store in a glass-stoppered bottle in a cool place. Starch solution[8] prepared in this manner will remain chemically stable for 2 or 3 days.

28.17 *Sulfate, Standard Solution* (1 mL = 0.100 mg SO_4^{-2}).-Refer to section 19.4.

28.18 *Sulfuric Acid* (sp. gr. 1.84).-Concentrated H_2SO_4 (sulfuric acid).[8]

28.19 *Thorin Solution* (20 g/L).-Dissolve 0.2 gram of thorin, which is 2 (2-hydroxy-3, 6-disulfo-1-naphthylazo) benzene arsonic acid, in 100 mL of water.

29. Standardization of Barium Chloride Solution

29.1 Prepare a series of standard sulfate solutions by diluting with water 0.0, 2.0, 5.0, 10.0, 15.0, 25.0, 35.0, and 50.0 mL of the standard sulfate solution (1 mL = 0.100 mg SO_4^{-2}) to 50 mL in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 4.0, 10.0, 20.0, 30.0, 50.0, 70.0, and 100.0 p/m or mg/L, respectively.

29.2 Determine the blank and sulfate equivalent of the barium chloride solution (note 9) in accordance with sections 30.3, 30.4, and 30.5.

NOTE 9.-A solution of known sulfate concentration should be run with each series of tests or new reagents to check standardization curve. The blank used to determine sulfate content is preferably that determined from standardization curve extrapolated to zero.

30. Procedure in Presence of Sulfite, Phosphate, and Chromium

30.1 In the presence of sulfite and phosphate interference, as in boiler water, pipet 25.0 mL of filtered sample containing 10 to 50 p/m (10 to 50 mg/L) of the sulfate ion into a 100-mL beaker. Add 0.5 mL of starch indicator and titrate sulfite with iodine solution (1 mL = 0.480 mg SO_4^{-2}) (note 10). Record volume of standard iodine solution required to obtain a blue color.

NOTE 10.-A separate sample may be used to determine the sulfite by methods of ASTM D 1339.

30.2 Add 2 to 3 drops of phenolphthalein indicator solution and adjust the pH to about 10.3 with HCl (1 + 99) or NH_4OH (1 + 99). Add 0.3 to 0.5 gram of $MgCO_3$ and boil gently for 5 minutes, using a cover glass to minimize evaporation loss. Cool to 50 °F (10 °C) (note 11). Filter through acid-washed, open-texture, rapid filter paper into a 50-mL volumetric flask. Wash precipitate with three 5-mL portions of water at 50 °F. If chromium is present or suspected, add, with shaking, a few drops of H_2O_2. Adjust volume to 50 mL with water.

NOTE 11.-Phosphate ion is almost completely precipitated at or below 50 °F (10 °C), but solubility increases with increasing temperature.

30.3 Pass solution through ion-exchange column and discard first 25 to 30 mL of effluent (note 12). Pipet 10.0 mL of the next effluent into a small, white porcelain dish of 100- to 125-mL capacity.

NOTE 12.-When amount of sample is limited, sample may be passed through the small ion-exchange column described in section 27.2 and rinsed through with four or five times its volume of water so that final elutriate is 50.0 mL. Concentrate this elutriate to 10.0 mL, or take a 10.0-mL aliquot.

30.4 Add 40 mL of alcohol and 2 drops of thorin indicator. Adjust the pH to 3.8 to 4.0 by carefully adding dropwise NH_4OH (1 + 99) until solution just turns pink (note 13). Then add HCl (1 + 99) dropwise until pink color disappears.

NOTE 13.-If NH_4OH is added too fast, it is possible to overrun color change from yellow to pink and sample continues to be

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[8] Reagent used for standardization only.

yellow. It is then impossible to develop pink color by addition of NH_4OH.

30.5 Prepare a blank using water and reagents described in sections 30.1 to 30.4, and record iodine solution used for sulfite correction of blank. Titrate sample with $BaCl_2$ solution (1 mL = 0.500 mg SO_4^{-2}), using untitrated yellow blank as a color reference, to a stable pink color which deepens to a reddish pink on overtitration. Then titrate blank to same color reached in sample. Allow a time lapse of 3 to 5 seconds between additions of last few increments of $BaCl_2$ solution.

NOTE 14.-The color change may best be seen with constant stirring and a daylight fluorescent light. If such a light is not available, use of blue tinted glasses, such as American Optical No. F-9247, is helpful.

NOTE 15.-For very low sulfate concentrations, a less concentrated $BaCl_2$ solution (1 mL = 0.200 mg SO_4^{-2}) is advised. A standard sodium sulfate solution may be added to sample to raise total sulfate concentration to 10 to 15 p/m or mg/L of the sulfate ion. This additional sulfate must be subtracted from final results.

31. Procedure in Absence of Sulfite, Phosphate, and Chromium

31.1 Pass 50 mL of filtered sample directly through ion exchange column (note 11). Collect 10.0 mL of effluent and proceed in accordance with sections 30.3, 30.4, and 30.5, using extrapolated blank.

32. Procedure in Presence of Negligible Interferences

32.1 If interfering cations are low and high accuracy is not required, as in certain control tests, directly titrate 10.0 mL of filtered sample in accordance with procedure described in sections 30.4 and 30.5.

33. Calculation

33.1 Calculate the sulfate ion concentration in original sample as follows:

Sulfate, p/m (mg/L) =

$$\frac{(V_1 - B_1)(500)}{S_1} - \frac{(V_2 - B_2)(480)}{S_2} \qquad (3)$$

where:

V_1 = milliliters of $BaCl_2$ solution required for titration of sample,
V_2 = milliliters of iodine solution required for titration of sample for sulfite correction,
B_1 = milliliters of $BaCl_2$ solution required for titration of blank,
B_2 = milliliters of iodine solution required for titration of blank for sulfite correction,
S_1 = milliliters of original sample titrated, consideration being given to any dilution when passing through ion-exchange column, and
S_2 = milliliters of original sample titrated for sulfite correction.

33.2 The Bureau has never performed the sulfate ion determination by the volumetric method; therefore, no typical data or calculation form are provided.

34. Precision and Bias[9]

34.1 Titration of the sulfate ion in the range of 5 to 100 mg/L, after ion-exchange treatment, is accurate to 1.5 mg/L. The precision of this method up to 100 mg/L (excluding laboratory differences) is 0.7 mg/L. Single-operator precision may be expected to be 0.5 mg/L.

34.2 The bias for this method is not known.

METHOD D-CHROMATOGRAPHY METHOD (CONDUCTIVITY MEASUREMENT)

35. Scope

35.1 Determination of the common anions such as Br^- (bromide), Cl^- (chloride), F^- (fluoride), NO_3^- (nitrate), NO_2^- (nitrite), PO_4^{-3} (phosphate), and SO_4^{-2} (sulfate) is often desirable to characterize a water and/or to assess the need for specific treatment. Although conventional colorimetric, electrometric, or titrimetric methods are available for determining individual anions, only ion chromatography [4,5,6,7] provides a single instrumental technique that may be used for their rapid, sequential measurement. Ion chromatography eliminates the need to use hazardous reagents, and it effectively distinguishes among the halides (Br^-, CL^-, and F^-) and the oxides (SO_3^{-2} - SO_4^{-2} or NO_2^- - NO_3^-).

36. Summary of Method

36.1 A water sample is injected into a stream of carbonate-bicarbonate eluant and passed through a series of ion exchangers. The anions of interest are separated on the basis of their relative affinites for a low capacity, strongly basic anion exchanger (guard and separator column). The separated anions are directed onto a strongly acidic cation exchanger (suppressor column) where they are converted to their highly conductive acid form, and the carbonate-bicarbonate eluant is converted to a weakly conductive carbonic acid. The separated anions, in their acid form, are then measured by conductivity and identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area or peak height.

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[9] Supporting data giving results of cooperative tests may be obtained on loan from ASTM Headquarters, 1916 Race St., Philadelphia, PA, 19103, by requesting as RR: D-19-145.

37. Interferences

37.1 Any substance that has a retention time coinciding with that of any anion to be determined will interfere. For example, any relatively high concentrations of low-molecular-weight organic acids will interfere with the determination of chloride and fluoride; and a high concentration of any one ion will interfere with the resolution of other ions. Sample dilution overcomes many interferences. To resolve uncertainties of identification or quantitation, use the method of known additions. Spurious peaks may result from contaminants in reagent water, glassware, or sample processing apparatus. Because small sample volumes are used, scrupulously avoid contamination.

38. Minimum Detectable Concentration

38.1 The minimum detectable concentration of an anion is a function of sample size and conductivity scale used. Generally, minimum detectable concentrations are in the range of 0.05 mg/L for F^- and 0.1 mg/L for Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{-3}, and SO_4^{-2} with a 100-µL sample loop and a 10-µmho full-scale setting on the conductivity detector. Similar values may be achieved by using a higher scale setting and an electronic integrator.

39. Apparatus

39.1 *Chromatograph.*-An ion chromatograph including an injection valve, sample loop, guard, separator and suppressor columns, a temperature-compensated small-volume conductivity cell (6 µL or less), and a strip-chart recorder capable of full-scale response of 2 seconds or less. An electronic peak integrator is optional. The ion chromatograph shall be capable of delivering 2 to 5 mL of eluant per minute at a pressure of 200 to 1,000 lbf/in^2 (1400 to 6900 kPa)

39.2 *Separator Column.*-An anion separator column with styrene divinylbenzene-based low-capacity pellicullar anion-exchange resin capable of resolving Br^-, Cl^-, F^-, NO_3^-, NO_2^-, PO_4^{-3}, and SO_4^{-2} (4 × 250 mm).*

39.3 *Guard Column.*-Identical to separator column except use (4 × 50 mm)† to protecct separator column from fouling by particulates or organics.

39.4 *Suppressor Column.*-The suppressor column is a high-capacity cation-exchange resin capable of converting eluant and separated anions to their acid forms.[10]

40. Reagents

40.1 *Water.*-Deionized or distilled water free from interferences at the minimum detection limit of each constituent, and filtered through a 0.2-µm membrane filter to avoid plugging columns.

40.2 *Eluant Solution.*-Sodium bicarbonate-sodium carbonate, 0.003 *M* (molar) $NaHCO_3$ - 0.0024 *M* Na_2CO_3: Dissolve 1.008 grams of $NaHCO_3$ and 1.0176 grams of Na_2CO_3 in water and dilute to 4 L (liters).

40.3 *Regenerant Solution 1* (H_2SO_4) 1*N* (normality).-Use this regenerant when suppressor is not a continuously regenerated one.

40.4 *Regenerant Solution 2* (H_2SO_4) 0.025*N*.-Dilute 2.8 mL of concentrated H_2SO_4 to 4 L or 100 mL of regenerant solution 1 to 4 L. Use this regenerate with continuous regeneration-fiber suppressor system.

40.5 *Standard Anion Solutions,* (1000 mg/L).-Prepare a series of standard anion solutions by determining the indicated amount of salt, dried to a constant mass at 221 °F (105 °C), to 1000 mL (table 2). Store in plastic bottles in a refrigerator; these solutions are stable for at least 1 month.

Table 2. - Standard anion solutions.

Anion[1]	Salt	Amount, g/L
CL^-	NaCl	1.6485
F^-	NaF	2.2100
Br^-	NaBr	1.2876
NO_3^-	NaNo3	1.3707
NO_2^-	$NaNO_2$	*1.4998
PO_4^{-3}	KH_2PO_4	1.4330
SO_4^{-2}	K_2SO_4	1.8141

[1] Expressed as compound.

* Do not ovendry, dry to a constant mass in a desiccator.

40.6 *Combined Working Standard Solution, High Range.*-Combine 10 mL of Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{-3} standard anion solutions, 1 mL of the BR^-, and 100 mL of the SO_4^{-2} standard solutions; dilute to 1000 mL; and store in a plastic bottle protected from light. Solution contains 10 mg/L each of Cl^-, F^-, NO_3^-, NO_2^-, PO_4^{-3}; 1 mg of Br^- per liter; and 100 mg of SO_4^{-2} per liter. Prepare fresh daily.

40.7 *Combined Working Standard Solution, Low Range.*-Dilute 100 mL of the high range working standard solution to 1000 mL and store in a plastic bottle protected from light. Solution contains 1.0 mg/L each of Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{-3}; 0.1 mg of Br^- per liter; and 10 mg of SO_4^{-2} per liter. Prepare fresh daily.

40.8 *Alternative Combined Working Standard Solutions.*-Prepare appropriate combinations according to anion concentration to be determined. If NO_2^- and PO_4^{-3} are not included, the combijned working standard is stable for 1 month.

41. Procedure

41.1 *System Equilibration.*-Turn on ion chromatograph and adjust eluant flow rate to approximate the separation achieved in figures 2 or 3 (2 to 3 mL/min). Adjust detector to desired setting (usually 10 µmho) and

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* Dionex Part No. 030827 (normal run), Part No. 030831 (fast run), or equivalent.

† Dionex Part No. 030825 (normal run), Part No. 030830 (fast run), or equivalent.

[10] Dionex Part No. 030828 (regular), Part No. 35350 (fiber), or equivalent.

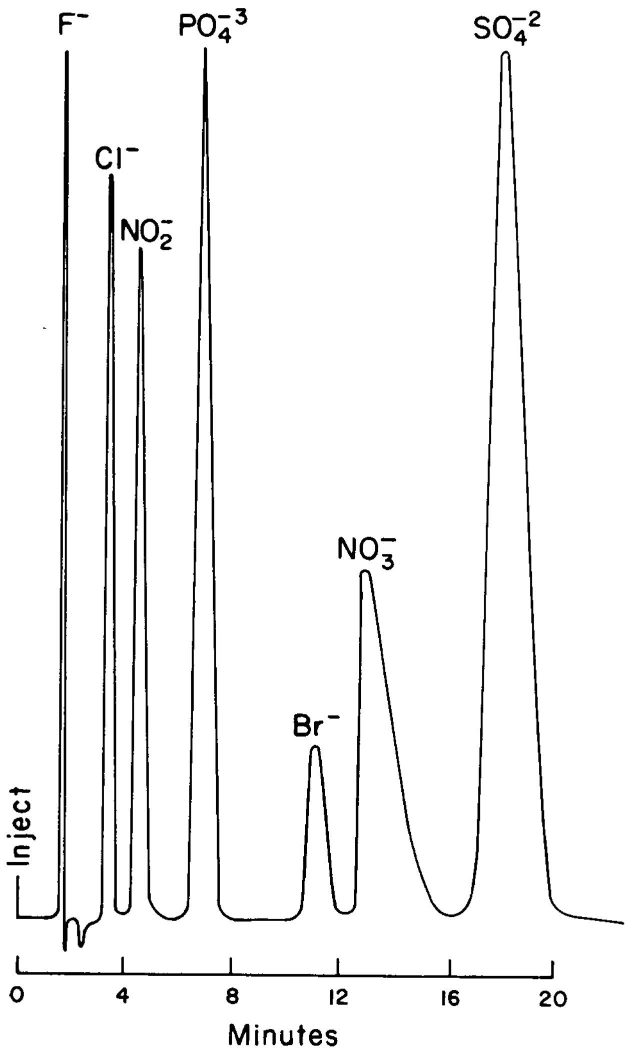

Figure 2. - Typical inorganic anion separation using normal-run columns.

allow system to come to equilibrium (15 to 20 min). A stable base line indicates equilibrium conditions. Adjust detector offset to zero-out the eluant conductivity. Then, with the fiber suppressor, adjust the regeneration flow rate to maintain stability, usually 2.5 to 3 mL/min.

41.2 *Calibration.*-Inject standards containing a single anion, or a mixture, and determine approximate retention times. Observed times vary with conditions; however, if standard eluant and anion separator column are used, retention is always in the order of F^-, Cl^-, NO_2^-, PO_4^{-3}, Br^-, NO_3^-, and SO_4^{-2}. Inject at least three different concentrations for each anion to be measured, and construct a calibration curve by plotting peak height or area against concentration on linear graph paper. Recalibrate whenever the detector setting is changed. With a system requiring suppressor regeneration, the NO_2^- interaction with the suppressor may lead to erroneous NO_2^- results; make this determination only when suppressor is at the same stage of exhaustion as during standardization, or recalibrate frequently. In this type of system, the water dip[11] may shift slightly during suppressor exhaustion and, with a fast-run column, this may lead to slight interference for F^- or Cl^-. To eliminate this interference, analyze standards that bracket the expected result, eliminate water dip by diluting sample with eluant, or by adding concentrated eluant to the sample to give the same HCO_3^-/CO_3^{-2} concentration as in the eluant. If sample adjustments are made, adjust standards and blanks identically.

If linearity is established for a given detector setting, it is acceptable to calibrate with a single standard. Record the peak height or area and retention time to permit calculation of the calibration factor, *F*.

41.3 *Sample Analysis.*-If necessary, remove sample particulates by filtering through a prewashed 0.2-μm-pore-diameter membrane filter. Using a prewashed syringe of 1 to 10 mL capacity, equipped with a male luer fitting, inject enough of the sample or standard to flush sample loop several times. For a 0.1-mL sample loop, inject at least 1 mL. Switch ion chromotograph from load to inject mode and record peak heights and retention times on strip chart recorder. After the last peak (SO_4^{-2})has appeared and the conductivity signal has returned to base line, another sample can be injected.

41.4 Regeneration.-For systems without fiber suppressor, regenerate with 1*N* H_2SO_4 in accordance with the manufacturer's instructions when the conductivity base line exceeds 300 μmho when the suppressor column is on line.

42. Calculations

42.1 Calculate concentration of each anion, in milligrams per liter, by referring to the appropraiate calibration curve. Alternatively, when response is shown to be linear, use the following equation:

$$C = HFD \qquad (4)$$

where:

C = milligrams of anion per liter,
H = peak height or area,
F = response factor = concentration of standard/height (or area) of standard, and
D = dilution factor for those samples requiring dilution.

42.2 Because this method is direct by reading from the ion chromatograph with corrections made, no typical calculation form or data is included.

43. Precision and Bias

43.1 Samples of reagent water, to which were added the common anions, were analyzed in 15 laboratories; results are shown in table 3.

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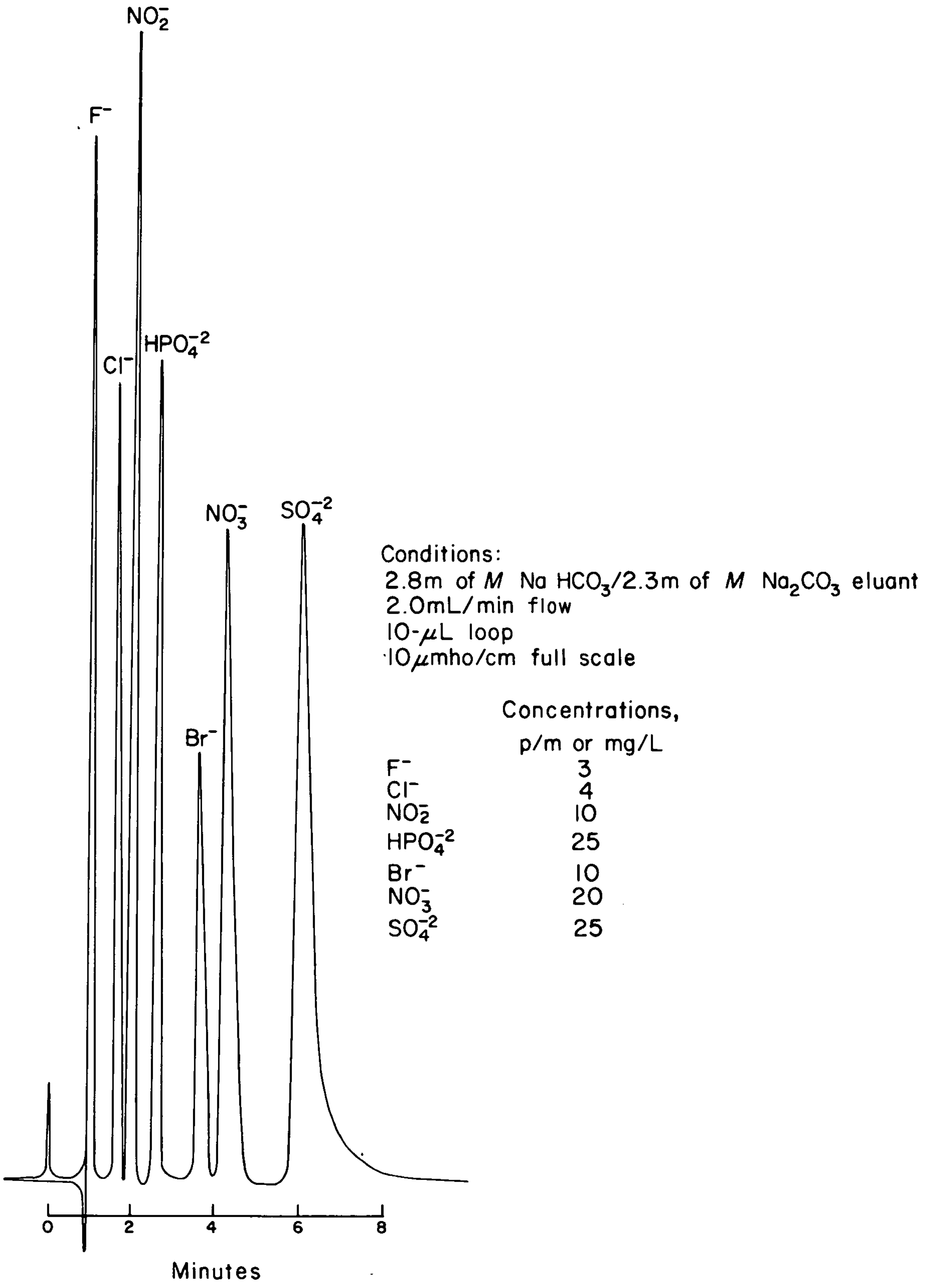
[11] Water dip occurs because water conductivity in sample is less than eluant conductivity (eluant is diluted by water).



Conditions:
2.8m of *M* Na HCO_3/2.3m of *M* Na_2CO_3 eluant
2.0mL/min flow
10-µL loop
10µmho/cm full scale

	Concentrations, p/m or mg/L
F^-	3
Cl^-	4
NO_2^-	10
HPO_4^{-2}	25
Br^-	10
NO_3^-	20
SO_4^{-2}	25

Figure 3. – Fast-run column separation.

Table 3. – Precision and bias observed for anions at various concentration levels in reagent water.

Anion	Amount added, p/m or mg/L	Amount found, p/m or mg/L	Overall precision, p/m or mg/L	Single-operator precision, p/m or mg/L	Significant bias, 95 % level
F^-	0.48	0.49	0.05	0.03	No
F^-	4.84	4.64	0.52	0.46	No
Cl^-	0.76	0.86	0.38	0.11	No
Cl^-	17	17.2	0.82	0.43	No
Cl^-	455	471	46	13	No
NO_2^-	0.45	0.09	0.09	0.04	Yes (neg.)
NO_2^-	21.8	19.4	1.9	1.3	Yes (neg.)
Br^-	0.25	0.25	0.04	0.02	No
Br^-	13.7	12.9	1.0	0.6	No
PO_4^{-3}	0.18	0.10	0.06	0.03	Yes (neg.)
PO_4^{-3}	0.49	0.34	0.15	0.17	Yes (neg.)
NO_3^-	0.50	0.33	0.16	0.03	No
NO_3^-	15.1	14.8	1.15	0.9	No
SO_4^{-2}	0.51	0.52	0.07	0.03	No
SO_4^{-2}	43.7	43.5	2.5	2.2	No

44. Report

44.1 Figures 3 through 7 of USBR 3100 show typical reporting forms for this procedure.

45. References

[1] Rosen, Joseph, *Reagent Chemicals and Standards*, D. Van Nostrand Co., Inc., New York, N.Y.

[2] *United States Pharmacopeia and National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

[3] Fritz, James S., and Stanley S. Yamamura, "Rapid Microtitration of Sulfate," *Analytical Chemistry*, vol. 27, No. 9, p. 1461, September 1955.

[4] Small, H., T. Stevens, and W. Bauman, "Novel Ion Exchange Chromatographic Method Using Conductimetric Detection," *Analytic Chemistry*, 47:1801, 1985.

[5] Fishman, M., and G. S. Pyen, "Determination of Selected Anions in Water by Ion Chromatograph," *Water Res. Invest.*, 79-101, U.S.G.S., 1979.

[6] Jenke, D., "Anion Peak Migration in Ion Chromatography," *Analytic Chemistry*, 53:1536, 1981.

[7] Bynum, M. I., S. Tyree, and W. Weiser, "Effect of Major Ions on the Determination of Trace Ions by Ion Chromatography," *Analytic Chemistry*, 53:1935, 1981.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4029-92

PROCEDURE FOR

DENSITY AND VOIDS IN AGGREGATE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4029; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 29-78.

1. Scope

1.1 This designation covers the procedure for determination of density and voids in fine, coarse, or mixed aggregates.

2. Applicable Documents

2.1 *USBR Procedures*:

1010 Calibrating Unit Weight Measures
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 29 Standard Test Method for Unit Weight and Voids in Aggregate[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Material[1,2]

3. Significance and Use

3.1 This test procedure is often used to determine necessary density values for use in designing portland cement concrete mixtures.

3.2 Voids in aggregate for concrete may also be calculated by this procedure.

3.3 In USBR work, it is normal to proportion and adjust masses in concrete batching by saturated-surface-dry masses. This test procedure discusses densities, percentage of voids, and bulk specific gravities on a dry basis and not on a saturated-surface-dry basis.

4. Apparatus

4.1 *Balance*.–The balance or scale shall be accurate within 0.1 percent of test load at any point within range of use. The range of use shall be considered to extend from mass of empty measure to mass of measure plus contents at 100 lbm/ft^3 (1602 kg/m^3).

4.2 *Tamping Rod*.–The tamping rod shall be a round, straight, steel rod of 5/8-inch (15.9-mm) diameter and about 24 inches (610 mm) in length, having one end rounded to a hemispherical tip of same diameter as rod.

4.3 *Measure*.–A cylindrical, metal measure with handles shall be provided. Measure shall be watertight, with top and bottom true and even, machined to accurate dimensions on inside, and sufficiently rigid to retain its form under rough usage. The top rim shall be smooth and plane within 0.01 inch (0.25 mm) and shall be parallel to bottom within 0.5° (note 1). Measures of the two larger sizes shown in table 1, 0.5 and 1 ft^3 (0.014 and 0.028 m^3), shall be reinforced around top with a metal band to provide an overall wall thickness of not less than 0.20 inch (5.1 mm) in the upper 1-1/2 inches (38 mm). The capacity and dimensions of the measures shall conform to limits shown in table 1.

NOTE 1.–Top rim is considered plane if a 0.01-inch (0.25-mm) feeler gauge cannot be inserted between rim and a piece of 1/4-inch (6.4-mm) or thicker plate glass laid over measure. The top and bottom are considered parallel if slope between pieces of plate glass in contact with top and bottom does not exceed 1 percent in any direction.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling

6.1 Sampling should generally be accomplished in accordance with USBR 4075, and sample reduction in accordance with USBR 4702.

7. Calibration

7.1 *Measure*.–Fill measure with water at room temperature and cover with a piece of plate glass in such a way as to eliminate bubbles and excess water. Determine

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

Table 1a. – Dimensions of measures (inch-pound units).[1]

Capacity, ft^3	Inside diameter, inches	Inside height, inches	Min. thickness of metal Bottom, inch	 Wall, inch	Max. size of aggregate,[2] inch
0.1	6.0 ± 0.1	6.1 ± 0.1	0.20	0.10	1/2
0.33	8.0 ± 0.1	11.5 ± 0.1	0.20	0.10	1
0.5	10.0 ± 0.01	11.0 ± 0.1	0.20	0.12	1-1/2
1.0	14.0 ± 0.1	11.2 ± 0.1	0.20	0.12	4

[1] Indicated size of measure may be used to test aggregates of a maximum nominal size equal to or less than size shown.
[2] Based on sieves with square openings.

Table 1b. – Dimensions of measures (SI-metric).[1]

Capacity, m^3	Inside diameter, mm	Inside height, mm	Min. thickness of metal Bottom, mm	 Wall, mm	Max. size of aggregate,[2] mm
0.003	155 ± 2	160 ± 2	5.0	2.5	12.5
0.010	205 ± 2	305 ± 2	5.0	2.5	25.0
0.015	255 ± 2	295 ± 2	5.0	3.0	37.5
0.030	355 ± 2	305 ± 2	5.0	3.0	100.0

[1] Indicated size of measure may be used to test aggregates of a maximum nominal size equal to or less than size shown.
[2] Based on sieves with square openings.

net mass of water in measure to an accuracy of ±0.1 percent. Measure temperature of water, and determine its density from table 2. Calculate factor for measure by dividing density of water by mass required to fill measure. Refer to USBR 1010 for additional information on calibration.

7.2 *Scale*.–Calibrate scale in accordance with USBR 1012.

7.3 *Oven*.–Calibrate oven in accordance with USBR 1020.

8. Conditioning

8.1 Dry sample of aggregate to an essentially constant mass, preferably in an oven at 230±9 °F (110±5 °C).

9. Rodding Procedure

9.1 The rodding procedure is applicable to aggregates having a maximum size of 1-1/2 inches (37.5 mm) or less.

9.1.1 Fill measure one-third full and level surface with fingers. Rod layer of aggregate with 25 strokes of tamping rod evenly distributed over surface. Then, fill measure two-thirds full and again level and rod. Finally, fill measure to overflowing and again rod. Level surface of aggregate with fingers or a straightedge in such a way that any slight projections of larger pieces of coarse aggregate approximately balance larger voids in surface below top of measure.

9.1.2 When rodding first layer, do not allow rod to strike bottom of measure forcibly. When rodding second and third layers, use only enough force to cause tamping rod to penetrate previous layer of aggregate.

9.1.3 Determine mass of measure and its contents, and record net mass of aggregate to nearest 0.1 percent. Multiply the determined net mass by the factor calculated as described in section 7.1. The product is density of aggregate by rodding.

9.1.4 Repeat rodding procedure for two additional tests. If the spread of the three tests exceeds 1 percent of average net mass, additional tests should be conducted. The average of the net masses for all tests shall be used to determine the density.

10. Jigging Procedure

10.1 The jigging procedure is applicable to aggregates having a maximum size greater than 1-1/2 inches (37.5 mm) but less than or equal to 4 inches (100 mm).

10.1.1 Fill measure in three approximately equal layers as described in section 9.1.1, compacting each layer by placing measure on a firm base, such as a concrete floor, raising opposite sides of measure alternately about 2 inches (51 mm), and allowing measure to drop in such a manner as to hit floor with a sharp, slapping blow. By this method, the aggregate particles will arrange themselves in a densely compacted condition. Drop the measure 50 times in this manner, 25 times on each side. Level surface of aggregate with fingers or a straightedge in such a way that any slight projections of larger pieces of coarse aggregate approximately balance larger voids in surface below top of measure.

10.1.2 Determine mass of measure and its contents, and record net mass of aggregate to nearest 0.1 percent. Multiply the determined net mass by the factor calculated as described in 7.1. The product is density of aggregate by jigging.

10.1.3 Repeat jigging procedure for two additional tests. If the spread of the three tests exceeds 1 percent of average net mass, additional tests should be conducted. The average of the net masses for all tests shall be used to determine the density.

11. Shoveling Procedure

11.1 The shoveling procedure is applicable to aggregates having a maximum size of 4 inches (100 mm) or less.

11.1.1 Fill measure to overflowing using a shovel or scoop, discharging aggregate from a height not to exceed 2 inches (51 mm) above top of measure. Exercise care to prevent, so far as possible, segregation of particle sizes of which sample is composed. Level surface of aggregate with fingers or a straightedge in such a way that any slight projections of larger pieces of coarse aggregate approximately balance larger voids in surface below top of measure.

11.1.2 Determine mass of measure and its contents, and record net mass of aggregate to nearest 0.1 percent. Multiply the determined net mass by the factor calculated as described in 7.1. The product is the loose density of the aggregate.

11.1.3 Repeat shoveling procedure for two additional tests. If the spread of the three tests exceeds 1 percent of average net mass, additional tests should be conducted. The average of the net masses for all tests shall be used to determine the density.

12. Calculations

12.1 *Void Content in Aggregate.*-The void content in aggregate can be calculated using the density measured by the rodding, jigging, or shoveling procedures:

$$V = \frac{(AM) - B}{AM} (100) \qquad (1)$$

where:

V = percent of voids,
A = bulk specific gravity (ovendry basis) as determined in accordance with USBR 4127 or 4128,
B = density of aggregate in pound mass per cubic foot (kilograms per cubic meter), and
M = density of water, 62.4 lbm/ft^3 (1000 kg/m^3)

12.2 A typical calculation form is shown on figure 1.

13. Report

13.1 Use figure 1 to report the density of the aggregate and the percent of voids, and whether the results were obtained by the rodding, jigging, or shoveling procedure. The report shall also include:

- Percent of voids in aggregate compacted by rodding
- Percent of voids in aggregate compacted by jigging
- Percent of voids in loose aggregate

14. Precision and Bias

14.1 The multilaboratory standard deviation has been found to be 1.5 lbm/ft^3 (24.0 kg/m^3) for nominal 3/4-inch (19.0-mm) maximum size, normal mass, coarse aggregate using 0.5-ft^3 (0.014-m^3) measures. Therefore, results of two properly conducted tests from two different laboratories on samples of same coarse aggregate should not differ by more than 4.2 lbm/ft^3 (67.3 kg/m^3). The corresponding single-operator standard deviation has been found to be 0.7 lbm/ft^3 (11.2 kg/m^3). Therefore, results of two properly conducted tests by same operator on same coarse aggregate should not differ by more than 2.0 lbm/ft^3 (32.0 kg/m^3) (note 2).

NOTE 2.-These precision values represent the 1S and D2S limits as described in ASTM C 670.

Table 2a.–Absolute density of water in pound mass per cubic foot.

°F	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
32	62.418	.418	.418	.419	.419	.419	.419	.420	.420	.420
33	.420	.420	.421	.421	.421	.421	.421	.421	.422	.422
34	.422	.422	.422	.422	.423	.423	.423	.423	.423	.423
35	.423	.424	.424	.424	.424	.424	.424	.424	.424	.425
36	.425	.425	.425	.425	.425	.425	.425	.425	.425	.425
37	.425	.426	.426	.426	.426	.426	.426	.426	.426	.426
38	.426	.426	.426	.426	.426	.426	.426	.426	.426	.426
39	.426	.426	.426	.426	.426	.426	.426	.426	.426	.426
40	.426	.426	.426	.426	.426	.426	.426	.426	.426	.426
41	.426	.426	.426	.426	.425	.425	.425	.425	.425	.425
42	.425	.425	.425	.425	.425	.425	.424	.424	.424	.424
43	.424	.424	.424	.424	.424	.423	.423	.423	.423	.423
44	.423	.423	.422	.422	.422	.422	.422	.422	.421	.421
45	.421	.421	.421	.421	.420	.420	.420	.420	.420	.420
46	.419	.419	.419	.419	.418	.418	.418	.418	.418	.417
47	.417	.417	.417	.417	.416	.416	.416	.416	.415	.415
48	.415	.415	.414	.414	.414	.414	.413	.413	.413	.412
49	.412	.412	.412	.411	.411	.411	.410	.410	.410	.410
50	.409	.409	.409	.408	.408	.408	.407	.407	.407	.406
51	.406	.406	.405	.405	.405	.404	.404	.404	.403	.403
52	.403	.402	.402	.402	.401	.401	.400	.400	.400	.399
53	.399	.399	.398	.398	.397	.397	.397	.396	.396	.395
54	.395	.395	.394	.394	.393	.393	.393	.392	.392	.391
55	.391	.390	.390	.390	.389	.389	.388	.388	.387	.387
56	.386	.386	.386	.385	.385	.384	.384	.383	.383	.382
57	.382	.381	.381	.380	.380	.379	.379	.378	.378	.377
58	.377	.376	.376	.375	.375	.374	.374	.373	.373	.372
59	.372	.371	.371	.370	.370	.369	.369	.368	.368	.367
60	.366	.366	.365	.365	.364	.364	.363	.363	.362	.361
61	.361	.360	.360	.359	.359	.358	.357	.357	.356	.356
62	.355	.354	.354	.353	.353	.352	.351	.351	.350	.350
63	.349	.348	.348	.347	.347	.346	.345	.345	.344	.343
64	.343	.342	.342	.341	.340	.340	.339	.338	.338	.337
65	.336	.336	.335	.334	.334	.333	.332	.332	.331	.330
66	.330	.329	.328	.328	.327	.326	.326	.325	.324	.324
67	.323	.322	.322	.321	.320	.319	.319	.318	.317	.317
68	.316	.315	.314	.314	.313	.312	.312	.311	.310	.309
69	.309	.308	.307	.306	.306	.305	.304	.303	.303	.302
70	.301	.300	.300	.299	.298	.297	.297	.296	.295	.294
71	.293	.293	.292	.291	.290	.290	.289	.288	.287	.286
72	.286	.285	.284	.283	.282	.282	.281	.280	.279	.278
73	.278	.277	.276	.275	.274	.273	.273	.272	.271	.270
74	.269	.269	.268	.267	.266	.265	.264	.263	.263	.262
75	.261	.260	.259	.258	.257	.257	.256	.255	.254	.253
76	.252	.251	.251	.250	.249	.248	.247	.246	.245	.244
77	.243	.243	.242	.241	.240	.239	.238	.237	.236	.235
78	.235	.234	.233	.232	.231	.230	.229	.228	.227	.226
79	.225	.224	.223	.223	.222	.221	.220	.219	.218	.217
80	.216	.215	.214	.213	.212	.211	.210	.209	.208	.207
81	.206	.206	.205	.204	.203	.202	.201	.200	.199	.198
82	.197	.196	.195	.194	.193	.192	.191	.190	.189	.188
83	.187	.186	.185	.184	.183	.182	.181	.180	.179	.178
84	.177	.176	.175	.174	.173	.172	.171	.170	.169	.168
85	.167	.166	.165	.164	.162	.161	.160	.159	.158	.157
86	.156	.155	.154	.153	.152	.151	.150	.149	.148	.147

Table 2b.–Absolute density of water in kilograms per cubic meter.

°C	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	999.84	.85	.85	.86	.87	.87	.88	.88	.89	.90
1	.90	.91	.91	.91	.92	.92	.93	.93	.93	.94
2	.94	.94	.95	.95	.95	.96	.96	.96	.96	.96
3	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97
4	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97
5	.97	.96	.96	.96	.96	.96	.95	.95	.95	.94
6	.94	.94	.94	.93	.93	.92	.92	.92	.91	.91
7	.90	.90	.89	.89	.88	.88	.87	.87	.86	.86
8	.85	.84	.84	.83	.82	.82	.81	.80	.80	.79
9	.78	.77	.77	.76	.75	.74	.73	.73	.72	.71
10	.70	.69	.68	.67	.66	.65	.65	.64	.63	.62
11	.61	.60	.59	.57	.56	.55	.54	.53	.52	.51
12	.50	.49	.48	.46	.45	.44	.43	.42	.40	.39
13	.38	.36	.35	.34	.33	.31	.30	.29	.27	.26
14	.24	.23	.22	.20	.19	.17	.16	.14	.13	.11
15	.10	.08	.07	.05	.04	.02	.01	.99*	.98*	.96*
16	998.94	.93	.91	.89	.88	.86	.84	.83	.81	.79
17	.77	.76	.74	.72	.70	.69	.67	.65	.63	.61
18	.60	.58	.56	.54	.52	.50	.48	.46	.44	.42
19	.41	.39	.37	.35	.33	.31	.29	.27	.24	.22
20	.20	.18	.16	.14	.12	.10	.08	.06	.04	.01
21	997.99	.97	.95	.93	.90	.88	.86	.84	.82	.79
22	.77	.75	.72	.70	.68	.66	.63	.61	.59	.56
23	.54	.51	.49	.47	.44	.42	.39	.37	.35	.32
24	.30	.27	.25	.22	.20	.17	.15	.12	.10	.07
25	.04	.02	.99*	.97*	.94*	.91*	.89*	.86*	.84*	.81*
26	996.78	.76	.73	.70	.68	.65	.62	.59	.57	.54
27	.51	.49	.46	.43	.40	.37	.35	.32	.29	.26
28	.23	.20	.18	.15	.12	.09	.06	.03	.00	.97*
29	995.94	.91	.89	.86	.83	.80	.77	.74	.71	.68
30	.65	.62	.59	.56	.53	.49	.46	.43	.40	.37

* First three significant figures shown in next line.

Spec. or Solic. No. DC-7612	Structure GRAVITY SECTION	Tested by T. GAETO D. MOOTER Date 2-3-83
Project CARLSBAD	Item MIX DESIGN Location DENVER, COLO.	Computed by T. GAETO Date 2-3-83
Feature BRANTLEY DAM	Station ~ Offset ~ Depth ~ to ~	Checked by D. MOOTER Date 2-4-83

DENSITY AND VOIDS IN AGGREGATE

Measure No. 1 Volume of Measure (ft³) 0.4991 Mass of Measure (lbm) 19.20

MSA: 2 inch(es) Particle Size Range: No.4 to 2 inches(es)

Proportion: 40 % No.4 to 1", 60 % 1 to 2", ___ % ______

Bulk Sp. Gr. (ovendry) 2.77 2.80 ______

Resultant Sp. Gr. (Blend): (Sum of Sp. Gr. Times Percentage of Each Size Fraction)

Sp. Gr. (2.77)(40 %) + Sp. Gr. (2.80)(60 %) + Sp. Gr. (___)(___%) + Sp. Gr. (___)(___%) = 2.79

Density of Water 62.274 lbm/ft³ at Water Calibration Temp. 73.4 °F

Consolidation Method: Rodding ___ Jigging ✓ Shoveling ___

Test No.	Measure Calibration	1	2	3	4	5	6	7
Mass of Measure and Contents, lbm	50.28	79.06	78.64	79.92	79.16			
Mass of Measure, lbm	19.20	19.20	19.20	19.20	19.20			
Mass of Contents, lbm	31.08	59.86	59.44	60.72	59.96			
Factor: Density H_2O/Mass H_2O, ft³	2.0037	2.0037	2.0037	2.0037	2.0037			
Dry Density, lbm/ft³		119.9	119.1	121.7	120.1			
No. 1 119.9								
No. 2 119.1								
No. 3 121.7								
No. 4 120.1								
No. 5								
No. 6								
No. 7								
Avg. of 3: 360.7/3		120.2	120.2	120.2				
Avg of 4 : 480.8/4		120.2	120.2	120.2	120.2			
Difference from Avg., lbm		-0.3	-1.1	+1.5				
Difference from Avg., %		0.2	0.9	1.2				

$$V = \frac{(AM) - B}{AM} (100)$$

where:

$$V = \frac{(2.79)(62.4) - 120.2}{(2.79)(62.4)}(100) = 31\ \%$$

V = percent of voids,
A = bulk specific gravity (ovendry basis),
B = density of aggregate, lbm/ft³, and
M = density of H_2O, 62.4 lbm/ft³.

Figure 1a. - Sample data and calculation form (inch-pound units).

Spec. or Solic. No. DC-7612	Structure GRAVITY SECTION	Tested by T. GAETO D. MOOTER Date 2-4-83
Project CARLSBAD	Item MIX DESIGN Location DENVER, COLO.	Computed by T. GAETO Date 2-4-83
Feature BRANTLEY DAM	Station — Offset — Depth — to —	Checked by D. MOOTER Date 2-4-83

DENSITY AND VOIDS IN AGGREGATE

Measure No. 6 Volume of Measure (m^3) 0.01499 Mass of Measure (kg) 9.24

MSA: 50 mm Particle Size Range: 4.75 to 50 mm

Proportion: 40 % 4.75 to 25mm, 60 % 25 to 50 mm, ___ % ______

Bulk Sp. Gr. (ovendry) 2.77 2.80 ______

Resultant Sp. Gr. (Blend): (Sum of Sp. Gr. Times Percentage of Each Size Fraction)

Sp. Gr. (2.77)(40 %) + Sp. Gr. (2.80)(60 %) + Sp. Gr. (___)(___%) + Sp. Gr. (___)(___%) = 2.79

Density of Water 997.54 kg/m^3 at Water Calibration Temp. 23 °C

Consolidation Method: Rodding ___ Jigging ✓ Shoveling ___

Test No.	Measure Calibration	1	2	3	4	5	6	7
Mass of Measure and Contents, kg	24.19	38.02	37.86	38.44	38.07			
Mass of Measure, kg	9.24	9.24	9.24	9.24	9.24			
Mass of Contents, kg	14.95	28.78	28.62	29.20	28.83			
Factor: Density H_2O/Mass H_2O, m^3	66.725	66.725	66.725	66.725	66.725			
Dry Density, kg/m^3		1920	1910	1948	1924			
No. 1 1920								
No. 2 1910								
No. 3 1948								
No. 4 1924								
No. 5								
No. 6								
No. 7								
Avg. of 3: 5778/3		1926	1926	1926				
Avg of 4 : 7702/4		1926	1926	1926	1926			
Difference from Avg., kg		-6	-16	+22				
Difference from Avg., %		0.3	0.9	1.1				

$$V = \frac{(AM) - B}{AM} (100)$$

where:

$$V = \frac{(2.79)(1000) - 1926}{(2.79)(1000)} (100) = 31 \%$$

V = percent of voids,

A = bulk specific gravity (ovendry basis),

B = density of aggregate, kg/m^3, and

M = density of H_2O, 1000 kg/m^3.

Figure 1b. - Sample data and calculation form (SI-metric).

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4031-92

PROCEDURE FOR

MAKING AND CURING CONCRETE TEST SPECIMENS IN FIELD

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4031; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 31-84.

1. Scope

1.1 This designation covers the procedures for making and curing cylinder and beam test specimens in the field from concrete used in construction.

NOTE 1.–For making and curing test specimens in laboratory, see USBR 4192. For making and curing test specimens from no-slump concrete, such as roller compacted concrete, see USBR 4906.

2. Applicable Documents

2.1 *USBR Procedures*:

1440 Calibrating the Vibratory Table for Maximum Index Unit Weight Testing
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4192 Making and Curing Concrete Test Specimens in Laboratory
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4906 Casting No-Slump Concrete in Cylinder Molds Using Vibratory Table

2.2 *ASTM Standards*:

C 31 Standard Method of Making and Curing Concrete Test Specimens in the Field.[1]
C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically[1]
C 511 Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1,2]

3. Apparatus

3.1 *Molds*:

3.1.1 *General*.–Molds for specimens, or molds for fastening to specimens in contact with the concrete, shall be made of steel, cast iron, or other nonabsorbent material that is nonreactive with concrete containing portland or other hydraulic cements. Molds shall hold their dimensions and shape under conditions of severe use, and shall be watertight during use, as judged by their ability to hold water. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through joints. A positive means shall be provided to hold baseplates firmly to the molds. Molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

3.1.2 *Cylinder Molds*.–The cylinder molds shall conform to section 3.1.1 and to ASTM C 470, except that paper or cardboard molds will not be allowed, and bottom of all molds shall be flush with bottom of sidewall (no inside crimp), see figure 1.

NOTE 2.–Satisfactory reusable molds may be made from cold-drawn, seamless steel tubing or from steel pipe, see figure 2. These tubular sections shall be cut to proper length, slotted by machine on one side parallel to axis, and fitted with a means of closing the slot and attaching a base plate. Split-tube molds should be machined inside, if necessary, to ensure compliance with dimensional tolerances after slotting and clamping.

NOTE 3.–Molds made from less rigid materials, such as formed sheet metal and certain plastics, should be used with care to ensure they are not deformed more than stipulated tolerances during use. Tubes or bands of heavy gauge metal around the mold during molding of the specimen can be used to maintain dimensional tolerances.

3.1.3 *Beam Molds*.–The beam molds shall be rectangular in shape, and of dimensions required to produce the specimens as stipulated in section 4.2. Inside surfaces of molds shall be smooth. The sides, bottom, and ends of molds shall be at right angles to each other and shall be straight, true, and free of warpage. The maximum variation from the nominal cross section shall not exceed 1/8 inch (3.2 mm) for molds with a depth or breadth of 6 inches (152 mm) or more. The molds shall produce

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.01.

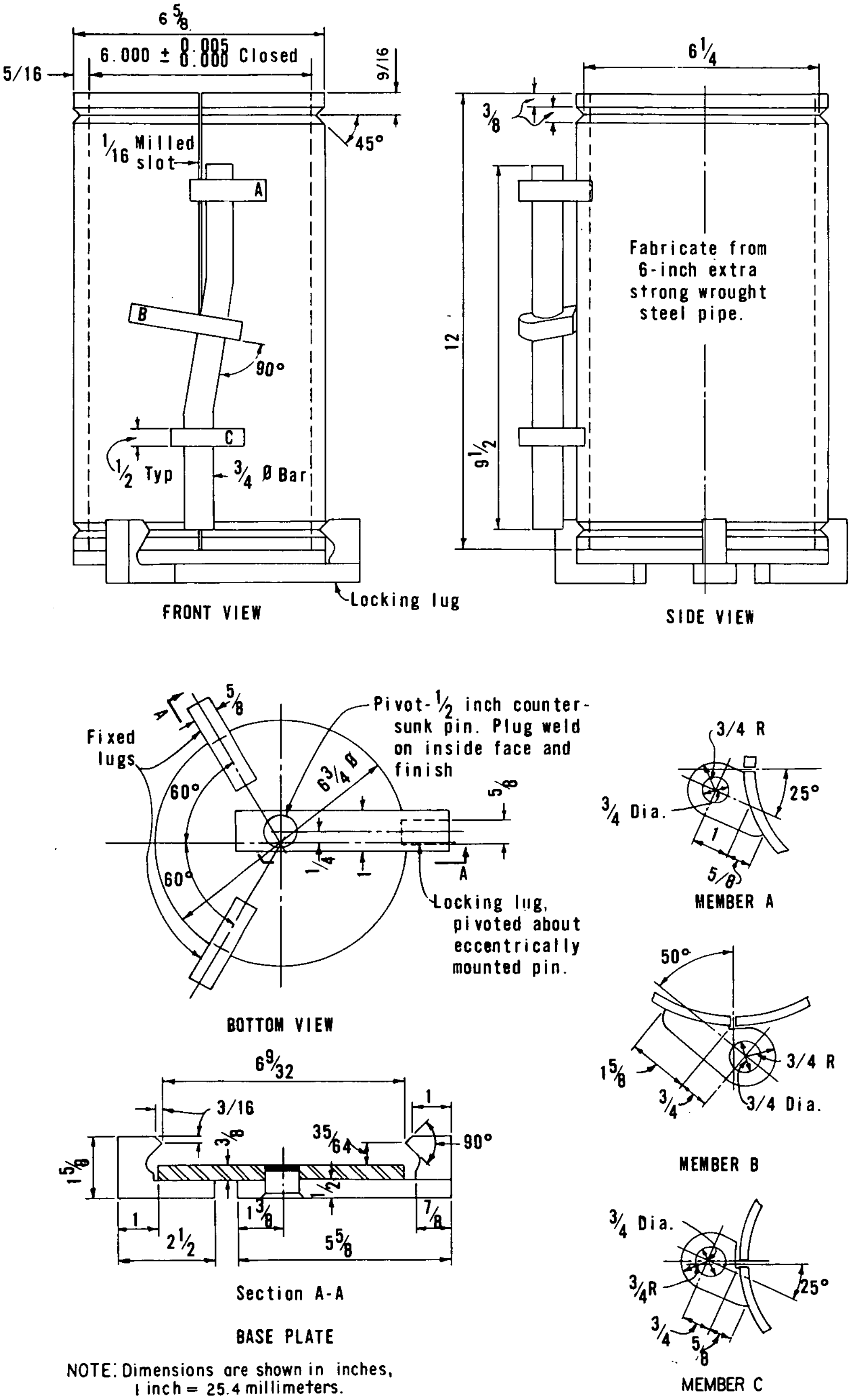


Figure 2. - Test cylinder mold. 288-D-3270.

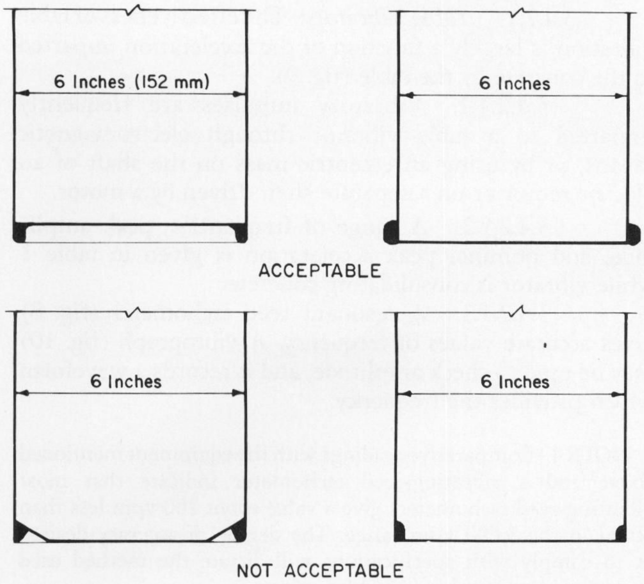


Figure 1. - Fabrication details of can bottoms (metal band not shown). 288-D-2660.

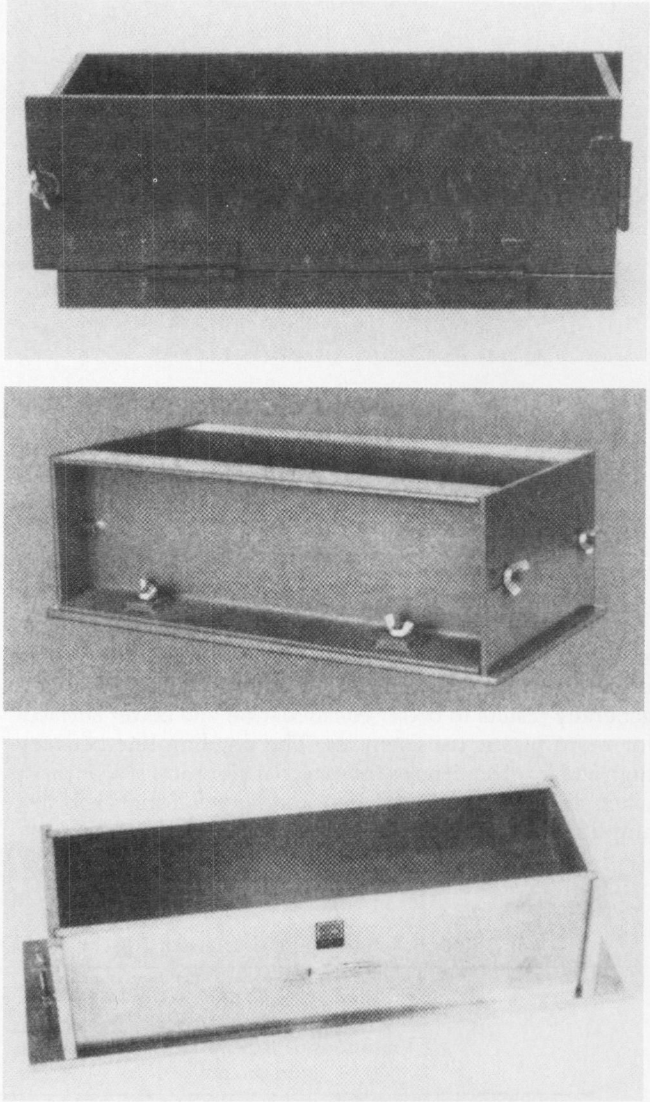


Figure 3. - Typical flexural beam molds.

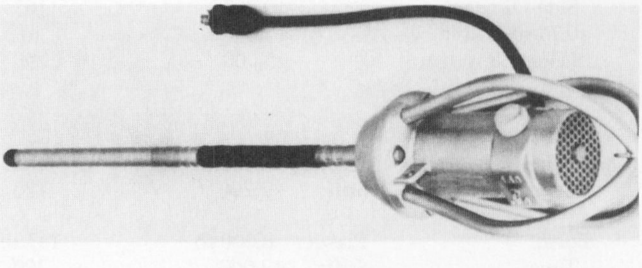


Figure 4. - Post-type vibrator for laboratory use.

specimens not more than 1/16 inch (1.6 mm) shorter than required length in accordance with section 4.2; however, specimens may exceed the required length by more than 1/16 inch. Examples of molds that have been acceptable are shown on figure 3.

3.2 *Tamping Rods.*-Two different sizes of tamping rods are used by the Bureau. The larger rod is 5/8 inch (16 mm) in diameter and about 24 inches (610 mm) long, and the smaller rod is 3/8 inch (10 mm) in diameter and about 12 inches (305 mm) long. The smaller rod is used for smaller-sized cylinders in special studies research work. Each rod shall be a round, straight steel rod with at least the tamping end rounded to a hemispherical tip of same diameter as rod. Both ends of rod may be rounded, if preferred.

3.3 *Mallets.*-The mallet shall have a rubber or rawhide head with a mass of 1.25± 0.50 lbm (567± 227 g).

3.4 *Vibrators.*-Concrete vibrators are classified in two categories — internal and external. External vibrators are subdivided into vibrating tables and form vibrators.

3.4.1 *Internal Vibrators*:

3.4.1.1. The internal vibrators (figs. 4 and 5) shall have rigid or flexible shafts, preferably powered by electric motors.

3.4.1.2. The outside diameter or side dimension of the vibrating elements shall be at least 0.75 inch (19 mm) and not greater than 1.5 inches (38 mm).

3.4.1.3. The combined length of shaft and vibrating element shall exceed maximum depth of section being vibrated by at least 3 inches (76 mm).

3.4.1.4. A range of frequencies, while vibrator is operating in concrete, and a calculated peak amplitude and nominal peak acceleration in air is given in table 1.

3.4.1.5. The vibrating reed tachometer (fig. 6) is a simple device for checking the frequency of the internal vibrator operating in air or in concrete. Several vibrator supply firms have prepared scales on stickers which may readily be attached to the vibrator head (fig. 7). This is a visual-effect scale (optical wedge) that provides an approximate measure of maximum amplitude and the distribution of amplitude along the head. A resonant reed

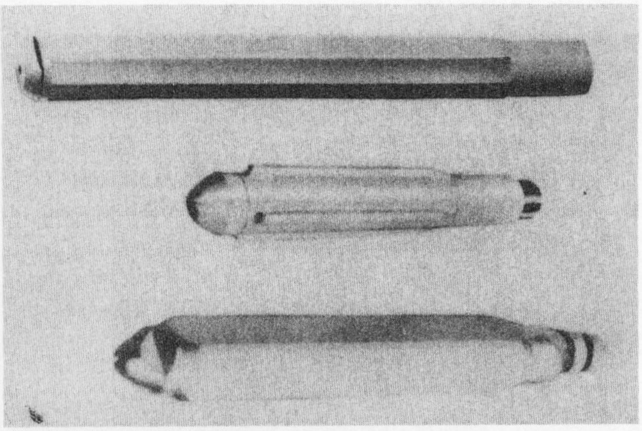


Figure 5. - Some special shapes of vibrator heads: fluted (top), finned (middle), and square (bottom). Pentagonal and hexagonal shapes are also available.

tachometer (fig. 8) is a more expensive instrument that indicates more accurate values of frequency.

3.4.2 *External Vibrators.*-Low-frequency high amplitude vibration is normally preferred for stiffer mixtures. High frequency, low amplitude vibration generally results in better consolidation and better surfaces for more plastic consistencies. The dividing line between high and low frequencies for external vibration is arbitrarily taken as 6,000 vpm (100 Hz) and between high and low amplitude 0.005 inch (0.13 mm).

3.4.2.1. *Table Vibrators.*-The effectiveness of table vibration is largely a function of the acceleration imparted to the concrete by the table (fig. 9).

3.4.2.1.1. Vibratory impulses are frequently imparted to a table vibrator through electromagnetic means, or by using an eccentric mass on the shaft of an electric motor or on a separate shaft driven by a motor.

3.4.2.1.2. A range of frequencies, peak amplitude, and nominal peak acceleration is given in table 1 while vibrator is consolidating concrete.

3.4.2.1.3. A resonant reed tachometer (fig. 8) gives accurate values of frequency. A vibrograph (fig. 10) may be used to check amplitude, and it records a waveform which provides the frequency.

NOTE 4.-Comparative readings with the equipment mentioned above and a vibrating-reed tachometer indicate that most vibrating-reed tachometers give a value about 200 vpm less than actual in the 3,600 vpm range. The degree of accuracy desired or to comply with specifications will dictate the method used in determining amplitude and frequency.

3.4.2.2. *Form Vibrators.*-Form vibrators are self-cooling and can be either the rotary or reciprocating type (fig. 11).

3.4.2.2.1. Rotary-type form vibrators produce essentially simple harmonic motion. The impulses have components both perpendicular to and in the plane of the form. This type may be pneumatically, hydraulically, or electrically driven.

Table 1. - Range of characteristics, performance, and application of internal and external vibrators.

	Frequency, f		Average Amplitude, Y_p		Nominal Peak Acceleration, A_p
	Vibrations or Revolutions/min, vpm or rpm	Cycles, Hz	inch	millimeter	g* Desired
			Internal Vibrator		
	Under Load				†
Type Vibrator Outside Dia. or Side Dimension 0.75 to 1.50 in (19 to 38 mm)	10,000 to 15,000	167 to 250	0.0167 to 0.0300	0.424 0.762	74 300
			External Vibrators		
Table Type	Plastic: 3,600 to Stiff: 7,200	60 to 120	0.0081 to 0.0136 0.0041 to 0.0068	0.206 to 0.345 0.104 to 0.173	3 to 5 6 to 10
Form Type	Plastic: 8,000 to Stiff: 12,000	133 to 200	0.0006 to 0.0011 0.0007 to 0.0012	0.015 to 0.028 0.018 to 0.031	1 to 2 3 to 5

* $g = 32.17398$ ft/s² (9.80665 m/s²).

† A calculated acceleration with frequency and amplitude assumed in air. From ACI 309R, the frequency of internal vibrators under load is approximately 4/5 the frequency in air. With this allowance made, acceleration A_p in g's is equal to $4\pi^2 f^2 Y_p \div g$:

where:

f = $1/t$ = frequency, vibration cycles or vibrations per second (Hz),

Y_p = amplitude (deviation from point of rest, inch (mm); peak amplitude or one-half peak-to-peak amplitude or displacement,

g = 386 in/s² (9810 mm/s²), and

t = time for one complete revolution or vibration cycle, second.

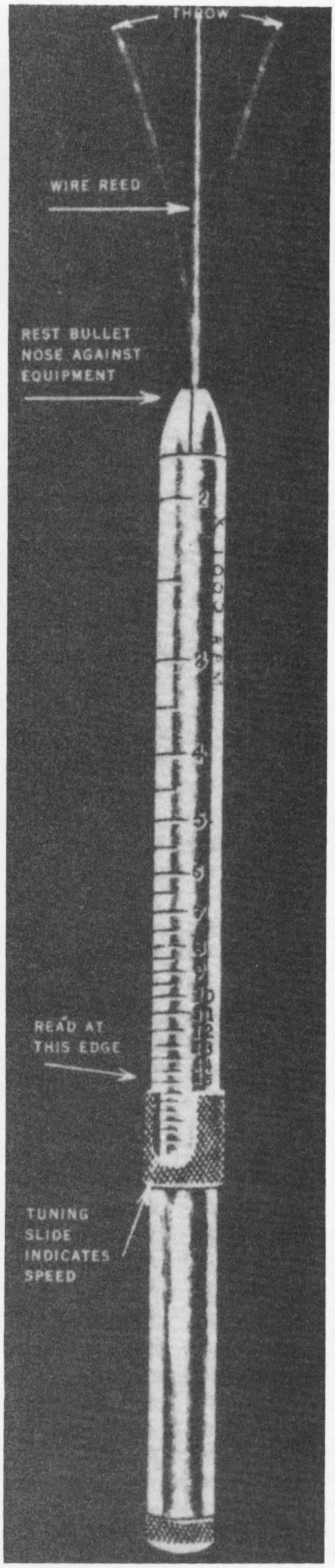
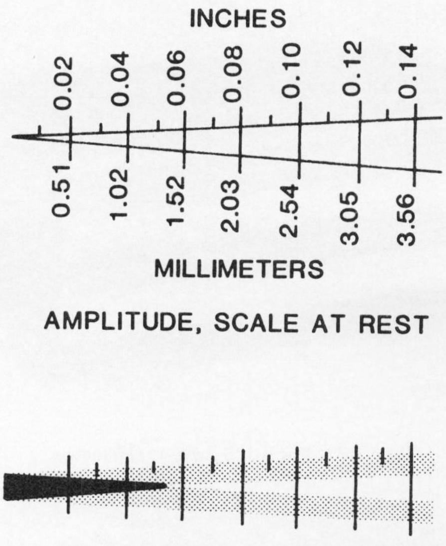


Figure 6. – Vibrating reed tachometer.



AMPLITUDE, SCALE AT REST

SCALE DURING VIBRATION

(Indicating an amplitude of 0.055 inches (1.4 mm))

INSTRUCTIONS FOR USE

Attach scale to vibrator head at point where amplitude is desired, with centerline of "V" parallel to axis of vibrator. With head vibrating, a black triangle forms at the apex of the "V". The scale reading at tip of triangle is peak amplitude (half the peak-to-peak displacement). A hand reading glass (2 to 3X) will improve accuracy of reading. With care, this device is capable of an accuracy of about 0.005 inch(0.127 mm).

Figure 7. – Visual effect scale for measuring amplitude of vibrator operating in air.

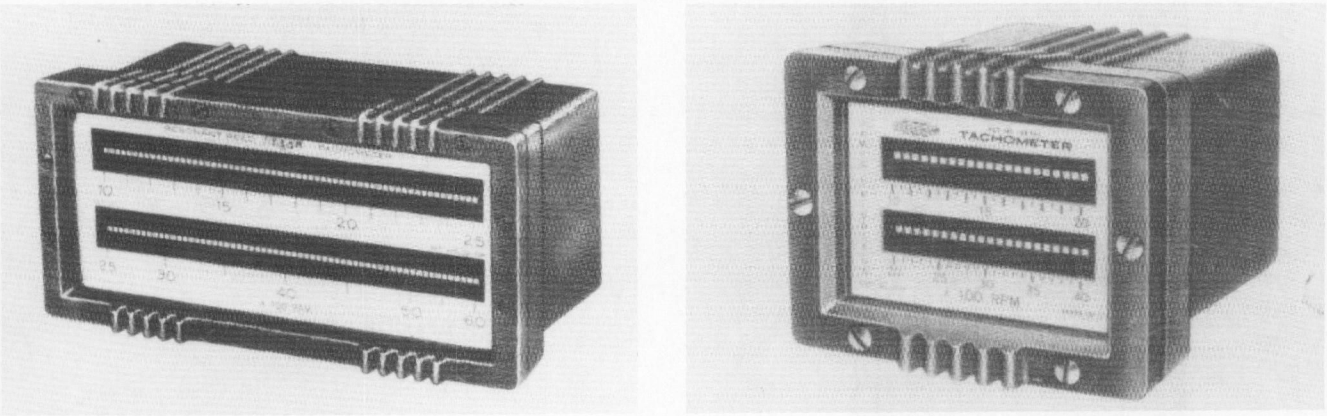
3.4.2.2.2. Reciprocating-type form vibrators accelerate a piston in one direction, stopped (by impacting against a steel plate), and then accelerate in the opposite direction. This type is pneumatically driven. These vibrators produce impulses acting perpendicular to the form. The principles of simple harmonic motion do not apply in this case.

3.4.2.2.3. A range of frequencies, peak amplitude, and normal peak acceleration is given in table 1 while vibrator is consolidating concrete.

3.4.2.2.4. Data listed under section 3.4.2.1.3 is applicable to form vibrators as well as table vibrators.

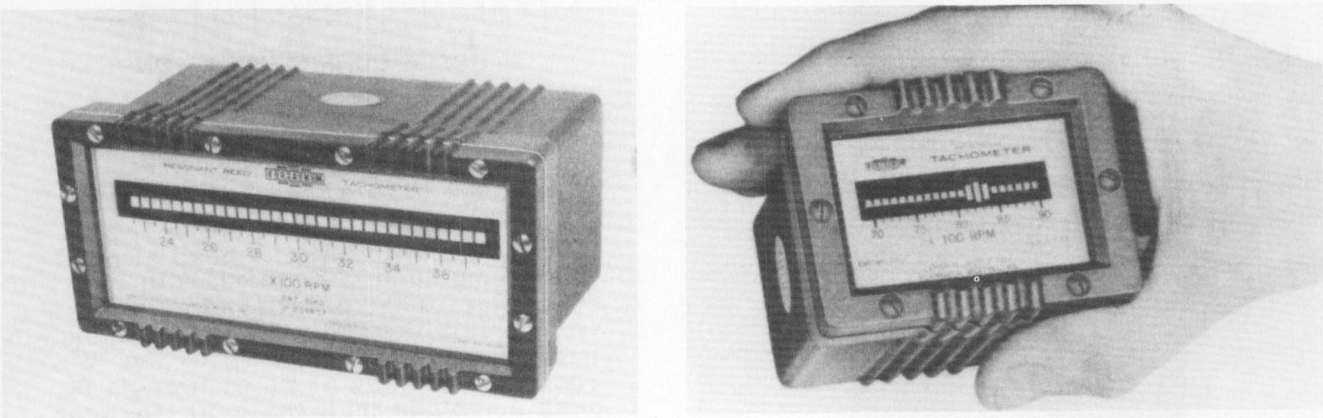
3.5 *Small Tools*.–Miscellaneous tools which may be required are shovels, pails, strike-off bar, wood float, magnesium float, blunted trowels, steel trowel, straightedge, feeler gauge, scoops, and rulers.

3.6 *Slump Apparatus*.–The apparatus for measurement of slump shall conform to requirements of USBR 4143.



Type T-72, 3 by 6-1/8- by 2-15/16 inches

Type T-62, 2-1/4- by 3 by 2-15/16 inches



Type T-71, 3 by 6-1/8- by 2-15/16 inches

Type T-61, 2-1/4- by 3 by 2-15/16 inches

Figure 8. – Resonant reed tachometers.

3.7 *Sampling and Mixing Receptacle.*–This receptacle shall be a suitable heavy-gauge metal pan, wheelbarrow, or a flat and clean nonabsorbent mixing board of sufficient capacity to allow easy mixing by shovel or trowel of entire sample.

3.8 *Air Content Apparatus.*–For low density concrete, the apparatus for measuring air content shall conform to requirements of USBR 4173. For normal or high density concrete, apparatus shall conform to requirements of USBR 4173 or 4231.

4. Test Specimens

4.1 *Compressive Strength Specimens.*–The compressive strength specimens shall be cylinders of concrete cast and hardened in an upright position, with a length equal to twice the diameter. The standard specimen shall be a 6- by 12-inch (152- by 305-mm) cylinder when nominal maximum size of coarse aggregate does not exceed 1-1/2 inches (37.5 mm). When coarse aggregate exceeds 1-1/2 inches, diameter of cylinder shall be at least three times the nominal maximum size of coarse aggregate in concrete (note 5). Unless required by project specifications, cylinders smaller than 6 by 12 inches shall not be made in the field.

NOTE 5.–The mold diameter is determined by the nominal maximum size of aggregate (nominal maximum size permits a limited amount of marginal oversize particles). The minimum mold diameter must be at least three times the nominal maximum size aggregate. Odd size diameter molds could meet these requirements, but past research has primarily been conducted using 8-, 12-, 18-, and 36-inch (203-, 305-, 457-, and 914-mm) diameter cylinders with a length-to-diameter ratio of 2. For further clarification of sizing nomenclature, see table 2 and figure 12.

4.1.1 *Number of Specimens, Test Ages, and Frequency.*–Ideally, three specimens should be tested at each age for which test results are desired. However, the economic consideration in fabricating, handling, capping, and breaking concrete cylinders and the space requirement for storing the cylinders in a moist cure room preclude excessive cylinder fabrication. A guideline for the minimum number of cylinders per test batch to satisfy the varying

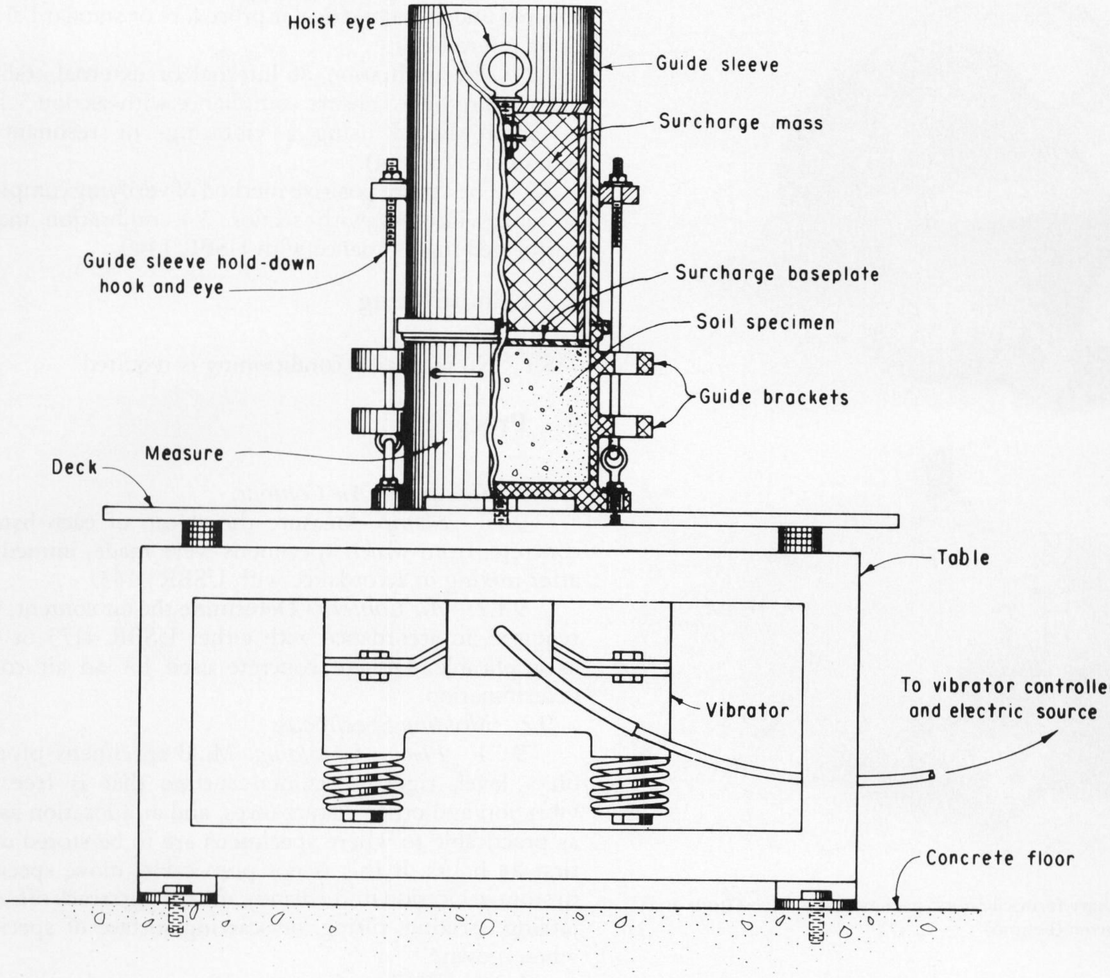


Figure 9. - Vibratory table. 101-D-592.

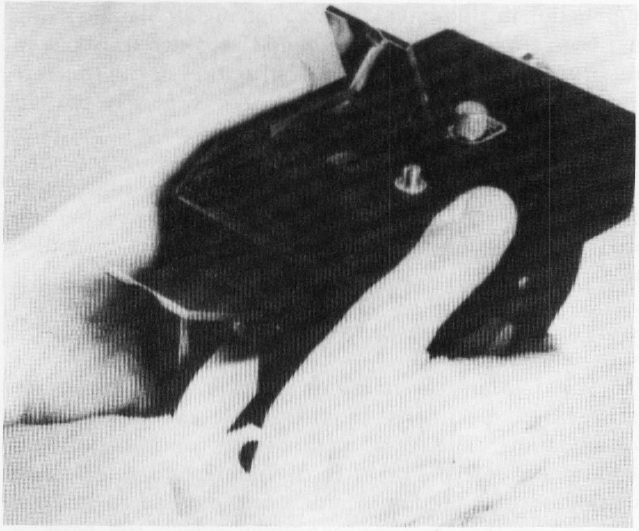


Figure 10. - Using a vibrograph to determine amplitude and frequency of a vibrating form or table.

design criteria for design strength for each mixture is shown in table 3, and a guideline for the frequency of test batches based on time or yardage is shown in table 4.

4.2 *Flexural Strength Specimens.*–The flexural strength specimens shall be rectangular beams of concrete cast and hardened with the long axes horizontal. The beam length shall be at least 2 inches (51 mm) greater than three times the depth, as tested. The ratio of width to depth as molded shall not exceed 1.5. When beams are cast specifically for the flexure test, the standard beam shall be 6 by 6 inches (152 by 152 mm) in cross section, and shall be used for concrete with a maximum size of coarse aggregate up to 2 inches (51 mm). However, many beams that are 4 by 4 inches (102 by 102 mm) are cast for other tests such as volume change and dynamic properties. Flexure tests on these 4- by 4-inch beams are permitted with maximum size aggregate up to 1-1/2 inches (37.5 mm). When coarse aggregate exceeds 2 inches, the smaller cross-sectional dimension of beam shall be at least three times the nominal maximum size of the coarse aggregate.

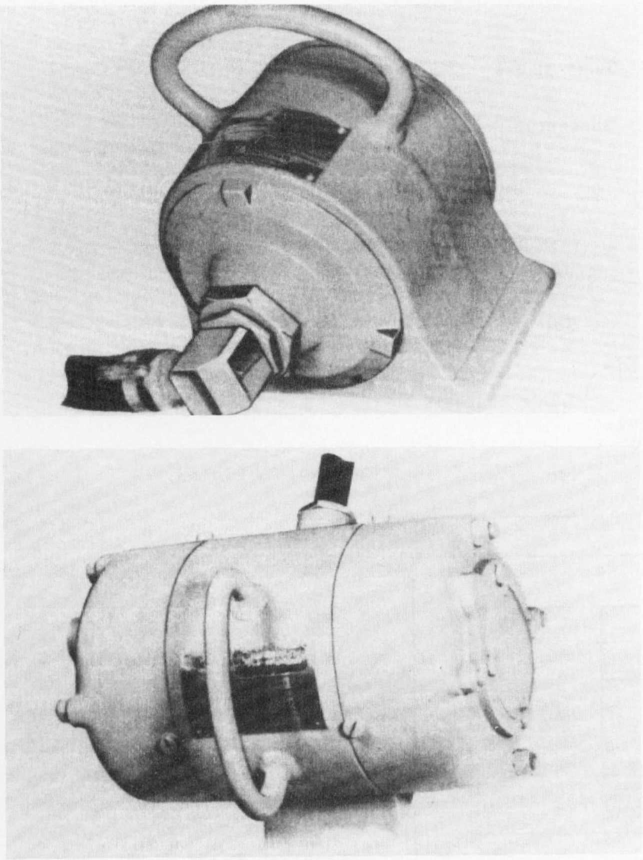


Figure 11. - Rotary form vibrators: pneumatically driven (top) and electrically driven (bottom).

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling Concrete

6.1 Take samples of concrete for test specimens in accordance with USBR 4172. Record the location of concrete deposition within the structure that is representative of the samples taken.

6.2 *Wet Sieving.*-If nominal maximum size of aggregate is greater than 1-1/2 inches (37.5-mm), wet sieve the mix across the 1-1/2-inch sieve in accordance with USBR 4172 to accommodate molds or measures as required.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

7.2 The calibration of internal or external (table or form) vibrators to ensure compliance with section 3.4 may be accomplished using a vibrating- or resonant-reed tachometer (note 4).

7.3 For a more positive method of verifying compliance of table vibrators with section 3.4, calibration may be performed in accordance with USBR 1440.

8. Conditioning

8.1 No particular conditioning is required.

9. Procedure

9.1 *Slump and Air Content*:

9.1.1 *Slump.*-Measure the slump of each batch of concrete, from which specimens were made, immediately after mixing in accordance with USBR 4143.

9.1.2 *Air Content.*-Determine the air content, when required, in accordance with either USBR 4173 or 4231, as applicable. Discard concrete used for an air content determination.

9.2 *Molding Specimens*:

9.2.1 *Place of Molding.*-Mold specimens promptly on a level, rigid, horizontal surface that is free from vibration and other disturbances, and at a location as near as practicable to where specimens are to be stored during first 24 hours. If this is not practicable, move specimens to storage location immediately after being struck off. Avoid jarring, striking, tilting, or scarring surface of specimens when moving.

9.2.2 *Placing Concrete.*-Place concrete in molds using a scoop, blunted trowel, or shovel. Select each measure of concrete from mixing pan to ensure that it is representative of batch. It may be necessary to remix the concrete in mixing pan with a shovel or trowel to prevent segregation during molding of specimens. Move the scoop or trowel around top edge of mold as concrete is placed into it to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within mold. Further distribute the concrete by using a tamping rod prior to start of consolidation. In placing the final layer, operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

9.2.2.1 *Number of Layers.*-Make specimens in layers as indicated in table 5.

9.3 *Consolidation*:

9.3.1 *Methods of Consolidation.*-Preparation of satisfactory specimens requires different methods of consolidation. The two methods of consolidation are rodding and internal or external vibration. Base selection of method on the slump, unless the method to be used is stated in the specifications under which the work is being performed. Rod concretes with a slump greater than 3 inches (76 mm), rod or vibrate concretes with slump

Table 2. – Test sieves (U.S.A. Standard series) for various nominal sizes of coarse aggregate.

	SIZE DESIGNATION											
	9.5 mm (⅜ inch)	12.5 mm (½ inch)	19.0 mm (¾ inch)	19.0 mm (¾ inch)	25.0 mm (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm (2 inch)	63 mm (2-½ inch)	75 mm (3 inch)	100 mm (4 inch)	150 mm (6 inch)
	NOMINAL SIZE RANGE[1]											
SIEVE[1] DESIGNATION STANDARD (ALTERNATIVE)	4.75 to 9.5 mm (No. 4 to ⅜ inch)	4.75 to 12.5 mm (No. 4 to ½ inch)	9.5 to 19.0 mm (⅜ to ¾ inch)	4.75 to 19.0 mm[4] (No. 4 to ¾ inch)	4.75 to 25.0 mm[4] (No. 4 to 1 inch)	12.5 to 31.5 mm (½ to 1-¼ inch)	19.0 to 37.5 mm (¾ to 1-½ inch)	25.0 to 50 mm (1 to 2 inch)	31.5 to 63 mm (1-¼ to 2-½ inch)	37.5 to 75 mm (1-½ to 3 inch)	50 to 100 mm (2 to 4 inch)	75 to 150 mm (3 to 6 inch)
Significant[1,4] Oversize	11.2 mm (7/16 inch)	16.0 mm (⅝ inch)	22.4 mm (⅞ inch)	22.4 mm (⅞ inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	45 mm (1-¾ inch)	63 mm (2-½ inch)	75 mm (3 inch)	90 mm (3-½ inch)	125 mm (5 inch)	175 mm[6] (7 inch)
Nominal Oversize	9.5 mm (⅜ inch)	12.5 mm[5] (½ inch)	19.0 mm (¾ inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm[5] (2 inch)	63 mm (2-½ inch)	75 mm (3 inch)	100 mm[5] (4 inch)	150 mm[6] (6 inch)
Index[1] Sieve	8.0 mm (5/16 inch)	9.5 mm (⅜ inch)	16.0 mm (⅝ inch)	16.0 mm (0.530 inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	45 mm (1-¾ inch)	53 mm (2.12 inch)	63 mm (2-½ inch)	90 mm (3-½ inch)	125 mm (5 inch)
Nominal Undersize	4.75 mm (No. 4)	4.75 mm (No. 4)	9.5 mm) (⅜ inch)	4.75 mm (No. 4)	4.75 mm (No. 4)	12.5 mm[5] (½ inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm[5] (2 inch)	75 mm (3 inch)
Significant[1,4] Undersize	4.00 mm (No. 5)	4.00 mm (No. 5)	8.0 mm (5/16 inch)	4.00 mm (No. 5)	4.00 mm (No. 5)	11.2 mm (7/16 inch)	16.0 mm (⅝ inch)	22.4 mm (⅞ inch)	26.5 mm (1.06 inch)	31.5 mm (1-¼ inch)	45 mm (1-¾ inch)	63 mm (2-½ inch)
Typical[2] Minimum Percent Retained on Index Sieve	35	40	30	50	50	25	25	25	25	25	25	25

[1] Typical nominal separation points for coarse aggregates are 4.75, 9.5, 19.0, 37.5, 75, and 150 mm (No. 4, ⅜, ¾, 1-½, 3, and 6 inch). Significant oversize and undersize sieve openings for these separation points are approximately 7/6 and 5/6, respectively, of the nominal oversize and undersize sieve openings. The Index Sieve opening is at about 2/3 of the range between maximum and minimum sieve openings of the nominal size range. For other nominal size range separation points that may be specified for shotcrete, canal lining, pumping mixtures, roller-compacted concrete, etc., the openings for significant oversize, significant undersize, and index sieves shall also have approximately the same 7/6, 5/6, and 2/3 relationships. Openings of the wire cloth of successive standard sieves in ASTM E 11, Standard Specification for Wire-Cloth Sieves for Testing Purposes, progress from a base of 1 mm in the ratio of approximately $\sqrt[4]{2}:1$ and correspond to the values recommended by the International Standards Organization (ISO) in Geneva, Switzerland.

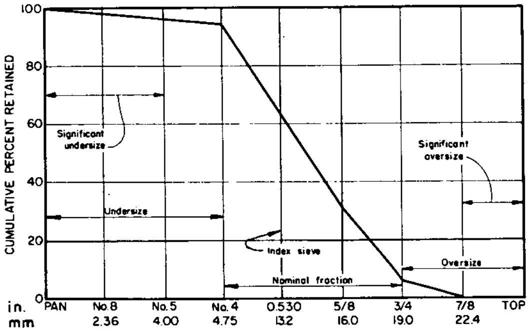
[2] These percentages were established based on experience by the Bureau of Reclamation and are appropriate for most naturally occurring, reasonably well graded, aggregates.

[3] The workability, pumpability, and finishing properties of concrete are often affected by the amount of small-size coarse aggregate. In order to improve these characteristics, it is desirable, particularly when using crushed aggregates, to minimize the percentage of material passing the 9.5 mm (⅜ inch) sieve. This may be accomplished by maximizing the amount of material retained on the Index sieve.

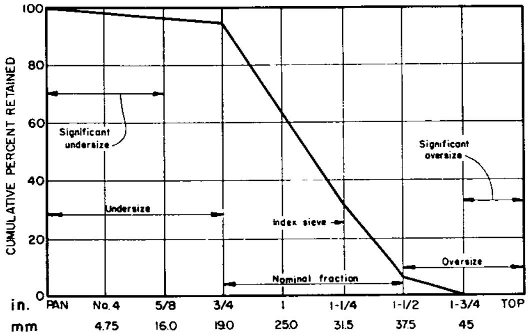
[4] For any size of processed coarse aggregate, where Reclamation specifications require finish screening at the batch plant, 0 (zero) percent shall be retained on the specified significant oversize sieve and not more than 2 percent shall pass the specified significant undersize sieve.

[5] These sieves are not in the ASTM E 11 standard series, but they are in common usage.

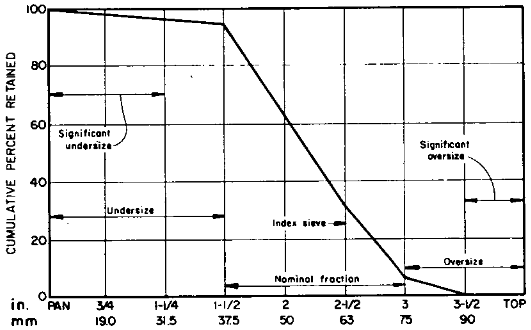
[6] These sieves are not included in the ASTM E 11 standard series and are larger than sizes contained in that standard. They may not be commercially available from customary laboratory equipment suppliers.



(a) No. 4 to ¾ in (4.75 to 19.0 mm) Nominal Size Range.



(b) ¾ to 1-½ in (19.0 to 37.5 mm) Nominal Size Range.



(c) 1-½ to 3 in (37.5 to 75 mm) Nominal Size Range.

Figure 12. - Sizing nomenclature for concrete aggretate.

of 1 to 3 inches (25 to 76 mm), and vibrate concretes with slump of less than 1 inch (25 mm).

NOTE 6.-Concretes of such low water content that they cannot be properly consolidated by methods described herein, or requiring other sizes and shapes of specimens to represent the product or structure, are not covered by this procedure. Specimens for such concretes shall be made in accordance with the requirements of the specific USBR designation concerned.

9.3.2 *Rodding.*-Place concrete in the mold in the required number of layers of approximately equal volume. For cylinders, rod each layer with rounded end of rod using the number of strokes required for that specimen size as indicated in table 6. Rod bottom layer throughout its depth. Distribute the strokes uniformly over cross section of mold and, for each upper layer, allow rod to penetrate about 1/2 inch (13 mm) into underlying layer when depth of layer is less than 4 inches (102 mm) and about 1 inch (25 mm) when depth is 4 inches or more. If voids are left by tamping rod, tap sides of mold lightly to close the voids. Extreme care must be taken when tapping sides of metal or plastic molds.

9.3.3 *Vibration.*-Maintain a standard duration time of vibration for the particular kind of concrete, vibrator, and specimen mold involved. Duration of vibration required will depend upon workability of concrete and effectiveness of vibrator. Sufficient vibration has been applied as soon as surface of concrete becomes relatively smooth and exhibits a shiny, wet appearance, at which time vibrator is slowly withdrawn. Continue vibration only long enough to achieve proper consolidation of concrete; overvibration may cause segregation. Fill molds and vibrate in the required number of approximately equal layers as shown in table 5. Place all concrete for each layer in mold before starting vibration of that layer. Add the final layer so as to avoid overfilling by more than 1/4 inch (6 mm). Finish the surface either during or after vibration when external vibration is used, and after vibration when internal vibration is used. When surface is finished after vibration, add only enough concrete to overfill mold about 1/8 inch (3 mm), work concrete into surface, and then finish.

9.3.3.1 *Internal Vibration.*-For cylinders, the ratio of diameter of cylinder to diameter of vibrating element shall be 4.0 or higher. In compacting the specimen, vibrator shall not be allowed to rest on or touch bottom or sides of mold. Carefully withdraw vibrator in such a manner that no air pockets are left in specimen. After vibration of each layer, tap sides of molds to ensure removal of large entrapped air bubbles at surface of mold; use extra care with metal or plastic molds.

9.3.3.1.1 *Cylinders.*-Use three insertions of vibrator at different points for each layer. Allow vibrator to penetrate through layer being vibrated, and about 1 inch (25 mm) into layer below.

9.3.3.1.2 *Beam.*-Insert vibrator at spaced intervals not exceeding 6 inches (152 mm) along centerline of long dimension of specimen. For specimens wider than 6 inches, use alternating insertions along two lines. Allow shaft of vibrator to penetrate about 1 inch (25 mm) into bottom layer.

9.3.3.2 *External Vibration.*-When external vibration is used, take care to ensure that mold is rigidly attached to or securely held against vibrating element or vibrating surface.

9.4 *Finishing.*-After consolidation by any of the methods, unless finishing has been performed during vibration (9.3.3), saw surface with a strike-off bar or edge of float, and float or trowel as required. Perform all finishing with minimum manipulation necessary to produce a flat, even surface that is level with rim or edge of mold and which has no depressions or projections more than 1/8 inch (3 mm). If a trowel is used, it is generally better to leave surface slightly high after striking-off and floating, with the intent of finishing flush with the trowel later. However,

Table 3. – Minimum number of cylinders per test batch to satisfy varying design criteria for design strength of each mixture.

Design strength, f_c'	Strength determined at age of specimen, days	Number of cylinders through age required of f_c'		Number of cylinders after assurance of f_c' or equivalent	
		6 by 12 inches (152 by 305 mm)	(*d* by 2*d*)*	6 by 12 inches (152 by 305 mm)	(*d* by 2*d*)*
28-day	7	1	–	0	–
	28	3	2***	3	2***
	90	1**	–	1**	–
	180	1**	–	1**	–
	365	1**	–	1**	–
90-day	7	1	–	0	–
	28	1	–	1	–
	90	3	2***	3	2***
	180	1**	–	1**	–
	365	1**	–	1**	–
180-day	7	1	–	0	–
	28	1	–	1	–
	90	1**	–	1**	–
	180	3	2***	3	2***
	365	1**	–	1**	–
365-day	7	1	–	0	–
	28	1	–	1	–
	90	1**	–	1**	–
	180	1**	–	1**	–
	365	3	2***	3	2***

* (*d* by 2*d*): This refers to mass concrete, which generally uses mold sizes of 8 by 16 inches (203 by 406 mm); 12 by 24 inches (305 by 610 mm); or 18 by 36 inches (457 by 914 mm).

** Every 15th batch.

*** Every 10,000 yd^3 (7646 m^3)

Table 4. – Frequency of test batches based on time and/or yardage.

Concrete Quantities	Cylinder Fabrication
1 to 12 yd^3 (0.8 to 9.2 m^3) per structure	One set: Each week or an accumulation of 50 yd^3 (38.2 m^3), whichever comes first.
12 to 50 yd^3 (9.2 to 38.2 m^3) per structure	One set: Each day or structure, whichever is completed first.
50 to 100 yd^3 (38.2 to 76.5 m^3) per day	One set: Each day
100 to 500 yd^3 (76.5 to 382 m^3) per day	Two sets: Each day
500 to 1000 yd^3 (382 to 765 m^3) per shift or day	Two sets: Each shift or day
1000 to 3000 yd^3 (765 to 2294 m^3) per shift or day	Three sets: Each shift or day
Over 3000 yd^3 (2294 m^3) per shift or day	Three sets: Each shift, or One set: For every 1000 yd^3 (765 m^3) per day

Table 5. - Number of layers required for specimens.

Specimen depth	Mode of compaction	Number of layers	Approximate depth of layers
Cylinders:			
12 inches (305 mm)	Rodding	3 (equal)	4 inches (102 mm)
Over 12 inches (> 305 mm)	Rodding	As required	4 inches (102 mm)
12 to 18 inches (305 to 457 mm)	Vibration	2 (equal)	One-half specimen depth
Over 18 inches (> 457 mm)	Vibration	3 (or more)	8 inches (203 mm), as near as practicable
Beams:			
6 to 8 inches (152 to 203 mm)	Rodding	2 (equal)	One-half specimen depth
Over 8 inches (> 203 mm)	Rodding	3 (or more)	4 inches (102 mm)
6 to 8 inches (152 to 203 mm)	Vibration	1	Depth of specimen
Over 8 inches (> 203 mm)	Vibration	2 (or more)	8 inches (203 mm), as near as practicable

Table 6. - Number of roddings to be used in molding cylinder specimens.

Diameter of cylinder, inches (mm)	Number of strokes per layer
6 (152)	25
8 (203)	50
10 (254)	75

work load priorities will generally negate this procedure for cylinders in the field. Take care not to overtrowel as this brings too much mortar to the surface and creates a weakened plane.

9.4.1 *Cylinders.*-After consolidation, finish top surfaces of cylinders by sawing with a strike-off bar or edge of a float, when consistency of concrete permits; and float or trowel as required.

9.4.2 *Beams.*-Beams shall be finished with a wood or metal float.

9.5 *Curing*:

9.5.1 *Covering After Finishing.*-To prevent evaporation of water from unhardened concrete, cover specimens immediately after finishing, preferably with a nonabsorptive, nonreactive plate or a sheet of tough, durable, impervious plastic. Wet burlap may be used for covering; however, care must be used to keep burlap wet until specimens are removed from molds. Placing a sheet of plastic over the burlap will help keep burlap wet.

9.5.2 *Initial Curing.*-During the first 24 hours after molding, store all test specimens under conditions that maintain the temperature immediately adjacent to specimens in the range of 60 to 80°F (15.6 to 26.7°C), and prevent loss of moisture from specimens. Store specimens in tightly constructed, firmly braced wooden boxes; stock watering tanks; damp sandpits; temporary buildings at construction sites; under wet burlap in favorable weather; in heavyweight closed plastic bags; or other suitable storage that meets the temperature and moisture loss requirements. Storage temperature may be regulated by using ventilation, by evaporation of water from sand or burlap (note 7), or by using heating devices such as stoves, light bulbs, or thermostatically controlled heating cables. A temperature record of specimen storage shall be established using maximum-minimum thermometers.

NOTE 7.-The temperature within damp sand and under wet burlap or similar materials will always be lower than temperature in surrounding atmosphere if evaporation takes place.

9.5.3 *Standard Laboratory Curing For Cylinders.*-Remove test specimens made for these requirements from molds after 20±4 hours of curing, and store in a moist condition at 73.4±3 °F (23.0±1.7 °C) until time of test. As applied to treatment of demolded specimens, moist curing means that test specimens shall have free water maintained on entire surface area at all times. This condition is obtained by immersion in saturated lime water (note 8), and may also be obtained by storage in a moist room or cabinet meeting requirements of ASTM C 511. Specimens shall not be exposed to dripping or running water.

NOTE 8.-Saturated lime (calcium hydroxide) water is defined as "that point where no further lime powder will go into solution." At 73.4±3 °F (23.0±1.7 °C), it requires 0.160 gram of lime per 100 millimeters of water to bring mixture to a saturated, lime-water state. This is about 1.33 pounds of lime for every 100 gallons of water. A small cloth bag of high-calcium, hydrated lime placed in each tank should keep lime water in a saturated condition. Lime water can irritate the skin and can cause rashes on hands and arms; consequently, personnel involved should wear gloves. Also, deep containers should be avoided by personnel, or a satisfactory mechanical means provided to remove specimens.

9.5.4 *Special Curing For Cylinders.*-Store test specimens for these requirements as near to the point of use as possible. As far as practicable, provide these specimens with the same protection from the elements on all surfaces as was given to portions of structure which they represent. Test specimens in the moisture condition that results from the specified curing treatment. To meet these conditions, specimens made for the purpose of determining when a structure may be put in service shall be removed from molds at time of removal of formwork.

9.5.5 *Standard Curing for Beams.*-Remove test specimens made for these requirements from mold between 20 and 48 hours after molding, and cure the specimens according to provisions of section 9.5.3, except that storage for a minimum of 20 hours immediately prior to testing shall be done in saturated lime water at 73.4±3 °F (23.0±1.7 °C). At end of curing period, between time specimens are removed from curing until testing is completed, prevent surface drying of specimens.

NOTE 9.-Relatively small amounts of surface drying of flexural specimens induce tensile stresses in extreme fibers that will markedly reduce indicated flexural strength.

9.5.6 *Special Curing for Beams.*-Cure test specimens made for this requirement in the same manner as curing the concrete in the structure, as near as practical. At the end of 48±4 hours after molding, move specimens in molds to a location preferably near a field laboratory and remove them from molds. Store specimens representing pavements or slabs on grade by placing them on ground as molded, with top surfaces up. Bank sides and ends of specimens with earth or sand that shall be kept damp, leaving top surfaces exposed to specified curing treatment. Store specimens representing structure concrete as near as possible to the point in the structure they represent, and afford them the same temperature protection and moisture environment as the structure. At end of curing period, leave specimens in place and exposed to elements in same manner as structure. Remove all beam specimens from field storage and store in lime water at 73.4±3 °F (23.0±1.7 °C) for 24±4 hours immediately before time of testing to ensure uniform moisture condition from specimen to specimen. Observe precautions given in section 9.5.5 to guard against surface drying between time of removal and from curing to testing.

10. Shipment to Laboratory

10.1 Cylinders shipped from field to laboratory for testing shall be packed in sturdy wooden boxes or other suitable containers surrounded by wet sand or wet sawdust, or other suitable packing material, and protected from freezing during shipment. Upon receipt by laboratory, cylinders shall be placed immediately in required curing at 73.4±3 °F (23.0±1.7 °C).

11. Calculations

11.1 No particular calculations are involved in this test procedure.

12. Report

12.1 Figure 13 shows a typical reporting form. The report shall include:

- Sampling procedure.
- Identity of sample with respect to location of concrete represented, and time of testing.
- Slump.
- Density.
- Air content.
- Type of specimens molded.
- Method of consolidation.
- Method of curing.
- Time and method of transporting to laboratory.

Spec. or Solic. No. DC-7612	Structure DAM	Tested by D. ARTER Date 11-6-86
Project BRANTLEY	Item 106 Location BLOCK B-12-9M	Computed by NA Date
Feature BRANTLEY DAM	Station — Offset @ CENTER Depth @ CENTER to —	Checked by NA Date

MAKING AND CURING CONCRETE TEST SPECIMENS IN FIELD

Sampling Procedure: Used a square-point shovel to obtain concrete from a 4-cubic yard bucket.

Production Rate: 680 yd³/day
Sets of: ☑ Cylinders ☐ Beams Representing Placement: 2
Number of: ☑ Cylinders ☐ Beams Representing Test: 7, 2

SPECIMEN IDENTIFICATION AND AGE FOR TESTING AND/OR BREAKING

Age in days	Cylinders, inches					Beams, inches	
	3 by 6	6 by 12	8 by 16	12 by 24	by	6 by 6 by	4 by 4 by
7		1					
28		1					
90		1					
180		1					
365		3		2			

Shift 1 Time 4:00 a.m. Mix I.D. No. M4-3256-2A Max. Size Aggregate 4 inch(es)
☑ Wet Screened Over 1½ -inch sieve

Consolidation Method: ☐ Rodding ☑ Internal Vibrator, diameter of vibrating head 1-inch round
☐ External Vibrator ☐ Form Vibrator, Type
☐ Table Vibrator (describe)

Lifts: No. 2 & 2 Thickness 6 & 12 inches Rodding: ____ Strokes per Lift
Slump 2½ inch(es) Density: ☑ Wet Screened 153.6 lbm/ft³ ☐ Total Mix ____ lbm/ft³
Air Content: ☑ Wet Screened 3.8 % ☐ Total Mix ____ %
Curing: Initial: Method In Trailer (Wet Burlap) Temp. 60 to 80 °F Time Frame 24 hours
Final: Method Fog Cure Temp. 73 to 76 °F Time Frame 1 to 365 days
Method of Transportation from Jobsite to Final Curing:
TRUCK BED OF PICKUP
(Buried in Wet Sand)

Figure 13a. – Typical reporting form (inch-pound units).

Spec. or Solic. No. DC-7612	Structure DAM	Tested by D. ARTER Date 11-6-86
Project BRANTLEY	Item 106 Location BLOCK B-12-9M	Computed by NA Date
Feature BRANTLEY DAM	Station ~ Offset @ CENTER Depth @ CENTER to ~	Checked by NA Date

MAKING AND CURING CONCRETE TEST SPECIMENS IN FIELD

Sampling Procedure: Used a square-point shovel to obtain concrete from a 3-cubic meter bucket.

Production Rate: 520 m³/day
Sets of: ☑ Cylinders ☐ Beams Representing Placement: 2
Number of: ☑ Cylinders ☐ Beams Representing Test: 7, 2

SPECIMEN IDENTIFICATION AND AGE FOR TESTING AND/OR BREAKING

Age in days	Cylinders, millimeters					Beams, millimeters	
	75 by 152	152 by 305	203 by 406	305 by 610	by	152 by 152 by	100 by 100 by
7		1					
28		1					
90		1					
180		1					
365		3		2			

Shift 1 Time 4:00 a.m. Mix I.D. No. M4-3256-2A Max. Size Aggregate 152 mm
☑ Wet Screened Over 37.5 -mm sieve

Consolidation Method: ☐ Rodding ☑ Internal Vibrator, diameter of vibrating head 25-mm round
☐ External Vibrator ☐ Form Vibrator, Type
☐ Table Vibrator (describe)

Lifts: No. 2 & 2 Thickness 152 & 305 mm Rodding: Strokes per Lift
Slump 64 mm Density: ☑ Wet Screened 91.1 kg/m³ ☐ Total Mix kg/m³
Air Content: ☑ Wet Screened 3.8 % ☐ Total Mix %
Curing: Initial: Method In Trailer (Wet Burlap) Temp. 15.6 to 26.7 °C Time Frame 24 hours
Final: Method Fog Cure Temp. 21.3 to 24.7 °C Time Frame 1 to 365 days
Method of Transportation from Jobsite to Final Curing:
TRUCK BED OF PICKUP
(Buried in Wet Sand)

Figure 13b. – Typical reporting form (SI-metric).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4039-92

PROCEDURE FOR

COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

INTRODUCTION

This test method is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4039; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 39-83b.

1. Scope

1.1 This designation covers the procedure for determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores.

NOTE 1.-For methods of molding concrete specimens, see USBR 4031 and 4192. For methods of obtaining drilled cores, see USBR 4042.

2. Applicable Documents

2.1 *USBR Procedures*:

1104 Load Verification of Testing Machines

4031 Making and Curing Concrete Test Specimens in Field

4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete

4192 Making and Curing Concrete Test Specimens in Laboratory

4617 Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:

C 39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

E 74 Standard Methods of Calibration of Force Measuring Instruments for Verifying the Load Indication of Testing Machines[2]

3. Summary of Procedure

3.1 This test procedure consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of specimen is calculated by dividing maximum load attained during test by cross-sectional area of specimen.

4. Significance and Use

4.1 Care must be exercised in interpretation of significance of compressive strength determinations by this test procedure because strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on size and shape of specimen; batching; mixing procedures; methods of sampling, molding, and fabrication; and the age, temperature, and moisture conditions during curing.

4.2 This test procedure may be used to determine compressive strength of cylindrical specimens prepared and cured in accordance with the Applicable Documents of section 2.1.

4.3 Results of this test procedure may be used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures; and similar uses.

5. Apparatus

5.1 *Testing Machine*.-The testing machine shall be of a type having sufficient capacity and capable of providing rates of loading prescribed in section 9.2.

5.1.1 Verification of calibration of testing machine in accordance with section 8 is required.

5.1.2 *Design*.-The design of the testing machine must include the following features:

5.1.2.1 Machine must be power operated and must apply load continuously rather than intermittently, and without shock. If machine has only one loading rate (meeting requirements of section 9.2), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

5.1.2.2 The space provided for the test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover potential loading range of testing machine and which complies with requirements of ASTM E 74.

NOTE 2.-The type of elastic calibration device most generally available and most commonly used for this purpose is the circular proving ring.

5.1.3 *Accuracy*.-The accuracy of testing machine shall be in accordance with the following provisions:

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 03.01.

5.1.3.1 The percentage of error for loads within proposed range of use of testing machine shall not exceed ±1.0 percent of indicated load.

5.1.3.2 Accuracy of testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one-third the difference between the maximum and minimum loads.

5.1.3.3 The test load, as indicated by testing machine and the applied load computed from readings of verification device, shall be recorded at each test point. Calculate the error and percentage of error for each point from these data as follows (note 3):

$$E = A - B \qquad (1)$$

$$E_p = \frac{100\,(A - B)}{B} \qquad (2)$$

where:

E = error,
E_p = percentage of error,
A = load indicated by machine being verified in pound force (newtons), and
B = applied load as determined by calibrating device after load value is corrected to calibrated temperature of device, in pound force (newtons).

NOTE 3.-The above calculation is not required for this particular test procedure as it is covered under the calibration procedures of USBR 1104, which are generally performed annually.

5.1.3.4 The report on verification of a testing machine shall state within what loading range machine was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall loading range be stated as including loads below the value which is 100 times the smallest change of load that can be estimated on load-indicating mechanism of testing machine or loads within that portion of the range below 10 percent of maximum range capacity.

5.1.3.5 In no case shall loading range be stated as including loads outside the range of loads applied during verification test.

5.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by use of a calibration diagram to obtain values within required permissible variation.

5.2 Testing machine shall be equipped,with two steel bearing blocks with hardened faces (note 4), one of which is a spherically seated block that will bear on upper surface of specimen, and the other a solid block on which specimen shall rest. Bearing faces of blocks shall have a minimum dimension at least 3 percent greater than diameter of specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.001 inch (0.025 mm) in any 6 inches (152 mm) of blocks 6 inches in diameter or larger, or by more than 0.001 inch in the diameter of any smaller block; new blocks shall be manufactured within one-half of this tolerance. When diameter of bearing face of spherically seated block exceeds diameter of specimen by 1/2 inch (13 mm) or more, concentric circles not more than 1/32 inch (0.8 mm) deep and not more than 3/64 inch (1.2 mm) wide shall be inscribed to facilitate proper centering.

NOTE 4.-It is desirable that bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machineable surface for maintenance of specified surface conditions (note 5). The top and bottom surfaces shall be parallel to each other. The block may be fastened to the platen of testing machine. The minimum horizontal dimension of the block shall be at least 3 percent greater than diameter of specimen to be tested. Concentric circles, as described in section 5.2, are optional on bottom block.

5.2.1.2 Final centering must be made with reference to upper spherical block. When lower bearing block is used to assist in centering specimen, the center of the concentric rings (when provided) or the center of the block itself must be directly below center of spherical head. Provision shall be made on the platen of machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 1 inch (25 mm) thick when new and at least 0.9 inch (22.5 mm) thick after any resurfacing operations.

NOTE 5.-If testing machine is so designed that platen alone can be readily maintained in specified surface condition, a bottom block is not required.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 Maximum diameter of bearing face of suspended spherically seated block shall not exceed the values shown in the following tabulation:

Diameter of test specimen		Maximum diameter of bearing face	
inches	(mm)	inches	(mm)
2	(51)	4	(102)
3	(76)	5	(127)
4	(102)	6.5	(165)
6	(152)	10	(254)
8	(203)	11	(279)

NOTE 6.-Square bearing faces are permissible, provided diameter of largest possible inscribed circle does not exceed diameter shown in previous tabulation.

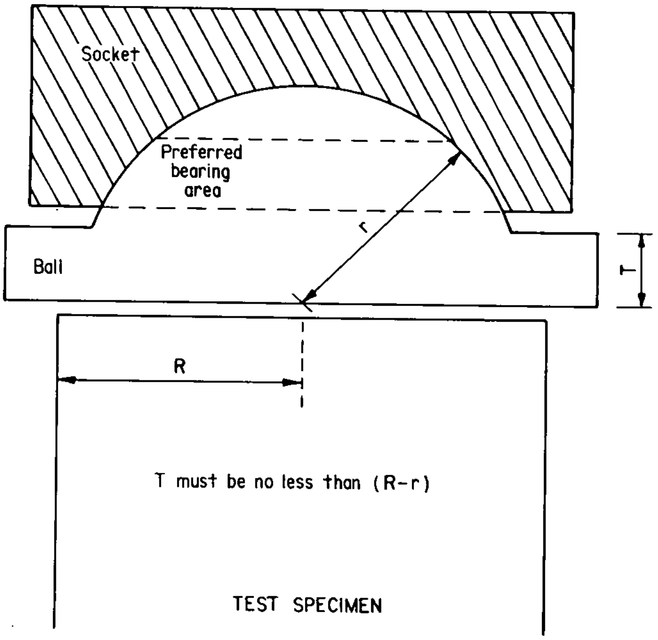
5.2.2.2 The center of the sphere shall coincide with surface of bearing face within a tolerance of ±5 percent of radius of sphere. Diameter of sphere shall be at least 75 percent of diameter of specimen to be tested.

5.2.2.3 Ball and socket must be so designed by manufacturer that steel in contact area does not permanently deform under repeated use, with loads up to 12,000 lbf/in^2 (82.7 MPa) on test specimen.

NOTE 7.–The preferred contact area is in the form of a ring, described as the preferred "bearing" area, as shown on figure 1.

5.2.2.4 The curved surfaces of socket and spherical portion shall be kept clean and lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure-type grease. After contacting specimen and application of a small initial load, further tilting of spherically seated block is not intended or desirable.

5.2.2.5 If radius of sphere is smaller than radius of largest specimen to be tested, the portion of bearing face extending beyond sphere shall have a thickness not less than the difference between radius of sphere and radius of specimen. The minimum dimension of bearing face shall be at least as great as diameter of sphere (see fig. 1).



Note— Provision shall be made for holding the ball in the socket and the entire unit in the testing machine.

Figure 1. - Schematic of a typical spherical bearing block.

5.2.2.6 Movable portion of bearing block shall be held closely in spherical seat; however, design shall be such that bearing face can be rotated freely and tilted at least 4° in any direction.

5.3 If the load of a compression machine used in concrete tests is registered on a dial, the dial shall be provided with a graduated scale that can be read to at least the nearest 250 lbf (1112 N) of load (note 8). The dial shall be readable within 1 percent of indicated load at any given load level within loading range. In no case shall loading range of a dial be considered to include loads below the value which is 100 times the smallest change of load which can be read on scale. Scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach graduation marks; width of end of pointer shall not exceed clear distance between smallest graduations. Each dial shall be equipped with a zero adjustment which is easily accessible from outside the dial case and with a maximum load indicator.

NOTE 8.–Along the arc described by end of pointer, 1/50 inch (0.5 mm) is considered to be as close as can be reasonably read. Also, one-half of a scale interval is about as close as can reasonably be read when scale spacing on load indicating mechanism is between 1/25 and 1/16 inch (1.0 and 1.6 mm). When spacing is between 1/16 and 1/8 inch (1.6 and 3.2 mm), one-third of a scale interval can be read with reasonable certainty. When spacing is 1/8 inch or more, one-fourth of a scale interval can be read with reasonable certainty.

6. Precautions

6.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Test Specimens

7.1 Specimens shall not be tested if any individual cylinder diameter differs from any other diameter of same cylinder by more than 2 percent.

NOTE 9.–This may occur when single-use molds are damaged or deformed during shipment, when flexible single-use molds are deformed during molding, or when a core drill deflects or shifts during drilling.

7.2 All test specimens for a given age shall be broken within the permissible time tolerances prescribed as follows:

Test age	Permissible tolerance
24 h (hours)	±0.5 h or 2.1%
3 days	2.0 h or 2.8%
7 days	6.0 h or 3.0%
28 days	20.0 h or 3.0%
90 days	2.0 days or 2.2%

7.3 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from curing room. When tested, neither end of compressive test specimens shall depart from perpendicularity to the axis by more than 0.25°, which is equal to about 1/16 inch in 12 inches (1.6 mm in 305 mm). Ends of compression test specimens that are not plane within 0.002 inch (0.051 mm) shall be capped (note 10). Test specimens shall be kept moist by any convenient method during the time between removal from moist storage and testing. Specimens shall be tested in a moist condition. Diameter of test specimen shall be determined to nearest 0.01 inch (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of specimen. This average diameter shall be used for calculating cross-sectional area.

NOTE 10.-For methods of capping compression specimens, see USBR 4617.

7.4 The number of individual cylinders measured for determination of average diameter may be reduced to 1 for every 10 specimens or 3 specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reuseable or single-use molds which consistently produce specimens with average diameters within a range of 0.02 inch (0.51 mm). When average diameters do not fall within this range or when cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculations of the unit compressive strength of the specimen. When diameters are measured at the reduced frequency, the cross-sectional area of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

7.5 The length of the test specimen shall be determined to nearest 0.1 inch (2.5 mm) by averaging two lengths measured on opposite sides of specimen. The length measurements shall include the thickness of one or both (whichever the case may be) properly bonded caps, but shall not include the thickness of compressible pads in the event they are used in place of caps. The average length shall be used for calculating the length-to-diameter ratio. The frequency of these measurements shall be the same as referenced in section 7.4.

8. Verification of Calibration

8.1 Verification of calibration of testing machines in accordance with USBR 1104 is required under the following conditions:

- After an elapsed interval since previous verification of 18 months maximum, but preferably after an interval of 12 months.
- On original installation or relocation of machine.
- Immediately after making repairs or adjustments which may in any way affect operation of mass determining system or values displayed, except for zero adjustments that compensate for the mass of tooling and/or specimen.
- Whenever there is reason to doubt accuracy of results without regard to time interval since last verification.

9. Procedure

9.1 *Placing Specimen.*-Place plain (lower) bearing block, with its hardened face up, on table or platen of testing machine directly under spherically seated (upper) bearing block. Wipe clean the bearing faces of upper and lower bearing blocks and surfaces of test specimen and place test specimen on lower bearing block. Carefully align axis of specimen with center of thrust of spherically seated block. As spherically seated block is brought to bear on specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

9.2 *Rate of Loading.*-Apply load continuously and without shock. On screw-type testing machines, the moving head shall travel at about 0.05 in/min (1.3 mm/min) when machine is idling. On hydraulically operated machines, apply load at a constant rate within the range of 20 to 50 (lbf/in^2)/s (0.14 to 0.34 MPa/s). During application of first half of anticipated load, a higher rate of loading shall be permitted. Make no adjustment in controls of testing machine while a specimen is yielding rapidly immediately prior to failure.

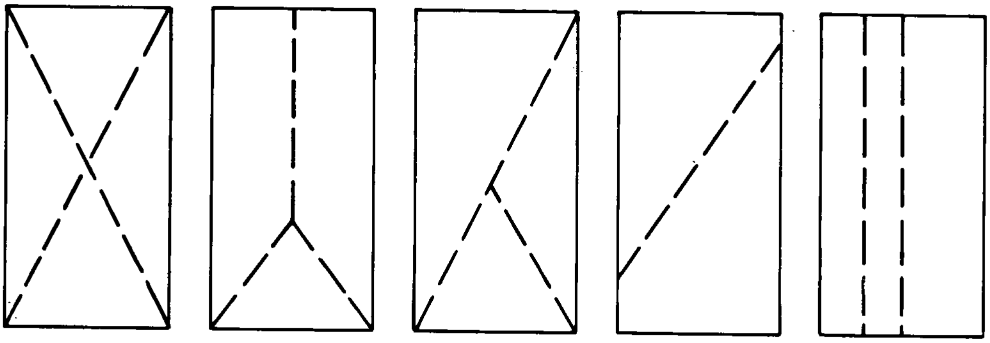
9.3 Apply load until specimen fails, and record maximum load carried by specimen during test. Note type of failure and appearance of concrete as suggested on figure 2.

10. Factors Affecting Test Results

10.1 *Effect of Wet Screening and Type of Curing.*-Cylinders of concrete used for compressive strength tests are generally 6 inches (152 mm) in diameter and 12 inches (305 mm) long. The strength of mass concrete in mass-cured larger cylinders, 18 by 36 inches (457 by 914 mm) or 12 by 24 inches (305 by 610 mm), can be estimated using figure 3. If strength of fog-cured 6- by 12-inch cylinders made with 1-1/2-inch (37.5-mm) maximum aggregate wet screened from full mass mix is known, strength of mass concrete at various ages can be predicted with a reasonable degree of accuracy. Also, if desired strength of mass concrete is known, figure 3 may be used to determine required strength of wet-screened, 6- by 12-inch cylinders.

10.2 *Effect of Cylinder Size.*-The test data shown on figure 4 are typical of relative strengths to be expected when same concrete is tested in cylinders varying in size from 2 by 4 inches (51 by 102 mm) to 36 by 72 inches (914 by 1829 mm), except that concretes containing 3/8- and 3/4-inch (9.5- and 19.0-mm) maximum aggregate were not tested in cylinders larger than 18 and 24 inches (457 and 610 mm) in diameter, respectively; and concretes containing 1-1/2-inch (37.5-mm) maximum aggregate were not tested in cylinders smaller than 6 inches (152 mm) in diameter. The values shown on figure 4 were based on the average of 28- and 90-day tests. Note that a much smaller reduction in strength is indicated as diameter of test specimen is increased beyond 18 inches (457 mm).

10.3 *Effect of Cylinder Height.*-A standard test cylinder has a diameter one-half its height. When available specimens do not have these relative dimensions, table 1 or figure 4 may be used to correct indicated strengths to make them comparable with those obtained from standard specimens. Since the curve on figure 4 is quite flat for ratios of 1.5 and over, small variations in height of specimen do not greatly affect strength.



Cone (a)

Cone and Split (b)

Cone and Shear (c)

Shear (d)

Columnar (e)

Figure 2. – Sketches of different types of fracture.

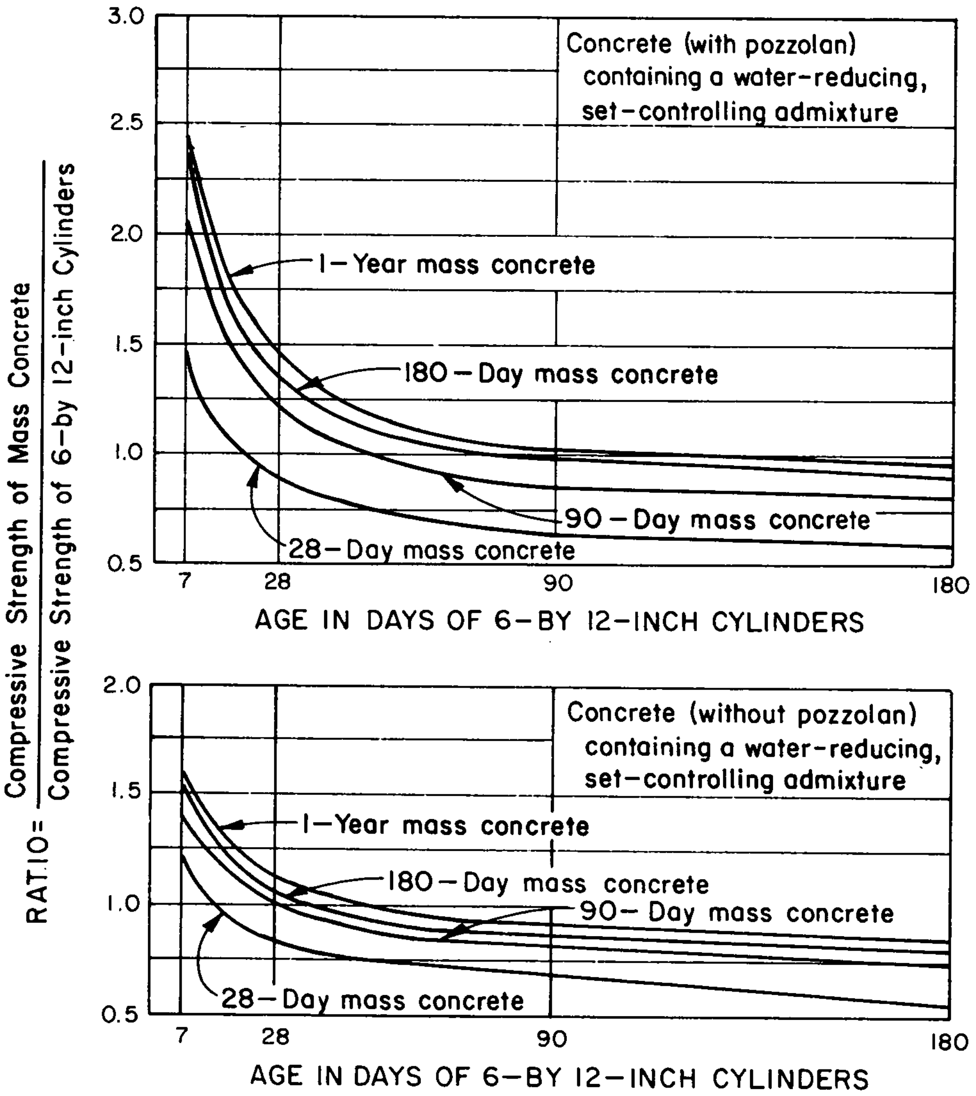


Figure 3. – Ratios of mass concrete compressive strengths in seal-cured cylinders to compressive strengths of 6- by 12-inch (152- by 305-mm) fog-cured cylinders. Fabricated from minus 1.5-inch (–37.5mm) MSA wet-sieved concrete.

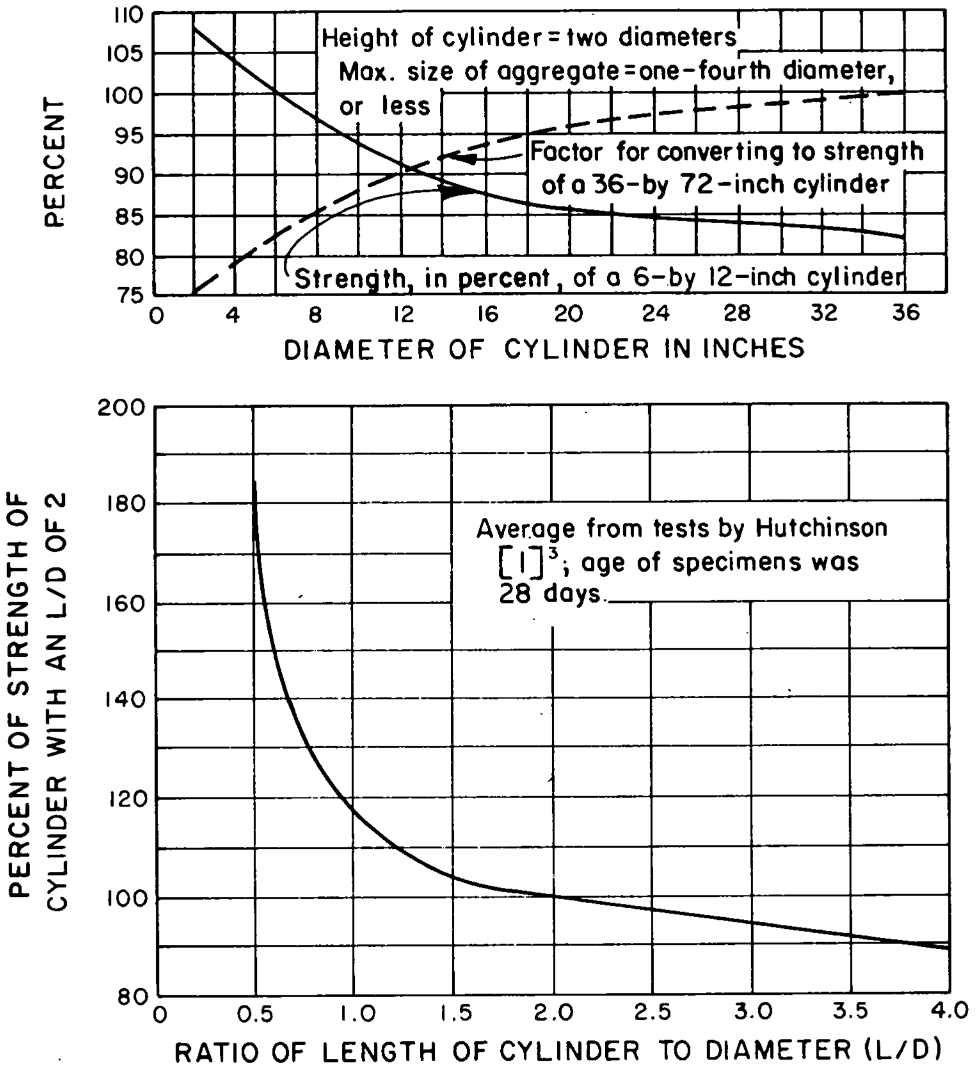


Figure 4. - Relationship of specimen length and diameter to compressive strength.

[1] Hutchinson, G. W., et al., Bulletin 16, Lewis Institute, Chicago, IL.

Table 1.-Strength correction factors for variations in *L/D*.

L/D	Factor, %	*L/D*	Factor, %
2.25	101.4	1.6	96.8
2.2	101.1	1.5	96.0
2.1	100.6	1.4	95.2
2.0	100.0	1.3	94.5
1.9	99.2	1.2	93.1
1.8	98.4	1.1	90.0
1.7	97.6	1.0	85.0

Note: Cylindrical specimens with an *L/D* less than 1.0 may be broken for information purposes but are not considered as acceptable specimens for strength evaluation. Cylindrical specimens with an *L/D* greater than 2.25 should be sawed to an *L/D* of 2.0.

11. Calculation

11.1 Calculate compressive strength of specimen by dividing maximum load carried by specimen during test by average cross-sectional area determined as described in section 7, express result to nearest 10 lbf/in^2 (0.1 MPa). A typical calculation form is shown on figure 5. Some typical examples follow.

11.1.1 Assume a 6- by 12-inch (152- by 305-mm) concrete cylinder without pozzolan, fog cured, and fabricated from minus 1-1/2-inch (37.5-mm) MSA wet-screened concrete indicated a 28-day compressive strength of 3,000 lbf/in^2 (20.7 MPa). From figure 3, use the following ratio:

$$\text{Ratio} = \frac{\text{compressive strength of mass concrete}}{\text{compressive strength of 6- by 12-inch cylinders}}$$

To predict strength of mass concrete at 1 year's age, pick the point on the abscissa (fig. 3) of the 28-day, 6- by 12-inch cylinder and project its intersection with the

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[3] Number in brackets refers to entry in Reference, section 14.

curve representing mass concrete at 1 year's age. This intersection is approximately at a ratio of 1.14. Therefore,

$$1.14 = \frac{\text{compressive strength of mass concrete}}{3{,}000\ \text{lbf/in}^2\ (20.7\ \text{MPa})}$$

and, compressive strength of mass concrete (1-year age)

$$= (1.14)\ 3{,}000\ \text{lbf/in}^2$$
$$= 3{,}420\ \text{lbf/in}^2\ (23.6\ \text{MPa})$$

11.1.2 Assume mass concrete without pozzolan had a required strength of 3,000 lbf/in^2 (20.7 MPa) at 180 days, what strength would be required of a 28-day, 6- by 12-inch concrete cylinder that was fog cured and fabricated from minus 1-1/2-inch MSA wet-sieved concrete? On figure 3, again select point on abscissa of 28-day, 6- by 12-inch cylinder and project its intersection with curve representing mass concrete at 180 days. This intersection is approximately at a ratio of 1.07. Therefore,

$$1.07 = \frac{3{,}000\ \text{lbf/in}^2}{\text{compressive strength of 6- by 12-inch cylinder}}$$

and, compressive strength of 6- by 12-inch cylinder at 28 days is:

$$\frac{3{,}000\ \text{lbf/in}^2}{1.07} = 2{,}804\ \text{lbf/in}^2\ (19.3\ \text{MPa})$$

11.1.3 Assume a 6- by 12-inch cylinder indicated a 28-day compressive strength of 3,000 lbf/in^2. To project what a 36- by 72-inch (914- by 1829-mm) cylinder would indicate at 28 days, locate 6-inch diameter on abscissa (fig. 4) and project its intersection with curve for factors for converting to strength of 36- by 72-inch cylinders. This intersection is approximately at the 82-percent level. Therefore,

$$(3{,}000)(0.82) = 2{,}460\ \text{lbf/in}^2\ (17\ \text{MPa})$$

11.1.4 Assume a 36- by 72-inch cylinder indicated a 28-day compressive strength of 3,000 lbf/in^2. To project what a 6- by 12-inch cylinder would indicate at 28 days, locate 6-inch diameter on abscissa (fig. 4) and project its intersection with the curve for factors for converting to strength of 36- by 72-inch cylinders. This intersection is the same as for the example in 11.1.3 of about 82 percent. Therefore,

$$\frac{3{,}000}{0.82} = 3{,}659\ \text{lbf/in}^2\ (25.2\ \text{MPa})$$

11.1.5 Assume an 8- by 16-inch (203- by 406-mm) cylinder indicated a 28-day compressive strength of 3,000 lbf/in^2. To project what a 6- by 12-inch or a 36- by 72-inch cylinder would indicate at 28 days, locate 8-inch diameter on abscissa (fig. 4) and project its intersection with the curve for strength in percent for 6- by 12-inch cylinders and the curve for factors for converting to strength for 36- by 72-inch cylinders. These intersections are approximately at the 85- and 96.6-percent level, respectively. Applying these percentages to the appropriate curve:

compressive strength of 6- by 12-inch cylinder

$$= \frac{3{,}000}{0.966} = 3{,}106\ \text{lbf/in}^2\ (21.4\ \text{MPa})$$

compressive strength of 36- by 72-inch cylinder

$$= (3{,}000)(0.85) = 2{,}550\ \text{lbf/in}^2\ (17.6\ \text{MPa})$$

11.1.6 Assume a cylinder has a compressive strength of 3,000 lbf/in^2 at any age, but with an *L/D* (length-to-diameter ratio) of 1.25. The standard *L/D* is 2.0. From table 1, correction factor for an *L/D* of 1.25 is 94.0 percent. Therefore,

$$(3{,}000)(0.9317) = 2{,}795\ \text{lbf/in}^2\ (19.27\ \text{MPa})$$

This is the compressive strength corrected to an *L/D* of 2.0. As an alternate to or a check of table 1, figure 4 can be used. Locate *L/D* of 1.25 on abscissa (fig. 4) and project its intersection with curve. This intersection is approximately at the 107.3-percent level. Therefore,

$$\frac{3{,}000}{1.073} = 2{,}795\ \text{lbf/in}^2\ \text{(same value obtained using table 1)}$$

11.2 The curves on figures 3 and 4 are not applicable for conversion of concrete or shotcrete cores smaller than 6- by 12-inch (152- by 305-mm) cylinders or varying diameters of cores or cylinders with length-to-diameter ratios of 1.0 or 2.0. Regression formulas have been developed for converting strengths of various size cores or cubes to equivalent strengths of different size cores or cubes in addition to 6- by 12-inch cylinders fabricated and cured in the fog room. These derivations are discussed in USBR 4042.

12. Report

12.1 Figure 5 shows a typical reporting form. The report shall include:

- Identification number.
- Diameter and length to nearest 0.01 inch (0.25 mm) and 0.1 inch (2.5 mm), respectively.
- Cross-sectional area in square inches (square millimeters).
- Maximum load in pound-force (newtons).
- Compressive strength calculated to nearest 10 lbf/in^2 (0.1 MPa).
- Type of fracture.
- Defects in either specimen or caps.
- Age of specimen.

13. Precision and Bias

13.1 The precision and bias for this procedure have not been determined at this time.

14. Reference

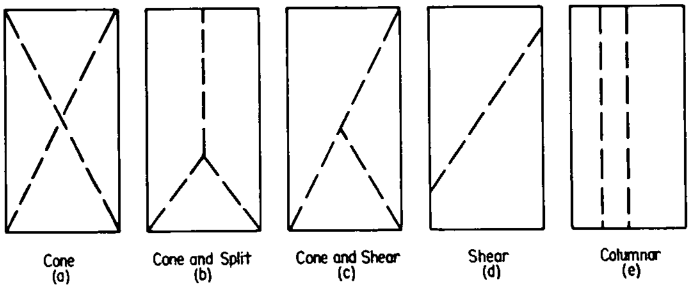
[1] Hutchinson, G. W., et al., Bulletin 16, Lewis Institute, Chicago, IL.

Spec. or Solic. No.	Structure DAM	Tested by V.GUY & D.PARADY Date 3-19-73
Project COLORADO RIVER STORAGE	Item 10-YEAR CORE PROGRAM Location	Computed by D. PARADY Date 3-19-73
Feature GLEN CANYON DAM	Station IDENT. Offset BY SPEC. Depth No. & to LEGEND	Checked by V. GUY Date 3-19-73

COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

Specimen No.	Length (L), inches			Diameter (D), inches			Capped or Ground	L/D Ratio	Area, in²	Total load, lbf	Comp. Str., lbf/in²	Corr. for L/D, Comp. Str., lbf/in²	Type of fracture
	1st	2nd	Avg.	1st	2nd	Avg.							
8A-32-1			20.2			9.85	Ground	2.05	76.2	466,000	6,115	6,130	CONE
17A-19-1			20.2			9.90	↓	2.04	76.9	465,000	6,047	6,060	CONE
8A-19-1			20.4			9.87	↓	2.06	76.5	405,000	5,294	5,310	*
8A-20-1			20.3			9.87	↓	2.06	76.5	570,000	7,451	7,480	CONE
17A-26.5-1			20.0			9.85	↓	2.03	76.2	406,000	5,328	5,340	CONE & SPLIT
8A-6-1			20.2			9.87	↓	2.04	76.5	511,000	6,680	6,700	CONE

*DISBONDED AROUND A LARGE AGGREGATE



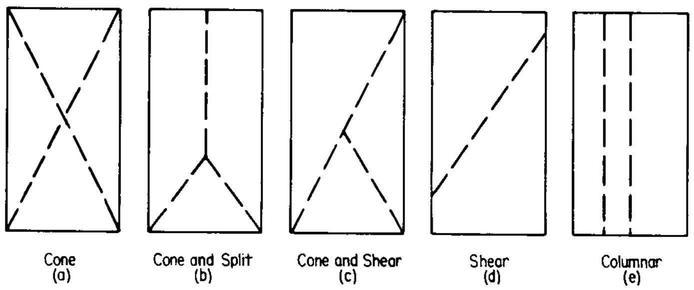
SKETCHES OF DIFFERENT TYPES OF FRACTURE

Figure 5a. - Compressive strength test results (inch-pound units). (inch-pound).

Spec. or Solic. No. DC-7612 5-CC-57-00690	Structure DAM - MIX DESIGN	Tested by T. GAETO Date 3-17-83
Project BRANTLEY, NEW MEXICO	Item 28-DAY CYL. COMP. STR.	Computed by T. GAETO Date 3-17-83
	Location DENVER, COLO.	
Feature BRANTLEY DAM	Station — Offset —	Checked by D. MOOTER Date 3-17-83
	Depth — to —	

COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

Specimen No.	Length (L), mm			Diameter (D), mm			Capped or Ground	L/D Ratio	Area, m^2x10^{-3}	Total load, kN	Comp. Str., MPa	Corr. for L/D, Comp. Str., MPa	Type of fracture
	1st	2nd	Avg.	1st	2nd	Avg.							
B4-20-55													
#5			304.8			152.40				472	25.8	—	CONE
#6										489	26.8	—	CONE
B4-30-55													
#5										444	24.3	—	CONE
#6			304.8			152.40				449	24.6	—	CONE
BA-40-55													
#5			304.8			152.40				385	21.1	—	CONE
#6										385	21.1	—	CONE
AVERAGES			304.8			152.40		2.00	18.24				



SKETCHES OF DIFFERENT TYPES OF FRACTURE

Figure 5b. – Compressive strength test results (SI-metric).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROCEDURE FOR

ORGANIC IMPURITIES IN FINE AGGREGATES FOR CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4040; the number immediately following the designation indicates year of original adoption or year of last revision. This procedure is a modified version of ASTM designation: C 40-79.

1. Scope

1.1 This designation covers the procedure for an approximate determination of presence of injurious organic compounds in fine aggregates that are to be used in cement mortar or concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
4075 Sampling Aggregates
4087 Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
4117 Materials Finer Than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:
C 40 Standard Test Method for Organic Impurities in Fine Aggregates for Concrete[1]
D 1544 Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)[2]

3. Significance and Use

3.1 This procedure is of significance in making a preliminary determination of the acceptability of fine aggregates.

3.2 The principal value of this procedure is to furnish a warning that organic impurities may be present. When a sample subjected to this test produces a color darker than the standard color solution (sec. 5.2), it is advisable to perform the test for the effect of organic impurities on the strength of mortar in accordance with USBR 4087

4. Apparatus

4.1 *Glass Bottles*.–Colorless glass, graduated bottles of oval cross section, 12-fluid ounce (about 350-mL) capacity, equipped with watertight stoppers or caps, and not soluble in the specified reagents.

5. Reagents and Reference Standard Color Solution

5.1 *Reagent Sodium Hydroxide Solution*(3 percent).–Dissolve 3 parts by mass of NaOH (sodium hydroxide) in 97 parts water.

5.2 *Reference Standard Color Solution*.–Dissolve reagent grade $K_2Cr_2O_7$ (potassium dichromate) in concentrated sulfuric acid (sp. gr. 1.84) at the rate of 0.250 g/100 mL of acid. Solution must be freshly made for the color comparison using gentle heat if necessary to effect solution.

5.3 A permanent color standard (note 1) may be prepared by dissolving 9 grams of chemically pure $FeCl_3 \cdot 6H_2$ (ferric chloride) and 1 gram of chemically pure $COCl_2 \cdot 6H_2O$ (cobalt chloride) in 3.38 fluid ounces (100 mL) of water to which 0.011 fluid ounce (0.33 mL) of HCl (hydrochloric acid) has been added. This mixture, when hermetically sealed in a glass bottle, will remain stable indefinitely (note 2).

NOTE 1.–It is preferable to use a permanent color standard when running a large quantity of tests.

NOTE 2.–This is the standard color solution used in the Bureau's Denver Office Laboratory.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Sampling

7.1 Sample shall be selected in general accordance with USBR 4075.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 06.01, 06.02, 06.03.

7.2 Obtain a test sample of fine aggregate with a mass of about 1 lbm (450 g) by quartering or by use of a sample splitter in accordance with USBR 4702.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

9. Procedure

9.1 Fill a glass bottle to the 4-1/2-fluid ounce (about 130-mL) level with the sample of fine aggregate to be tested.

9.2 Add a 3-percent NaOH solution in water until volume of fine aggregate and liquid, indicated after shaking, is 7 fluid ounces (about 200 mL).

9.3 Stopper bottle, shake vigorously, and allow to stand for 24 hours.

9.4 Figure 1 shows the typical equipment used in this procedure.

10. Determination of Color Value

10.1 *Standard Procedure.*–If using a temporary standard solution at end of 24-hour standing period, fill a glass bottle to 2-1/2-fluid ounce (about 75-mL) level with fresh reference standard color solution, prepared no longer than 2 hours previously, as prescribed in section 5.2. Then, compare color of supernatant liquid above test sample with that of reference standard color solution and record whether it is lighter, darker, or of equal color to reference standard. Make color comparison by holding the two bottles close together and looking through them.

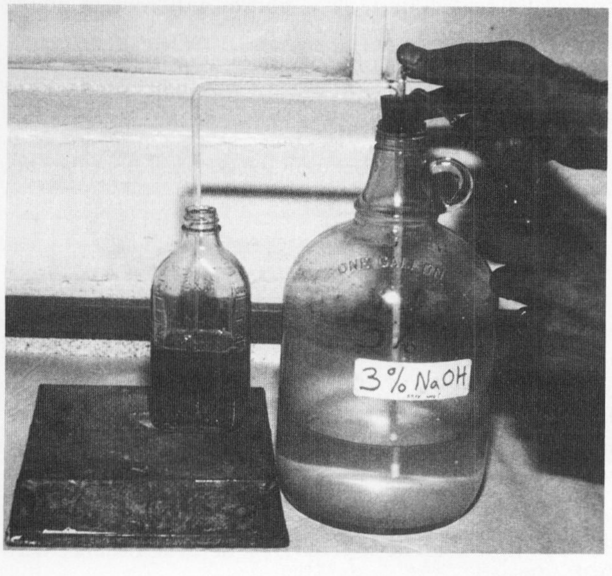

Figure 1. - Typical test equipment. P801-D-81040

10.2 *Alternate Procedure.*–To define more precisely the color of liquid of test sample, five permanent color solutions including the "standard" color may be made in accordance with procedures of ASTM D 1544 using the colors as shown in table 1. The comparison procedure described in section 10.1 shall be used, except that the organic plate number which is nearest the color of the supernatant liquid above the test specimen shall be reported. When using this alternative procedure, it is not necessary to prepare reference standard color solution.

Table 1. - Color standards for organic impurities.

Gardner Color Standard No.	Organic Plate No.
5	1
8	2
11	3 (standard)
14	4
16	4

NOTE 3.–A suitable instrument consists of the glass color standards mounted in a plastic holder. The instrument is provided with all five organic plate number colors.

11. Interpretation of Results

11.1 If color of supernatant liquid is darker than reference standard color solution, the fine aggregate under test shall be considered to possibly contain injurious organic compounds, and further tests should be made before approving the fine aggregate for use in concrete.

11.2 Solutions darker than the standard color indicate presence of more than 500 parts per million of tannic acid. If a darker solution is obtained, test should be repeated on a representative sample of fine aggregate that has been washed in water in accordance with USBR 4117 to determine whether this washing removes contaminating organic compounds. If solution still remains darker than standard color, further tests are required to determine nature of material and its effect on time-of-setting and strength of cement.

11.3 A fine aggregate failing this test may be used if, when tested in accordance with USBR 4087, relative mortar strength at 7 and 28 days is not less than 95 percent.

12. Calculations

12.1 No specific calculations are required in this procedure; however, figure 2 in USBR 4075 includes a visual color determination.

13. Report

13.1 A suggested reporting form is shown on figure 3 of USBR 4075.

14. Precision and Bias

14.1 This test procedure produces no numerical values; therefore, determination of precision and bias is not practical.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4042-92

PROCEDURE FOR

OBTAINING AND TESTING DRILLED CORES AND SAWED BEAMS OR CUBES OF CONCRETE AND SHOTCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4042; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 42-84a.

1. Scope.

1.1 This designation covers the procedure for obtaining, preparing, and testing cores drilled from concrete or shotcrete for length and compressive or splitting tensile strength determinations; and beams or cubes sawed from concrete slabs or shotcrete test panels for compressive or flexural strength determinations.

2. Applicable Documents

2.1 *USBR Procedures*:
4039 Compressive Strength of Cylindrical Concrete Specimens
4094 Specifications for Ready-Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory
4496 Splitting Tensile Strength of Cylindrical Concrete Specimens
4617 Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:
C 42 Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[1]
C 78 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Third-Point Loading)[1]
C 116 Standard Test Method for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure[1]
C 174 Standard Method for Measuring Length of Drilled Concrete Cores[1]

2.3 *ACI Manual*:
301 Chapter 17, Evaluation and Acceptance of Concrete; and paragraph 17.3.2.1, Core Tests[2]
318 Chapter 4, Evaluation and Acceptance of Concrete; and paragraph 4.8.4.3, Investigation of Low-Strength Test Results[2]

3. Apparatus

3.1 *Core Drill*.–This drill is used for obtaining the cylindrical core specimens. For specimens to be removed by drilling downward perpendicular to a horizontal surface, a shot drill may be satisfactory; for specimens taken by drilling in other directions or when test specimen diameter is to be accurately determined for a more precise calculation of compressive strength, a diamond drill shall be used.

3.2 *Saw*.–The saw is used for cutting beam or cube specimens to size for compressive and flexural strength tests. Saw shall have a diamond or silicon-carbide cutting edge and shall be capable of cutting specimens which conform to the prescribed dimensions, without excessive heating or shock.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Sampling

5.1 *General*:

5.1.1 Samples of hardened concrete for use in the preparation of strength test specimens shall not be taken until concrete has become hard enough to permit sample removal without disturbing the bond between mortar and coarse aggregate. In general, concrete shall be 14 days old before specimens are removed. Shotcrete may be cored or sawed at any age over 24 hours, or as low as 6-hour's age if it contains a hardening accelerator. When preparing strength test specimens from samples of hardened concrete or shotcrete, samples that show abnormal defects or samples that have been damaged in process of removal shall not be used.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *ACI Manual of Concrete Practice*, part 3, "Use of Concrete in Buildings–Design, Specifications, and Related Topics." Available from American Concrete Institute, P O Box 19150, Redford Station, Detroit, Michigan 48219.

5.1.2 Specimens containing embedded reinforcement shall not be used for determining the splitting tensile strength, and specimens for determining flexural strength shall not be used if reinforcement is embedded in tensile portion of specimen.

NOTE 1.-Cores or cubes, for determining compressive strength, that contain embedded reinforcement can yield either higher or lower values than cores or cubes without embedded steel. These specimens should be avoided if possible or trimmed to eliminate the reinforcement, provided a length-to-diameter ratio of 1.00 or more can be attained in cores or a minimum 3-inch (76-mm) cubed specimen can be obtained from sawing.

5.2 *Core Drilling.*-A core specimen taken perpendicular to a horizontal surface shall be located, when possible, so that its axis is perpendicular to the bed of concrete as originally placed and not near formed joints or obvious edges of a unit of deposit. A specimen taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit, when possible, and not near formed joints or obvious edges of a unit of deposit.

5.3 *Saw Cutting.*-Remove a slab or panel sufficiently large to secure desired test specimens without the inclusion of any concrete that has been cracked, spalled, undercut, or otherwise damaged.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

7. Conditioning

7.1 Conditioning of specimens are described in sections 9.3, 10.2, 11.2, and 12.2.

DRILLED CORES

8. Dimensions of Drilled Core Specimens

8.1 *Diameter and Length.*-A core specimen for determination of length shall have a minimum diameter of 3 inches (76 mm). Measure the core length in accordance with provisions of ASTM C 174.

9. Compressive Strength

9.1 *Test Specimens.*-The diameters of core specimens for determination of compressive strength should preferably be at least three times, and must be at least two times, the maximum nominal size of the coarse aggregate used in the concrete. The length of the specimen, when capped, shall be as nearly as practicable twice its diameter. A concrete core having a maximum length of less than 95 percent of its diameter before capping or a length less than its diameter after capping shall not be tested. A shotcrete core having a maximum length of less than 95 percent of its diameter before capping or a length less than its diameter after capping shall not be tested.

9.2 *Preparation of Test Specimen.*-The ends of core specimens to be tested in compression shall be essentially smooth, perpendicular to longitudinal axis, and of same diameter as body of specimen. If necessary, saw or tool ends of specimens until the following requirements are met:

- Projections, if any, shall not extend more than 0.2 inch (5 mm) above end surfaces.
- End surfaces shall not depart from perpendicularity to longitudinal axis by more than 5°.
- Diameters of ends shall not depart more than 0.1 inch (2.5 mm) from mean diameter of specimen.

9.3 *Moisture Conditioning.*-Submerge the test specimens in lime-saturated water at 73.4±3.0 °F (23.0±1.7 °C) for at least 40 hours immediately prior to making compression test. Test specimens promptly after removal from water storage. During the period between removal from water storage and testing, keep specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric.

NOTE 2.-When so directed, cores may be tested in a moisture condition other than that achieved by the conditioning of section 9.3. Length-to-diameter correction factors shown in section 9.7 are applicable to both dry and soaked concrete. Direction for consideration of testing in a moisture condition other than that achieved by soaking for at least 40 hours may be found in ACI 301, chapter 17; and ACI 318, chapter 4.

9.4 *Capping.*-Before making the compression test, cap or grind ends of specimens in conformance with USBR 4617. The capped surfaces of specimens shall conform to the planeness requirements of USBR 4192.

9.5 *Measurement.*-Prior to testing, determine the average length by averaging two lengths measured on opposite sides of capped specimen. Determine average diameter by averaging two measurements taken at right angles to each other about midheight of specimen. Measure core length and diameters to nearest 0.01 inch whenever possible, but to at least the nearest 0.1 inch (2.5 mm). Use these measurements to compute the length-to-diameter ratio.

NOTE 3.-Most shot-drilled cores will not be smooth enough to justify measuring diameters closer than the nearest 0.1 inch (2.5 mm).

9.6 *Testing.*-Test specimens in accordance with applicable provisions of USBR 4039.

9.7 *Calculations*:

9.7.1 Calculate compressive strength of each concrete specimen using computed cross-sectional area based on average diameter of specimen. If the *L/D* (length-to-diameter ratio) of concrete specimen is appreciably less than two, make allowance for this by multiplying compressive strength by applicable correction factor shown in table 1 or by using figure 1 (table 1 is a reciprocal of figure 1). The ratio of *L/D* is defined as the overall

Table 1.–Strength correction factors for variations in *L/D* = 2.

L/D	Factor, percent	*L/D*	Factor, percent
2.25	101.4	1.6	96.8
2.2	101.1	1.5	96.0
2.1	100.6	1.4	95.2
2.0	100.0	1.3	94.5
1.9	99.2	1.2	93.1
1.8	98.4	1.1	90.0
1.7	97.6	1.0	85.0

Note: Cylindrical specimens with an *L/D* less than 1.0 may be broken for information purposes, but are not considered as acceptable specimens for strength evaluation. Cylindrical specimens with an *L/D* greater than 2.25 should be sawed to an *L/D* of 2.0.

length of cylinder or core, including cap, divided by average diameter.

9.7.2 Calculate compressive strength of each shotcrete specimen using computed cross-sectional area based on average diameter of specimen. If so directed, shotcrete core specimens shall be cut to an *L/D* of 1.0. Correction to an *L/D* of 1.0 from an occasional variation of that ratio may be applied using table 2.

Table 2.–Strength correction factors for variations in *L/D* = 1.

L/D	Factor, percent	*L/D*	Factor, percent
2.25	119.3	1.3	111.2
2.2	118.9	1.2	109.5
2.1	118.4	1.1	105.9
2.0	117.6	1.0	100.0
1.9	116.7	0.9	96.8
1.8	115.8	0.8	91.5
1.7	114.8	0.7	85.4
1.6	113.9	0.6	77.3
1.5	112.9	0.5	63.9
1.4	112.0		

Note: Clyindrical specimens with an *L/D* less than 0.5 may be broken for informational purposes, but are not considered as acceptable specimens for strength evaluation. Cylindrical specimens with an *L/D* greater than 1.0 should be sawed to an *L/D* of 1.0 because of the large correction factor involved.

9.8 *Report.*–Figure 3 shows a typical concrete core data sheet. Figure 4 shows a typical test data reporting form. The report shall include:

- Identification number.
- Diameter of test specimen, in inches (millimeters).
- Length of test specimen after capping, in inches (millimeters).
- Cross-sectional area of test specimen, in square inches (square centimeters).
- Maximum load, in pound force (kilonewtons).
- Compressive strength to the nearest 10 lbf/in^2 or 0.05 MPa when diameter is measured to nearest 0.01 inch (0.25 mm), and to nearest 50 lbf/in^2 or 0.35 MPa when diameter is measured to nearest 0.1 inch (2.5 mm) (after correction for *L/D*, when required).
- Direction of load application on specimen with respect to horizontal plane of concrete as placed.
- Type of fracture, if other than standard.
- Moisture condition at time of testing.
- Nominal maximum size of aggregate.
- Defects in either specimen or caps.
- Age of specimen.

10. Splitting Tensile Strength

10.1 *Test Specimens.*–The diameters of core specimens for determination of splitting tensile strength should preferably be at least three times and must be at least two times the maximum nominal size of coarse aggregate used in the concrete. The length of the specimen shall be at least equal to the diameter. The ends of the specimen shall be essentially smooth and perpendicular to the longitudinal axis. The ends of the specimens shall not be capped.

10.2 *Moisture Conditioning.*–Prior to testing, condition specimens as described in section 9.3.

10.3 *Bearing Surfaces.*–The line of contact between specimen and each bearing strip shall be straight and free of any projections or depressions higher or deeper than 0.01 inch (0.25 mm). When line of contact is not straight or contains projections or depressions greater than 0.01 inch, grind or cap specimen to produce bearing lines meeting these requirements (note 4). Do not use specimens with projections or depressions greater than 0.1 inch. When capping is used, caps shall be as thin as practicable and shall be formed of high-strength capping compound.

NOTE 4.–Figure 2 illustrates a device suitable for applying caps to 6-inch (152-mm) diameter specimens to be used in the splitting tensile test.

10.4 *Testing.*–Test specimens in accordance with applicable provisions of USBR 4496.

10.5 *Calculations and Report.*–Calculate the splitting tensile strength, and report the results as required in USBR 4496 (fig. 6). Indicate that the specimen was a core, and show the moisture condition at time of testing.

SAWED CUBES

11. Compressive strength

11.1 *Test Specimens.*–A cube specimen for the determination of compressive strength shall generally have a cross section of 3 by 3 inches (76 by 76 mm), measured to nearest 0.05 inch (1.3 mm). Perform the sawing operation so that concrete will not be weakened by shock or by heating. The sawed surfaces shall be smooth, plane, and parallel; and free from steps, ridges, and grooves. Take care in handling sawed cube specimens to avoid chipping or cracking.

11.1.1 *Preparation of Test Specimens.*–The bearing faces of the specimen shall not depart from a plane by more than 0.002 inch (0.05 mm); bearing faces that are not plane shall be ground or capped to meet this 0.002-inch tolerance. Capping procedures shall follow the applicable

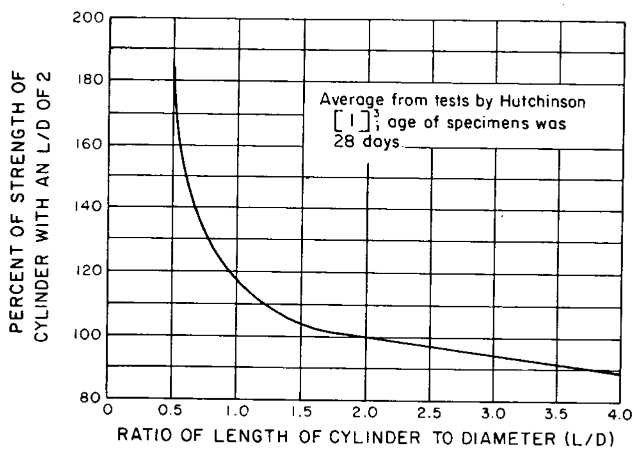

Figure 1. – Relationship of length and diameter of concrete specimen to compressive strength.

provisions of USBR 4617. Caps shall cover full width of cube.

11.2 *Moisture Conditioning.*–Submerge test specimens in lime-saturated water at 73.4±3 °F (23.0±1.7 °C) for at least 40 hours immediately prior to test. Test specimens promptly after removal from water storage. During period between removal from water storage and testing, keep specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric.

NOTE 5.–When so directed, cubes may be tested in a moisture condition other than that achieved by the conditioning of section 11.2.

11.3 *Testing.*–Apply the load continuously and without shock. Adjust the loading to a constant rate within the limits of 35±15 lbf/in^2 (241±103 kPa) per second. Test specimens to failure. Record the total load indicated by testing machine at failure of test specimen.

NOTE 6.–A limited literature search indicates that cubes on which the compressive load is applied in the same direction as the direction of deposition and compaction of the concrete may show higher compressive strength results than when a load is applied perpendicular or in a direction at right angles to the direction of deposition and compaction of the concrete.

11.4 *Calculations.*–Figure 5 shows a typical calculation form. Calculate unit compressive strength to nearest 10 lbf/in^2 or 0.05 MPa using the cross-sectional area as determined in section 11.1.

11.5 *Report.*–Figure 5 can also be used as a reporting form. The report shall include:

- Specimen identification number.
- Cube dimensions, in inches (millimeters).
- Cross-sectional area, in square inches (square millimeters).
- Maximum load, in pound force (kilonewtons).
- Compressive strength to the nearest 10 lbf/in^2 or 0.05 MPa.
- An indication of method of obtaining specimen.
- Direction of load application on specimen with respect to horizontal plane of concrete as placed.
- Age of specimen and details of curing.
- A description of failure and appearance of concrete.
- A description of conditions of curing specimens and moisture condition at time of test.

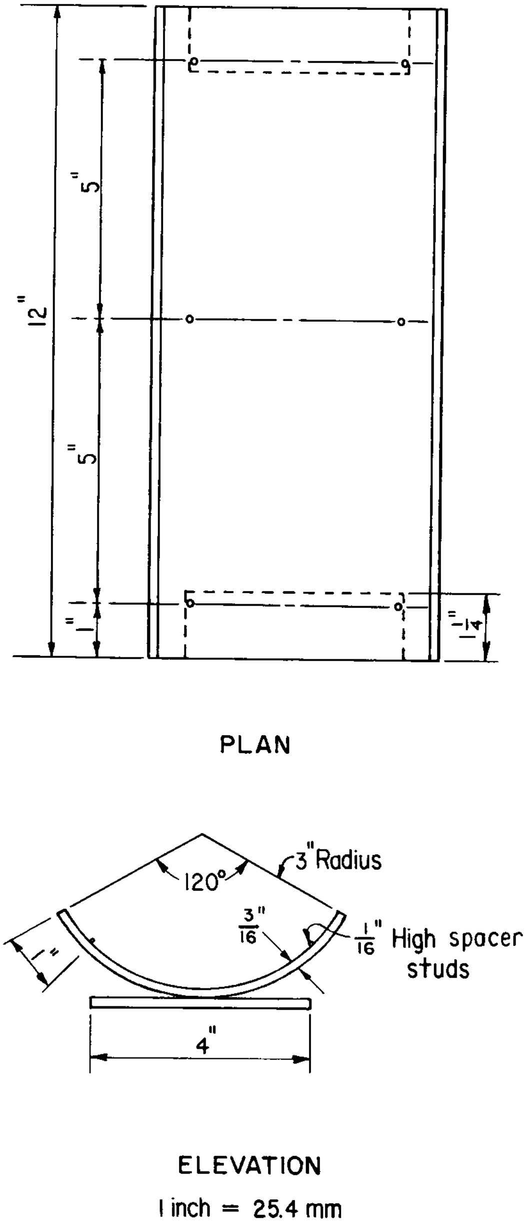

Figure 2. – Suitable capping device for the Splitting Tensile Strength Test.

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[3] Number in brackets refers to entry in Reference, section 14.

SAWED BEAMS

12. Flexural Strength

12.1 *Test Specimen.*-A beam specimen for determination of flexural strength shall generally have a cross section of 6 by 6 inches (152 by 152 mm) (note 7). Specimen shall be at least 21 inches (533 mm) in length; however, when two tests for flexural strength are to be made in one beam, specimen shall be at least 33 inches (838 mm) long. Perform sawing operation so that concrete will not be weakened by shock or by heating. The sawed surfaces shall be smooth, plane, and parallel; and free from steps, ridges, and grooves. Take care in handling sawed beam specimens to avoid chipping or cracking.

NOTE 7.-In many cases, particularly with prisms cut from pavement slabs, width will be controlled by size of coarse aggregate and depth by thickness of slab.

12.2 *Moisture Conditioning.*-Submerge test specimens in lime-saturated water at 73.4±3 °F (23.0±1.7 °C) for at least 40 hours immediately prior to flexure test. Test specimens promptly after removal from water storage. During period between removal from water storage and testing, keep specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric.

12.2.1 When so directed, beams shall be tested in a moisture condition other than that achieved by the conditioning of section 12.2. Relatively small amounts of drying of surface of flexural specimens induce tensile stresses in extreme fibers that will markedly reduce indicated flexural strength.

12.3 *Testing.*-Test specimens in accordance with applicable provisions of ASTM C 78.

NOTE 8.-Compressive strengths of portions of beams broken in flexure may be determined by testing such portions as modified cubes in accordance with ASTM C 116.

NOTE 9.-Sawing may significantly reduce indicated flexural strength; therefore, beams shall be tested with the molded surface in tension when possible. Location of tension face with respect to position of concrete as placed, and position of sawed surfaces should be noted on report.

12.4 *Calculations and Report.*-No typical forms for calculations and reporting for this section on sawed beams are provided because the Bureau does not usually analyze flexural strength in accordance with ASTM C 78. Flexural strength studies performed by the Bureau are generally on 4- by 4- by 30-inch (102- by 102- by 762-mm) molded specimens.

13. Precision and Bias

13.1 The precision and bias statements for this procedure are not known at this time.

14. Reference

[1] Hutchinson, G. W., et al., Bulletin 16, Lewis Institute, Chicago, IL.

Spec. or Solic. No. 4D-C 7427
Structure TUNNEL LINING
Drilled by CONSTRUCTORS-PAMCO(OPER. UNKNOWN) Date UNKNOWN
Project COLORADO RIVER STORAGE
Item CONCRETE CORE
Location CROWN
Placed Date 8-20-81
Feature SERVICE ROAD TUNNEL REHABILITATION, GLEN CANYON P.P.
Station 1+81 Offset 1 FOOT RT. OF ℄
Depth 0 to 45 INCHES

DRILLED CONCRETE CORES

Present Condition of Structure: GOOD
Core No.: 3 Core Diameter: 2¾ INCHES Length: 45 INCHES
Direction Drilled: VERTICALLY UPWARD
Rate Drilled Per Hour: UNKNOWN
Remarks: CORES TAKEN TO ASSURE FILLING IN CROWN, VISUAL INSPECTION FOR SEGREGATION, CHECK ON DENSIFICATION AND DETERMINE COMPRESSIVE STRENGTH. NINE CORES TAKEN. CORE NO. 3 BROKEN IN FIVE SECTIONS AT 9, 12, 21¼, AND 34¼ INCHES. FOUNDATION SANDSTONE CONTACT AT 39 INCHES WITH 6-INCH FOUNDATION RECOVERY.

THE FOLLOWING INFORMATION IS DESIRED FOR THE CHARACTER OF THE CONCRETE

Cement: Brand ______ Source NOT AVAILABLE Type ASS. TYPE II LA
Pozzolan: Brand NOT USED Source ______ Class ______
Sand Source LOCAL READY-MIX Gravel Source SAME
Max. Size Aggregate, inches ~~(mm)~~ 1½ Total Aggregate, lbm/yd^3 (kg/m^3) UNKNOWN Percent Sand UNKNOWN
Type of Concrete (interior, exterior, [✓ other]) TUNNEL LINING Type of Cure CURING COMPOUND
Field Mix (by weight): 1: UNKNOWN W/(C+P) UNKNOWN Slump, inches ~~(mm)~~ 4¼ (AVG) Percent Air 5.1% (AVG)
Cement Content, lbm/yd^3 (kg/m^3) UNKNOWN Pozzolan Content, lbm/yd^3 (kg/m^3) NONE
Water Content, lbm/yd^3 (kg/m^3) UNKNOWN Density, lbm/ft^3 (kg/m^3) UNKNOWN
Temperature, °F (°C): Max. Air NOT TAKEN Min. Air NOT TAKEN Mix Water NOT TAKEN Concrete NOT TAKEN
Type of Mold Used for Test Cylinders PLASTIC Test Cylinder No. UNKNOWN
Control Cylinder Compressive Strength, lbf/in^2 (MPa): 7-Day UNKNOWN 28-Day UNKNOWN 90-Day UNKNOWN

Remarks:
0 TO 9-INCH, FAIR DISTRIBUTION OF 1½-INCH AGGREGATE — LACK OF CONSOLIDATION
9 TO 12 INCHES, REASONABLE DISTRIBUTION OF 1½-INCH AGG. — BAD CONSOLIDATION
12 TO 21¼ INCHES, GOOD DISTRIBUTION OF 1½-INCH AGG. — SLIGHT LACK OF CONSOLIDATION
21¼ TO 34¼ INCHES, GOOD DISTRIBUTION OF 1½-INCH AGG. — GOOD CONSOLIDATION
34¼ TO 39 INCHES, FAIR DISTRIBUTION OF 1½-INCH AGG. — SLIGHT LACK OF CONSOLIDATION
39 TO 45 INCHES, NO BOND, TWO PIECES OF SANDSTONE CORE

Figure 3. – Concrete core data sheet.

Spec. or Solic. No. 40-C7427	Structure TUNNEL LINING	Tested by D. PARODY Date 12-23-81
Project COLORADO RIVER STORAGE	Item CONCRETE CORE Location CROWN	Computed by D. PARODY Date 12-23-81
Feature SERVICE ROAD TUNNEL REHABILITATION, GLEN CANYON P.P.	Station 1+81 Offset 1 FT R OF ℄ Depth SURFACE to 45 INCHES	Checked by E. SAMUELSON Date 12-23-81

CORE TEST DATA

Core No. 3-SEC.4(13") Date Placed 8-20-81 Age 125 DAYS Nominal Diameter, inches 2¾ MSA, inches 1½

Type of Core: ☒ Concrete ☒ Interior (Lining) ☐ Compression and Elasticity
☐ Rock ☐ Exterior ☐ Direct Tension

Moisture Condition: ☒ Saturated ☐ Other

Average Height	2.90	inch(es)
Average Diameter	2.75	inch(es)
L/D (length-to-diameter ratio)	1.05	
X-Section Area	5.94	in²
Mass of Core	1.27	lbm
Apparent Mass of Submerged Core	0.72	lbm
Apparent Mass of Can + Submerged Chain	NA	lbm
Mass of Water Displaced	0.55	lbm
Volume of Water Displaced	0.0088	ft³
Density of Core	144.3	lbm/ft³

Type of Cap: ☒ CAPPED ☐ GROUND
Test for E and μ: ☐ YES ☒ NO
☐ STATIC ☐ DYNAMIC

Total Compressive Load	31,700	lbf
Compressive Strength	5,337	lbf/in²
Compressive Strength (L/D) *	5,490	lbf/in²
E (modulus of elasticity)	NA	lbf/in²
μ (Poisson's ratio)	NA	
Total Tensile/Load	NA	lbf
Tensile Strength	NA	lbf/in²
Percent of Large Aggregate Exposed	NA	%
Percent of Broken Aggregate	NA	%

Construction Joint: ☐ YES ☒ NO
Location of Joint from Bottom NA inch(es)
Joint Break: ☐ YES NA ☐ NO

REMARKS: *THIS CORE WAS CORRECTED FOR COMPRESSIVE STRENGTH BASED ON AN L/D OF 1.0

Figure 4a. – Core test data (inch-pound units).

Spec. or Solic. No. 4D-C7427	Structure TUNNEL LINING	Tested by D. PARODY Date 12-23-81
Project COLORADO RIVER STORAGE	Item CONCRETE CORE Location CROWN	Computed by D. PARODY Date 12-23-81
Feature SERVICE ROAD TUNNEL REHABILITATION, GLEN CANYON P.P.	Station 1+81 Offset 0.3 m R of ℄ Depth SURFACE to 1143 mm	Checked by E. SAMUELSON Date 12-23-81

CORE TEST DATA

Core No. 3-SEC. 4 (330 mm) Date Placed 8-20-81 Age 125 DAYS Nominal Diameter, mm 70 MSA, mm 37.5

Type of Core: ☒ Concrete ☐ Rock ☒ Interior (Lining) ☐ Exterior ☐ Compression and Elasticity ☐ Direct Tension

Moisture Condition: ☒ Saturated ☐ Other

Average Height 73.7 mm
Average Diameter 69.9 mm
L/D (length-to-diameter ratio) 1.05
X-Section Area 0.00384 mm²
Mass of Core 0.577 kg
Apparent Mass of Submerged Core 0.327 kg
Apparent Mass of Can + Submerged Chain NA kg
Mass of Water Displaced 0.250 kg
Volume of Water Displaced 0.00011 m³
Density of Core 2308 kg/m³

Type of Cap: ☒ CAPPED ☐ GROUND
Test for E and μ: ☐ YES ☒ NO
☐ STATIC ☐ DYNAMIC
Total Compressive Load 141 kN
Compressive Strength 36.8 MPa
Compressive Strength (*L/D*) * 37.9 MPa
E (modulus of elasticity) NA GPa
μ (Poisson's ratio) NA
Total Tensile/Load NA kN
Tensile Strength NA kPa
Percent of Large Aggregate Exposed NA %
Percent of Broken Aggregate NA %
Construction Joint: ☐ YES ☒ NO
Location of Joint from Bottom NA mm
Joint Break: ☐ YES NA ☐ NO

REMARKS: *THIS CORE WAS CORRECTED FOR COMPRESSIVE STRENGTH BASED ON AN L/D OF 1.0

Figure 4b. – Core test data (SI-metric).

Spec. or Solic. No. DC-7134	Structure TUNNEL LINING	Tested by B. SIROKMAN Date 4-22-71 4-29-71 5-20-71
Project FRY-ARK	Item SHOTCRETE TEST PANELS Location MEREDITH FIELD OFF.-CO	Computed by E. SAMUELSON Date 4-22-71 4-29-71 5-20-71
Feature HUNTER TUNNEL	Station — Offset — Depth — to —	Checked by B. SIROKMAN Date 4-22-71 4-29-71 5-20-71

COMPRESSIVE STRENGTH OF CUBES
(SHOTCRETE)

Aggregate: MSA 1/2 inch Source TWIN MEADOWS ABOVE MEREDITH Sp. Gr.: Coarse 2.62 Fine 2.65
Cement: Brand IDEAL Type III LA Source PORTLAND, CO Sp. Gr. 3.17
Pozzolan: Class F Supplier WESTERN ASH Source PAGE, AZ Sp. Gr. 2.31
Admixtures:
AEA: Brand RELCRETE AIR Supplier MONIER RESOURCES
ACC: Brand RHEOBUILD Supplier MAC-USA
WRA: Brand PDA 25XL Supplier PROTEX INDUSTRIES
Fibers: Type STEEL-LINED(HOOKED) Supplier MITCHELL FIBERCON
Mix: Process ☐ Dry ☒ Wet Fibrous ☒ Yes ☐ No Accelerated ☒ Yes ☐ No
Proportions: Coarse Aggregate 45 %, Fine Aggregate 55 %, Cement 526 lbm/yd^3,
Pozzolon 132 lbm/yd^3, Pozzolan Replacement 20 %, W/(C+P) 0.40, AEA 7 oz/yd^3~~(mL/yd^3),~~
WRA 4 oz/cwt ~~(mL/lbm),~~ WRA (high range) 13 oz/cwt ~~(mL/lbm),~~ Fiber Content 130 lbm/yd^3,
Slump: Before HRWRA 2 inch, After HRWRA 4 inch; Air Content 6.0 %, Yield 3931 lbm/yd^3

Mix No. 1 I.D. No. 0.375-0.40-2(4) Nozzle Operator D. SCHULTZ Application Date 4-22-71

Application Times: VP-1, 9:42 a.m.; VP-2, 9:50 a.m.; HP-1, 10:11 a.m.; HP-2, 10:22 a.m.

Horizontal Application – Degrees Inclined: 90° DIRECTLY HORIZONTAL
Direction of Load Application on Specimen with Respect to Horizontal Plane of Concrete as Placed: PARALLEL

Figure X1.1

	Cube Dimensions x x inches	X-Section Area, in^2	Age			Total Load, lbf	Compressive Strength, lbf/in^2	Equivalent to 6- by 12-inch Cyl.
			Hours	Min.	Days			
Panel 1, Cube A	3.00 x 3.05 x 2.95	9.15	8	00		7,600	831	810*
B	3.01 x 3.00 x 2.99	9.03	8	05		7,080	784	760*
C	2.99 x 3.02 x 3.00	9.03			7	32,000	3,544	3,440
D	3.00 x 3.01 x 3.01	9.03			7	31,000	3,433	3,330
E	3.02 x 3.00 x 2.98	9.06			28	34,750	3,836	3,720
F	3.05 x 3.03 x 3.00	9.24			28	37,750	4,085	3,960
Panel 2, Cube A	2.95 x 3.05 x 3.00	9.00	8	10		7,640	849	840*
B	3.00 x 2.99 x 2.96	8.97	8	15		9,200	1,026	1,000
C	2.99 x 3.01 x 3.01	9.00			7	29,500	3,278	3,180
D	2.96 x 3.02 x 2.97	8.94			7	32,250	3,607	3,500
E	2.98 x 3.04 x 3.02	9.06			28	41,250	4,553	4,420
F	2.97 x 3.00 x 3.03	8.91			28	42,250	4,742	4,600
Vertical Application – Degrees Inclined: 0° DIRECTLY OVERHEAD								
Panel 1, Cube A	3.00 x 2.95 x 2.95	8.85	7	50		8,400	949	930*
B	2.98 x 3.01 x 3.05	8.97	7	55		8,400	936	910*
C	2.97 x 2.99 x 2.96	8.88			7	31,250	3,519	3,410
D	3.02 x 2.98 x 3.04	9.00			7	35,500	3,944	3,830
E	3.01 x 2.96 x 2.97	8.91			28	43,000	4,826	4,680
F	2.99 x 2.97 x 3.03	8.88			28	42,250	4,758	4,620
Panel 2, Cube A	3.04 x 2.98 x 3.05	9.06	8	05		9,000	993	960*
B	2.98 x 3.03 x 2.97	9.03	8	10		9,800	1,085	1,050
C	3.05 x 3.00 x 2.95	9.15			7	35,000	3,825	3,710
D	2.99 x 3.01 x 3.00	9.00			7	31,750	3,528	3,420
E	3.03 x 2.99 x 3.02	9.06			28	45,000	4,967	4,820
F	2.95 x 3.02 x 2.96	8.91			28	42,500	4,770	4,630

1 FL. OZ. = 29.57 mL

*FACTOR USED WITH CAUTION PER APP. XI

Figure 5a. – Compressive strength of sawed cubes (inch-pound units).

Spec. or Solic. No. DC-7134	Structure TUNNEL LINING	Tested by B. SIROKMAN 4-22-71 4-29-71 5-20-71 Date
Project FRY-ARK	Item SHOTCRETE TEST PANELS Location MEREDITH FIELD OFF. - CO	Computed by E. SAMUELSON 4-22-71 4-29-71 5-20-71 Date
Feature HUNTER TUNNEL	Station —— Offset —— Depth —— to ——	Checked by B. SIROKMAN 4-22-71 4-29-71 5-20-71 Date

COMPRESSIVE STRENGTH OF CUBES
(SHOTCRETE)

Aggregate: MSA 12.5 mm Source TWIN MEADOWS ABOVE MEREDITH Sp. Gr.: Coarse 2.62 Fine 2.65
Cement: Brand IDEAL Type III LA Source PORTLAND, CO Sp. Gr. 3.17
Pozzolan: Class F Supplier WESTERN ASH Source PAGE, AZ Sp. Gr. 2.31
Admixtures:
AEA: Brand RELCRETE AIR Supplier MONIER RESOURCES
ACC: Brand RHEOBUILD Supplier MAC-USA
WRA: Brand PDA 25XL Supplier PROTEX INDUSTRIES
Fibers: Type STEEL, 25-mm HOOKED Supplier MITCHELL FIBERCON
Mix: Process ☐ Dry ☒ Wet Fibrous ☒ Yes ☐ No Accelerated ☒ Yes ☐ No
Proportions: Coarse Aggregate 45 %, Fine Aggregate 55 %, Cement 312 kg/m³,
Pozzolon 78 kg/m³, Pozzolan Replacement 20 %, W/(C+P) 0.40, AEA 158 ~~oz/yd~~³(mL/m³),
WRA 2.61 ~~oz/cwt~~ (mL/kg), WRA (high range) 8.47 ~~oz/cwt~~ (mL/kg), Fiber Content 77 kg/m³,
Slump: Before HRWRA 51 mm, After HRWRA 102 mm; Air Content 6.0 %, Yield 2332 kg/m³

Mix No. 1 I.D. No. 9.5-0.40-51(102) Nozzle Operator D. SCHULTZ Application Date 4-22-71

Application Times: VP-1, 9:42 a.m.; VP-2, 9:50 a.m.; HP-1, 10:11 a.m.; HP-2, 10:22 a.m.

Horizontal Application – Degrees Inclined: 90° DIRECTLY HORIZONTAL
Direction of Load Application on Specimen with Respect to Horizontal Plane of Concrete as Placed: PARALLEL
Figure X1.1

	Cube Dimensions x x mm	X-Section Area, m²	Age			Total Load, kN	Compressive Strength, MPa	Equivalent to 152- by 305-mm Cyl.
			Hours	Min.	Days			
Panel 1, Cube A	76.2 x 77.5 x 74.9	0.00591	8	00		33.8	5.72	5.55*
B	76.5 x 76.2 x 75.9	0.00583	8	05		31.5	5.40	5.25*
C	75.9 x 76.7 x 76.2	0.00582			7	142.3	24.5	23.75
D	76.2 x 76.5 x 76.5	0.00583			7	137.9	23.7	23.00
E	76.7 x 76.2 x 75.7	0.00584			28	154.6	26.5	25.70
F	77.5 x 77.0 x 76.2	0.00597			28	167.9	28.1	27.25
Panel 2, Cube A	74.9 x 77.5 x 76.2	0.00580	8	10		34.0	5.86	5.70*
B	76.2 x 75.9 x 75.2	0.00578	8	15		40.9	7.08	6.85
C	75.9 x 76.5 x 75.7	0.00581			7	131.2	22.6	22.00
D	75.2 x 76.7 x 75.4	0.00577			7	143.4	24.9	24.15
E	75.7 x 77.2 x 76.7	0.00584			28	183.5	31.4	30.45
F	75.4 x 76.2 x 77.0	0.00575			28	187.9	32.7	31.70
Vertical Application – Degrees Inclined: 0° DIRECTLY OVERHEAD								
Panel 1, Cube A	76.2 x 74.9 x 74.9	0.00571	7	50		37.4	6.55	6.35*
B	75.7 x 76.5 x 77.5	0.00579	7	55		37.4	6.46	6.25*
C	75.4 x 75.9 x 75.2	0.00572			7	139.0	24.3	23.55
D	76.7 x 75.7 x 77.2	0.00581			7	157.9	27.2	26.40
E	76.5 x 75.2 x 75.4	0.00575			28	191.3	33.3	32.30
F	75.9 x 75.4 x 77.0	0.00572			28	187.9	32.8	31.80
Panel 2, Cube A	77.2 x 75.7 x 77.5	0.00584	8	05		40.0	6.85	6.65*
B	75.7 x 77.0 x 75.4	0.00583	8	10		43.6	7.48	7.25
C	77.5 x 76.2 x 74.9	0.00591			7	155.7	26.3	25.50
D	75.9 x 76.5 x 76.2	0.00581			7	141.2	24.3	23.55
E	77.0 x 75.4 x 76.7	0.00581			28	200.2	34.5	33.45
F	74.9 x 76.7 x 75.2	0.00574			28	189.0	32.9	31.90

1 FL. OZ. = 29.57 mL

*FACTOR USED WITH CAUTION PER APP. X1

Figure 5b. - Compressive strength of sawed cubes (SI-metric).

APPENDIX

X1. RESULTS OF BUREAU RESEARCH ON SHOTCRETE
(Nonmandatory Information)

X1.1 Shotcrete is frequently applied with a relatively small thickness. To evaluate such shotcrete using drilled cores or sawed cubes frequently requires smaller specimen sizes than normally used when evaluating concrete. Regression equations have been developed by the Bureau during research on the relationship between 6- by 12-inch (152- by 305-mm) cylinders, various size cores with length-to-diameter ratios of 1.0 and 2.0, and various sizes of cubes.[1] This research included fabricating slabs by pneumatically applied shotcrete and by normal concrete placement. Meaningful 6- by 12-inch cylinders could not be made by the pneumatically applied shotcrete. Table X1.1 shows a summary of average strength ratios for various specimen sizes; each ratio was based on 24 data points with each point being an average of three specimens. Shotcrete specimens have more scatter than concrete specimens because of greater variability in placement; therefore, the data in table X1.1 were taken only from concrete specimens. These data reflect the effect of specimen size and shape and also the edge effect from drilling and sawing. These relationships would not necessarily hold true for specimens cast in these sizes and shapes. All specimens were subjected to compressive load applied in the same direction of deposition of the concrete. Considerable variation in individual test results were noted, especially in the smaller specimens such as the 2- by 2-inch cores and 2- by 2-inch cubes where the edge effect had significant impact on the test results. Greater accuracy would be obtained using the regression equations shown in table X1.3 because they reflect changes in ratio at different strength levels. The range of strength of the test specimens in the test program was 1,000 to 6,000 lbf/in^2, and tables X1.1 and X1.3 should not be used outside this range. The relationships of strength values of cored and sawed specimens to the equivalent strength of cast 6- by 12-inch cylinders at low strength levels are particularly misleading because the regression equations do not go through point zero-zero. The data on 3- by 3-inch concrete cubes appear to be flawed with no logical explanation. Data from the shotcrete specimens (data not included) place the 3- by 3-inch cubes between the 4- by 4-inch cubes and the 2- by 2-inch cubes, which seems to be more reasonable. Except for the 3- by 3-inch cubes, there is good agreement between the concrete and shotcrete specimens.

X1.2 If sawed or drilled shotcrete cubes or cores are used to monitor construction strength requirements, the required average strength must also be modified in accordance with table X1.2 for the design requirement of the percentage of strength required to exceed the design strength, and the coefficient of variation obtained on the construction work.

X1.3 *Example Calculations Using Table X1.2(a)*.- Assume a design strength (f_c') of 3,000 lbf/in^2 is specified based on the compressive strength of a 6- by 12-inch cylinder subjected to standard laboratory curing. Assuming a coefficient of varation of 15 percent and to ensure the 80 percent of the cylinders exceed f_c', an average strength (f_{cr}) of 3,440 lbf/in^2 is required. From table X1.2(b), assume a design strength (f_c') of 20 MPa is specified based on the compressive strength of a 152- by 305-mm cylinder subjected to standard laboratory curing. Assuming a coefficient of variation of 15 percent and to ensure that 80 percent of the cylinders exceed f_c', an average strength (f_{cr}) of 22.95 MPa is required. From table X1.1, the ratio of a 3- by 3-inch core on the Y-axis is 99 percent of a 6- by 12-inch cylinder on the X-axis; and a 3- by 3-inch cube is 98 percent of a 6- by 12-inch cylinder on the X-axis. Therefore, 0.99 (3,440) = 3,406 (use 3,410) lbf/in^2 or 0.99 (22.95) = 22.72 (use 22.70) MPa strength for a 3- by 3-inch core and 0.98 (3,440) = 3,371 (use 3,370) lbf/in^2 or 0.98 (22.95) = 22.49 (use 22.50) MPa strength for a 3- by 3-inch cube.

X1.4 Tables X1.1 and X1.3 have not been converted to metric because metric molds are built to even numbers, and the specimen size would be somewhat different from those shown in the tables. Also, the ratios would be slightly different.

X1.5 A study of the data presented by Rutenbeck in addition to a literature search prompts this author, with Rutenbeck's concurrence, to generate a new table based on averages from table X1.1 and projected into specimen configurations. The specifications should state that a minimum core diameter of 3 inches and a minimum cube dimension of 3 inches shall be required because the edge effect from drilling and sawing smaller sized samples is highly significant. Table X1.4 is a simplification of the data shown in table X1.1. In table X1.1, the ratios for similar shaped specimens are nearly the same; e.g., as compared to a 6- by 12-inch cast cylinder, all three drilled core sizes with a *L/D* of 2.0 have nearly the same ratio as all the drilled cores with a *L/D* of 1.0. The same is true of the three cube sizes with the exception of the 3- by 3-inch cubes, which are about 10 percent different from the other two cube sizes. It is not known if the 3-inch cube ratios reflect an error in testing procedure or a real strength difference due to an unknown physical phenomenon. This author assumes that a testing error could be involved and, for reasons of logic and simplicity, chooses to average these values. Table X1.4 shows the results of averaging the ratios for specimens assumed to be the same. Because laboratory testing has shown (ACI SP-54, Rutenbeck) significantly higher coefficients of variation for 2-inch specimens, this procedure does not recommend the use of 2-inch specimens and the data for this size were not used in the preparation of table X1.4. The ratios for the remaining specimens were averaged, assuming that

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[1] Rutenbeck, T., "Shotcrete Strength Testing–Comparing Results of Various Specimens," ACI Publication SP-54, *Shotcrete for Ground Support*, 1977.

the results on the 4- by 8-inch and 3- by 6-inch cores to be identical, results on the 4-by 4-inch and 3- by 3-inch cores to be identical, and results on 4- by 4-inch and 3- by 3-inch cubes to be identical. Data on the cast cylinders (fig. 4 of USBR 4039) indicate that specimens with a *L*/*D* of 2.0 show increasing strengths as the specimen size gets smaller. It appears that, for drilled or sawed specimens, this effect is offset by surface damage that occurred during the cutting process. As the specimen size decreases, the percentage of damage from cutting increases the offsetting of the strength increase. Table X1.4 represents specimens of identical curing conditions, and does not reflect possible differences in laboratory curing of the 6- by 12-inch cylinders versus the field curing of structures or panels from which the cubes or cores are taken. Referring to discussion on f_{cr} in section X1.3 and using table X1.4, to achieve an equivalent compressive strength for the 6- by 12-inch cylinder of 3,440 lbf/in^2 indicated on the X-axis should yield on the Y-axis:

- (3,440)(0.86) = 2,958, use 2,960 lbf/in^2 for a core with a *L*/*D* of 2.0
- (3,440)(1.01) = 3,474, use 3,470 lbf/in^2 for a core with a *L*/*D* of 1.0
- (3,440)(1.04) = 3,578, use 3,580 lbf/in^2 for a cube

Conversely, whatever size or shape of specimen provided for compressive strength determinations, that size and shape could be substituted into the X-axis of table X1.4 utilizing the average conversion factor to analyze compliance with the specifications for whatever compressive strength that was specified for whatever configuration of specimen was selected.

Table X1.1. – Summary of average strength ratios, Y/X, of various specimen sizes. SM-74 Series (concrete slabs).

SPECIMEN SIZE IN INCHES

SPECIMEN SIZE IN INCHES

X → Y ↓	6x12 Cylinder	4x8 Core	3x6 Core	2x4 Core	4x4 Core	3x3 Core	2x2 Core	4x4 Cube	3x3 Cube	2x2 Cube
6x12 Cylinder		1.15	1.17	1.13	0.97	1.01	1.03	0.91	1.02	0.97
4x8 Core	0.87		1.02	0.98	0.84	0.87	0.89	0.78	0.89	0.84
3x6 Core	0.85	0.98		0.97	0.83	0.86	0.87	0.77	0.88	0.82
2x4 Core	0.88	1.02	1.04		0.86	0.89	0.90	0.80	0.91	0.85
4x4 Core	1.03	1.19	1.21	1.17		1.03	1.05	0.93	1.05	0.99
3x3 Core	0.99	1.15	1.17	1.13	0.97		1.02	0.90	1.02	0.96
2x2 Core	0.97	1.12	1.14	1.11	0.95	0.98		0.89	1.00	0.94
4x4 Cube	1.10	1.28	1.29	1.24	1.07	1.09	1.13		1.12	1.06
3x3 Cube	0.98	1.13	1.14	1.09	0.95	0.98	1.00	0.89		0.95
2x2 Cube	1.04	1.19	1.22	1.17	1.01	1.04	1.06	0.94	1.06	

Example: If the test strength of a 4-by 8-inch core is 4,000 lbf/in^2, the estimated strength of a 2-by 4-inch core would be:
(4,000)(1.02)=4,080 lbf/in^2

Table X1.2a. - Average strength that must be maintained to meet design requirements (inch-pound units).

Design strength (f'_c) lbf/in²	Percent of strength greater than design strength	Average strength required (f_{cr}) in lbf/in² so that 75, 80, 85, or 90 percent of tests are greater than design strength (f'_c) Coefficient of variation, percent				
		5	10	15	20	25
2,000	75	2,070	2,150	2,230	2,320	2,410
	80	2,090	2,190	2,290	2,410	2,540
	85	2,110	2,240	2,380	2,530	2,720
	90	2,140	2,300	2,490	2,710	2,980
2,500	75	2,590	2,680	2,790	2,900	3,010
	80	2,610	2,730	2,870	3,010	3,180
	85	2,640	2,790	2,970	3,170	3,400
	90	2,680	2,880	3,110	3,390	3,720
3,000	75	3,110	3,220	3,340	3,470	3,620
	80	3,130	3,280	3,440	3,620	3,810
	85	3,170	3,350	3,560	3,800	4,070
	90	3,210	3,450	3,730	4,070	4,460
3,500	75	3,620	3,760	3,900	4,050	4,220
	80	3,660	3,830	4,010	4,220	4,450
	85	3,690	3,910	4,160	4,440	4,750
	90	3,750	4,030	4,360	4,740	5,210
4,000	75	4,140	4,290	4,460	4,630	4,820
	80	4,180	4,370	4,590	4,820	5,090
	85	4,220	4,470	4,750	5,070	5,430
	90	4,280	4,600	4,980	5,420	5,950
4,500	75	4,660	4,830	5,010	5,210	5,430
	80	4,700	4,920	5,160	5,430	5,720
	85	4,750	5,030	5,350	5,700	6,110
	90	4,820	5,180	5,600	6,100	6,690
5,000	75	5,180	5,370	5,570	5,790	6,030
	80	5,220	5,470	5,730	6,030	6,360
	85	5,280	5,590	5,940	6,340	6,790
	90	5,350	5,750	6,220	6,780	7,440
5,500	75	5,690	5,900	6,130	6,370	6,630
	80	5,750	6,010	6,310	6,630	6,990
	85	5,810	6,150	6,530	6,970	7,470
	90	5,890	6,330	6,850	7,450	8,180
6,000	75	6,210	6,440	6,680	6,950	7,240
	80	6,270	6,560	6,880	7,240	7,630
	85	6,330	6,710	7,130	7,600	8,150
	90	6,420	6,910	7,470	8,130	8,930

NOTE: For an explanation on how this table was developed, see appendix X1 of USBR 4094.

Table X1.2b. - Average strength that must be maintained to meet design requirements (SI-metric units).

Design strength (f'_c) MPa	Percent of strength greater than design strength	Average strength required (f_{cr}) in megapascals so that 75, 80, 85, or 90 percent of tests are greater than design strength (f'_c) Coefficient of variation, percent				
		5	10	15	20	25
10	75	10.35	10.75	11.15	11.60	12.05
	80	10.45	10.95	11.45	12.05	12.70
	85	10.55	11.20	11.90	12.65	13.60
	90	10.70	11.50	12.45	13.55	14.90
15	75	15.55	16.10	16.70	17.35	18.10
	80	15.65	16.40	17.20	18.10	19.05
	85	15.85	16.75	17.80	19.00	20.35
	90	16.05	17.25	18.65	20.35	22.30
20	75	20.70	21.45	22.30	23.15	24.10
	80	20.90	21.85	22.95	24.10	25.45
	85	21.10	22.35	23.75	25.35	27.15
	90	21.40	23.00	24.90	27.10	29.75
25	75	25.90	26.85	27.85	28.95	30.15
	80	26.10	27.35	28.65	30.15	31.80
	85	26.40	27.95	29.70	31.70	33.95
	90	26.75	28.75	31.10	33.90	37.20
30	75	31.05	32.20	33.40	34.75	36.20
	80	31.35	32.80	34.40	36.20	38.15
	85	31.65	33.55	35.65	38.00	40.75
	90	32.10	34.55	37.35	40.65	44.65
35	75	36.25	37.55	39.00	40.55	42.20
	80	36.55	38.25	40.15	42.20	44.50
	85	36.95	39.15	41.60	44.35	47.55
	90	37.45	40.30	43.55	47.45	52.05
40	75	41.40	42.95	44.55	46.35	48.25
	80	41.80	43.75	45.90	48.25	50.85
	85	42.25	44.70	47.50	50.70	54.35
	90	42.80	46.05	49.80	54.20	59.50
45	75	46.60	48.30	50.15	52.10	54.25
	80	47.00	49.20	51.60	54.25	57.20
	85	47.50	50.30	53.45	57.05	61.10
	90	48.15	51.80	56.00	61.00	66.95
50	75	51.75	53.65	55.70	57.90	60.30
	80	52.25	54.65	57.35	60.30	63.55
	85	52.80	55.90	59.40	63.35	67.90
	90	53.50	57.55	62.25	67.75	74.40

Table X1.3. - Summary of slope and intercept values for linear regression equations. The slope is the top value shown in each block and the intercept is the bottom value. SM-74 Series (concrete slabs).

SPECIMEN SIZE IN INCHES

SPECIMEN SIZE IN INCHES

X → ↓ Y	6x12 Cylinder	4x8 Core	3x6 Core	2x4 Core	4x4 Core	3x3 Core	2x2 Core	4x4 Cube	3x3 Cube	2x2 Cube
6x12 Cylinder		1.410 -927	1.394 -782	1.351 -796	1.190 -925	1.164 -652	1.235 -846	1.046 -634	1.209 -740	1.011 -199
4x8 Core	0.676 796		0.988 104	0.934 182	0.835 39	0.816 234	0.857 132	0.712 323	0.819 263	0.695 613
3x6 Core	0.629 926	0.931 186		0.912 201	0.786 185	0.796 254	0.849 103	0.702 326	0.835 174	0.675 634
2x4 Core	0.668 888	0.964 193	0.999 129		0.830 121	0.830 238	0.880 99	0.760 200	0.906 30	0.729 526
4x4 Core	0.795 965	1.165 73	1.164 148	1.122 159		0.970 264	1.017 152	0.855 341	1.009 177	0.851 608
3x3 Core	0.792 837	1.159 -46	1.200 -120	1.142 -55	0.988 -88		1.050 -122	0.870 138	1.062 -160	0.839 520
2x2 Core	0.710 1099	1.029 343	1.081 221	1.024 298	0.875 315	0.887 387		0.794 400	0.905 366	0.780 692
4x4 Cube	0.872 946	1.333 -202	1.301 -37	1.244 -4	1.123 -203	1.094 63	1.174 -176		1.125 -3	0.936 531
3x3 Cube	0.696 1134	1.075 185	1.041 332	0.989 376	0.909 163	0.905 297	0.962 154	0.824 286		0.752 799
2x2 Cube	0.778 1073	1.115 288	1.150 231	1.134 150	0.978 127	0.947 393	1.043 80	0.872 313	0.944 445	

Example: The linear regression analysis plot with 2-by 4-inch core strength on the X-axis and 3-by 6-inch core strength on the Y-axis has a slope of 0.912 and an intercept of 201. Therefore, the linear regression equation is $Y = 0.912X + 201$ for strengths in pound force per square inch.

Table X1.4. – Averaged strength ratios by specimen configuration.

SPECIMEN SIZE IN INCHES

	→ X ↓ Y	6 x 12 Cylinder	3 x 6 and 4 x 8 Cores	3 x 3 and 4 x 4 Cores	3 x 3 and 4 x 4 Cubes
SPECIMEN SIZE IN INCHES	6 x 12 Cylinder	1.00	1.16	0.99	0.97
	3 x 6 and 4 x 8 Cores	0.86	1.00	0.85	0.83
	3 x 3 and 4 x 4 Cores	1.01	1.18	1.00	0.98
	3 x 3 and 4 x 4 Cubes	1.04	1.21	1.03	1.00

Example 1: A 6-by 12-inch cylinder on the X-axis is fabricated and cured by a standard laboratory procedure to an average strength (f_{cr}) of 3,440 lbf/in^2. By configuration , the required strength on the Y-axis would be:
For L/D = 2.0 , Y = (0.86)(3,440) = 2,960 lbf/in^2
For L/D = 1.0 , Y = (1.01)(3,440) = 3,470 lbf/in^2
For a cube , Y = (1.04)(3,440) = 3,580 lbf/in^2

Example 2: A 3-by 6-inch core on X-axis with f_{cr} = 3,000 lbf/in^2:
For a cylinder, Y = (1.16)(3,000) = 3,480 lbf/in^2
For L/D = 1.0, Y = (1.18)(3,000) = 3,540 lbf/in^2
For a cube , Y = (1.21)(3,000) = 3,630 lbf/in^2

Example 3: A 3-by 3-inch core on X-axis with f_{cr} = 3,500 lbf/in^2:
For a cylinder, Y = (0.99)(3,500) = 3,470 lbf/in^2
For L/D = 2.0, Y = (0.85)(3,500) = 2,980 lbf/in^2
For a cube , Y = (1.03)(3,500) = 3,610 lbf/in^2

Example 4: A 3-by 3-by 3-inch cube on X-axis with f_{cr} = 3,600 lbf/in^2:
For a cylinder, Y = (0.97)(3,600) = 3,490 lbf/in^2
For L/D = 2.0, Y = (0.83)(3,600) = 2,990 lbf/in^2
For L/D = 1.0, Y = (0.98)(3,600) = 3,530 lbf/in^2

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4075-92

PROCEDURE FOR
SAMPLING AGGREGATES

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4075; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 75-82.

1. Scope

1.1 This designation covers the procedure for the sampling of coarse and fine aggregates for the following:

- Preliminary investigation of potential supply source.
- Control of operations at source of supply.
- Control of operations at site of use.
- Acceptance or rejection of materials.

NOTE 1.-Sampling plans and acceptance and control tests vary with the type of construction in which the material is to be used. Attention is directed to ASTM E 105 and D 3665.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
4040 Organic Impurities in Fine Aggregates for Concrete
4087 Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
4088 Soundness of Aggregates Using Sodium Sulfate
4117 Materials Finer Than No. 200 (75 μm) Sieve in Mineral Aggregates by Washing
4123 Low Density Pieces in Aggregate
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4131 Resistance to Degradation of Small-Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine
4136 Sieve Analysis of Fine and Coarse Aggregates
4142 Clay Lumps and Friable Particles in Aggregates
4227 Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
4295 Petrographic Examination of Aggregate for Concrete
4535 Resistance to Degradation of Large-Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine
4566 Total Moisture Content of Aggregate by Drying
4666 Resistance of Concrete to Rapid Freezing and Thawing
4702 Reducing Field Samples of Aggregate to Testing Size
4903 Flat and Elongated Particles in Coarse and Fine Aggregate
4904 Percentage of Crushed Particles in Coarse and Fine Aggregate
5325 Performing Gradation Analysis of Gravel Size Fraction of Soils

2.2 *ASTM Standards*:
C 88 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate[1,2]
C 1137 Standard Test Method for Degradation of Fine Aggregate Due to Attrition[1]
D 75 Standard Practice for Sampling Aggregates[1,2,3]
D 2419 Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate[1,2]
D 3665 Standard Practice for Random Sampling of Paving Materials[2]
E 105 Standard Recommended Practice for Probability Sampling of Materials[2,4,5]
E 122 Standard Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process[4]
E 141 Standard Recommended Practice for Acceptance of Evidence Based On the Results of Probability Sampling[4]

3. Significance and Use

3.1 Sampling is equally as important as testing, and the sampler shall use every precaution to obtain samples that will show the nature and condition of the materials which samples represent.

3.2 Samples for preliminary investigation tests may be obtained by the Government or by the party responsible for development of the potential source (note 2). Samples of materials for control of production at source or control of work at site of use are obtained by manufacturer, contractor, or other parties responsible for accomplishing work. Samples for tests to be used in acceptance or rejection

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.08.
[4] *Annual Book of ASTM Standards*, vol. 14.02.

decisions by the Government are obtained by the Government or an authorized representative.

NOTE 2.-The preliminary investigation and sampling of potential aggregate sources and types is very important in determining availability and suitability of the largest single constituent entering into the construction. The preliminary investigation influences the type of construction from the standpoint of economics and governs the necessary material control, from the aggregate standpoint, to ensure durability of the resulting structure. This investigation should be done only by responsible, trained, and experienced personnel. For more comprehensive guidance, see appendixes X1 and X2.

4. Apparatus

4.1 *Excavating Equipment.*-Equipment such as bulldozers, backhoes, draglines, and bucket augers is recommended.

4.2 *Pan.*-A large pan with dimensions adequate for catching full stream of aggregate is necessary.

4.3 *Templates.*-Templates are needed for belts and windrows.

4.4 *Scale.*-Capacity of 1,000 lbm (454 kg).

4.5 *Sampling Tube.*-About 1-1/4 inches (30 mm) minimum diameter by about 6 feet (2 m) minimum length.

4.6 *Miscellaneous Tools.*-Tools such as a square-edged shovel, round-point shovel, brush, and dustpan are required.

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Securing Samples

6.1 *General.*-Where practicable, samples to be tested for quality shall be obtained from finished product. Samples from finished product to be tested for abrasion loss shall not be subject to further crushing or manual reduction in particle size preparation unless size of finished product is such that it requires further reduction for testing purposes.

6.1.1 The task of obtaining truly representative samples of aggregate is complicated because of the segregation that takes place when aggregate is handled or moved. The sampling procedures in section 8 describe methods which, if carefully adhered to, will generally compensate for segregation.

6.2 *Inspection.*-Material shall be inspected to determine discernible variations. The contractor or manufacturer shall provide suitable equipment needed for proper inspection and sampling.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

7.2 The scale shall be checked for calibration in accordance with USBR 1012.

8. Procedure

8.1 *Sampling From a Flowing Aggregate Stream (Bins or Belt Discharge).*-Select units to be sampled from the production by a random method, such as ASTM D 3665. Obtain at least three approximately equal increments, selected at random from unit being sampled, and combine to form a field sample whose mass equals or exceeds the minimum mass recommended in section 8.5. Take each increment from the entire cross section of the material as it is being discharged. To accomplish this, it is usually necessary to have a special device constructed for use at each particular plant. This device consists of a pan of sufficient size to intercept entire cross section of discharge stream and hold required quantity of material without overflowing. A set of rails may be necessary to support the pan as it is passed under discharge stream. Keep bins as full as possible to reduce segregation.

NOTE 3.-Sampling the initial discharge or the final few tons from a bin or conveyor belt increases the chances of obtaining segregated material, and should be avoided.

8.2 *Sampling From Conveyor Belt.*-Select units to be sampled from the production by a random method, such as ASTM D 3665. Obtain at least three approximately equal increments, selected at random, from unit being sampled and combine to form a field sample whose mass equals or exceeds the minimum mass recommended in 8.5. Stop conveyor belt while sample increments are being obtained. Insert two templates, the shape of which conforms to shape of belt in aggregate stream on belt, and space them such that material contained between them will yield an increment of required mass. Carefully scoop all material between templates into a suitable container, and then collect the fines on the belt with a brush and dustpan and add this material to the container.

8.3 *Sampling From Stockpiles or Transportation Units.*-Avoid sampling coarse aggregate or mixed coarse and fine aggregate from stockpiles or transportation units whenever possible, particularly when sampling is done for purpose of determining aggregate properties that may be dependent upon grading of sample. If circumstances make it necessary to obtain samples from a stockpile of coarse aggregate or a stockpile of combined coarse and fine aggregate, design a sampling plan for specific case under consideration. This approach will allow sampling agency to use a sampling plan that will give a confidence in the obtained results that is agreed upon by all parties concerned to be acceptable for the particular situation. The sampling plan shall define number of samples necessary to represent lots and sublots of specific sizes. General principles for sampling from stockpiles are also applicable to sampling from trucks, rail cars, barges, or other transportation units. For general guidance in sampling from stockpiles, see appendix X1.

8.4 *Sampling From Roadway (Bases and Subbases).*- Sample units selected from the production by a random method, such as ASTM D 3665. Obtain at least three approximately equal increments, selected at random from unit being sampled, and combine to form a field sample whose mass equals or exceeds the minimum mass recommended in 8.5. Take all increments from the roadway for the full depth of the material, taking care to exclude any underlying material. Clearly mark specific areas from which each increment is to be removed; a metal template placed over the area is a definite aid in securing approximately equal increment masses.

8.5 *Number and Masses of Field Samples*:

8.5.1 The number of field samples, obtained by one of the methods described in 8.1 through 8.4, required depends on the criticality of, and variation in, the properties to be measured. Designate each unit from which a field sample is to be obtained prior to sampling. The number of field samples from the production should be sufficient to give desired confidence in test results.

NOTE 4.-Guidance for determining number of samples required to obtain desired level of confidence in test results may be found in ASTM E 105, E 122, and E 141.

8.5.2 The field sample masses previously discussed are tentative; masses must be predicted on type and number of tests to which material is to be subjected and sufficient material obtained to provide for the proper execution of these tests. Standard acceptance and control tests are covered by Bureau standards and specify the portion of the field sample required for each specific test. Generally, amounts specified in table 1 will provide adequate material for routine grading and quality analysis. Extract test portions from field sample according to USBR 4702 or as required by other applicable test methods.

Table 1. - Size of samples.[1]

Maximum nominal size of aggregate[2]		Approximate minimum mass of field samples	
inches	(mm)	lbm	(kg)
Fine Aggregate			
No. 8	(2.36)	0.8	(0.4)
No. 4	(4.75)	0.8	(0.4)
Coarse Aggregate			
1/4	(6.3)	2	(1.0)
3/8	(9.5)	2	(1.0)
1/2	(12.5)	3	(1.25)
3/4	(19.0)	10	(4.50)
1	(25.0)	22	(10)
1-1/4	(31.5)	45	(20)
1-1/2	(37.5)	80	(40)
2	(50)	175	(80)
2-1/2	(63)	360	(160)
3	(75)	600	(280)
3-1/2	(90)	1,020	(460)
4	(100)	1,400	(640)
4-1/2	(115)	2,120	(960)
4-3/4	(120)	2,400	(1 100)
5	(125)	2,720	(1 240)
5-1/2	(140)	3,820	(1 740)
6	(150)	4,700	(2 140)
7	(175)	7,460	(3 380)
8	(200)	11,200	(5 200)
9	(225)	15,860	(7 200)
10	(250)	21,820	(9 900)
11	(275)	28,800	(13 060)
12	(300)	37,600	(17 200)
18	(450)	126,400	(57 400)

[1] This table is based on data in USBR 5325, which established minimum size samples for gradation analysis. It is assumed that, under sampling conditions such as test pits or stockpiles, four times the minimum gradation size sample would be required. Under more controlled conditions, such as a belt sample or samples from batcher bins, two times the minimum gradation size sample would probably assure adequate material for split-down.

[2] For processed aggregate, the maximum nominal size of particles is the largest sieve size listed in the applicable specifications upon which any material is permitted to be retained.

9. Shipping Samples

9.1 Transport aggregates in bags or other containers so constructed as to preclude loss or contamination of any part of sample or damage to contents from mishandling during shipment.

9.2 Shipping containers for aggregate samples shall have suitable individual identification attached and enclosed so that field reporting, laboratory logging, and test reporting may be facilitated. Figure 1 shows a suggested data sheet that should accompany the samples.

10. Calculations

10.1 No specific calculations are involved in this procedure; however, figure 2 shows a typical calculation form for various tests under other procedures that use this procedure as a reference.

11. Report

11.1 No specific reporting form is required for this test procedure; however, figures 3 and 4 show suggested reporting forms for various tests under other procedures that use this procedure as a reference. Other suggested reporting forms are given in appendixes X1 and X2.

12. Precision and Bias

12.1 Because of the nature of this test procedure, a precision and bias determintation is not possible.

Spec. or Solic. No. PRESPECIFICATION	Structure GLEN CANYON DAM	Sampled by L.T.L., C.A.L., & M.B. Date 8-20-56
Project COLORADO RIVER	Item CONCRETE AGGREGATE Location WAHWEAP CREEK DEPOSIT	Computed by Date
Feature GLEN CANYON UNIT	Station 12+50 Offset D/S LINE "D" Depth TP109 0 to 22.0 FEET	Checked by Date

SAMPLING AGGREGATES

QUARRY (NOT APPLICABLE)

Name ____________

Ownership ____________

Location ____________

☐ Developed ☐ Undeveloped

Distance From Proposed Construction ____________

Type of Roads ____________

☐ Sketch of Quarry Attached

Dimensions of Source ____________

Quantity and Character of Overburden ____________

Approximate Quantity Available ____________

Method of Obtaining Samples ____________

Number of Samples ____________

Size of Samples ____________

SAND AND GRAVEL DEPOSIT

Name WAHWEAP CREEK DEPOSIT

Ownership GOVERNMENT

Location SECTIONS 26, 27, 35, & 36 OF T.43S., R.3E. & SEC. 1 OF T.44S., R.3E., BOTH OF SALT LAKE BASE & MERIDIAN

☐ Developed ☑ Undeveloped

Distance From Proposed Construction 6 TO 9 MILES NW OF DAM

Type of Roads HAUL ROADS NEED TO BE BUILT

☐ Sketch of Deposit Attached (NO SKETCH CURRENTLY AVAILABLE)

Dimensions of Source 3 MILES IN LENGTH BY 800 FEET IN WIDTH

Quantity and Character of Overburden WIND-BLOWN SAND OF VARYING DEPTHS

Approximate Quantity Available 16 MILLION CUBIC YARDS

Method of Excavation DRAGLINE BUCKET

Dimensions of Pit or Trench PIT: 20 BY 50 FEET AT SURFACE

Method of Obtaining Samples DRAGLINE BUCKET

Number of Samples 9 PILES

Size of Samples 100 TO 2,000 POUNDS

Depth to Water Table 8.0 FEET Date 8-20-56

Notes: PUMPS WERE USED IN AN ATTEMPT TO SAMPLE BELOW WATER TABLE

Mark Bauer

Signature

Figure 1. – Sample data sheet to be submitted with aggregate samples.

Feature ROOSEVELT DAM	Project CENTRAL ARIZONA	Specifications DESIGN STAGE

☑ Aggregate ☐ Riprap ☐ Other: ____ Sample No. M-7724

TEST: ☑ Petrographic — Freeze and Thaw Durability — Date Received 9-5-85

☑ Routine Aggregate — ☑ Concrete — Processed by N. JOHNSON 9-5 TO 10-1-85

☐ Routine Riprap — ☐ Riprap — Tested by N. JOHNSON 10-17-85

☐ Other: ____ Computed by N. JOHNSON 10-17-85

Checked by R. HESS 11-4-85

Sample Source: PINTO CREEK (PIT-RUN) – ABOUT 12 MILES EAST OF ROOSEVELT DAM LOCATED IN T.3N., R.13E., GILA AND SALT RIVER MERIDIAN — ADMINISTRATED BY FOREST SERVICE

GRAVEL or RIPRAP

Grading - USBR 4136					24-Hour Specific Gravity and Absorption - USBR 4127						
Nominal Size Fraction		Mass Retained	Percent Retained		Test Sample Mass				$B-A$	$\frac{B-A}{A}(100)$	$\frac{B}{B-C}$
Inches or No.	~~mm~~	lbm ~~kg~~	Indiv.	Cumul.	B SSD Mass in Air, grams	C SSD Mass in Water, grams	$B-C$ Displaced Mass of Water, grams	A Mass of Ovendry Sample in Air, grams	Absorption Mass of Water, grams	Absorption, percent	SSD Bulk Specific Gravity
6+	150+										
3 to 6	75 to 150										
1½ to 3	37.5 to 75	104.9	27	27	2873	1794	1079	2840	33	1.16	2.66
¾ to 1½	19.0 to 37.5	101.9	26	53	2414	1510	904	2389	25	1.05	2.67
⅜ to ¾	9.5 to 19.0	81.4	21	74	1823	1127	696	1795	28	1.56	2.62
No. 4 to ⅜	4.75 to 9.5	99.5	26	100	1404	863	541	1384	20	1.45	2.60
Total Gravel Mass		387.7	—	—							
FM (Fineness Modulus)		—	—	7.64							
Sand Mass		457.3	—	—							
Total Sample Mass			—	—							
Percent Sand		—	54	—							

	Average	Weighted	No. 4 to 1½ inches (4.75 to 37 5 mm) Average	Weighted
Specific Gravity	2.64	2.64	2.63	2.63
Absorption, %	1.31	1.29	1.35	1.34

Los Angeles Abrasion - USBR 4131 ☑ Grading [✓ A] B C D - USBR 4535 ☐ Grading 1 2 3

		Mass, grams	Revolutions	Mass Retained No. 12 (1.70 mm), grams	Mass Loss, grams	Percent Loss
USBR 4131	Test Sample	5000	100	4738	262	5.24
	Abrasive Charge	NOT DET.	500	3783	1217	24.34
USBR 4535	Test Sample		200			
	Abrasive Charge		1000			

SAND

Nominal Sieve Size	Grading (As Received) USBR 4136								Grading (Washed) USBR 4136							
	Sample No. 1			Sample No. 2			Average		Sample No. 1			Sample No. 2			Average	
	Mass Ret., grams	% Retained Cum.	% Retained Indiv.	Mass Ret., grams	% Retained Cum.	% Retained Indiv.	% Retained Indiv.	% Retained Cum.	Mass Ret., grams	% Retained Cum.	% Retained Indiv.	Mass Ret., grams	% Retained Cum.	% Retained Indiv.	% Retained Indiv.	% Retained Cum.
* No. 4 ~~(4.75 mm)~~	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. 8 ~~(2.36 mm)~~	134	17	17	121	17	17	17	17	131	17	17	119	17	17	17	17
No. 16 ~~(1.18 mm)~~	298	38	21	284	39	22	21.5	38.5	284	38	21	273	39	22	22.5	38.5
No. 30 ~~(600 µm)~~	502	64	26	470	65	26	26	64.5	475	63	25	445	64	25	25	63.5
No. 50 ~~(300 µm)~~	685	88	24	637	88	23	23.5	88	646	86	23	601	86	22	22.5	86
No. 100 ~~(150 µm)~~	761	97	9	702	97	9	9	97	731	97	11	673	97	11	11	97
No. 200 (75 µm)																
Pan	781	100		722	100				754	100		696	100			
FM	—	3.04		—	3.06		3.05		—	3.01		—	3.03		3.02	
Washed Mass	**		—	**												

* Indicates oversize

** Indicates mass for USBR 4117

Organic Impurities - USBR 4040

COLOR ☑ As Received Clear [✓ 1] 2 3 (Std.) 4 5

☐ Washed Clear 1 2 3 (Std.) 4 5

Material Passing No. 200 (75-µm) Sieve USBR 4117

Test Sample Mass
Dry (B) = 1503
Washed (C) = 1450
Minus No. 200 (75 µm) $(B-C)$ = 53
Passing No. 200 ~~(75 µm)~~
$\frac{B-C}{B}(100)$ = 3.53 %

24-Hour Specific Gravity and Absorption - USBR 4128

Sample ☐ As Received ☑ Washed

Specific Gravity

Jar No. 1 Water Temp. = 71 °F ~~(°C)~~
SSD Sample Mass (B) = 714.4
Jar Calibration Mass (E) = 1327.9
Total Mass $(B+E)$ = 2042.3
Jar Sample Mass, Water (F) = 1778.9
Displacement $(B+E-F)$ = 263.4
Specific Gravity $\left(\frac{B}{B+E-F}\right)$ = 2.71

Absorption

Sample Mass
SSD (B) = 730.8
Dry (A) = 723.6
Absorption, Water $(B-A)$ = 7.2
Absorption, $\frac{B-A}{A}$ (100) = 1.08 %

Remarks:

Figure 2. - Physical properties of concrete aggregate and/or riprap (sheet 1 of 2).

Sodium Sulfate Soundness - USBR 4088

Bowl No. 22 Start Date 10-1-85 Results Date 10-11-85

Solution ☒ Fresh ☐ Reused Cycles ☒ 5 (Std.) ☐ Other

Sieve Size	Grading Standard		Grading Other	Sample Mass Before Test	Sample Mass After Test	Sample Mass Loss Actual, %	Sample Mass Loss Wgt'd., %
SAND							
No.8 (2.36 mm)	20			103.6	95.3	8.01	1.60
No.16 (1.18 mm)	20			103.3	97.6	5.52	1.10
No.30 (600 μm)	30			102.2	96.8	5.28	1.59
No.50 (300 μm)	30			101.3	96.8	4.44	1.33
Total Weighted	100			—	—	—	5.62
GRAVEL - RIPRAP							
2½ inch (63 mm)	—	—					
1½ inch (37.5 mm)	—	—					
¾ inch (19.0 mm)	50	—		2165.2	1985.8	8.29	4.14
⅜ inch (9.5 mm)	30	60		532.7	474.8	10.87	3.26
No.4 (4.75 mm)	20	40		106.9	99.1	7.30	1.46
Total Weighted	100	100		—	—	—	8.86

QUALITY EXAMINATION - COARSE SIZES

Sieve Size	Total Particles	Splitting No.	Splitting %	Crumbling No.	Crumbling %	Cracking No.	Cracking %	Flaking No.	Flaking %
2½ inch (63 mm)									
1½ inch (37.5 mm)									
¾ inch (19.0 mm)									

Comments: Not Evaluated

Low Density Pieces - USBR 4123

Size / Mass	1½-3 inch (37.5-75 mm)	¾-1½ inch (19.0-37.5 mm)	⅜-¾ inch (9.5-19.0 mm)	No.4-⅜ inch (4.75-9.5 mm)	Sand +No. 30 (600 μm)
Original Sample		NOT	RUN		
Float					
% Float					

Heavy Liquid: Specific Gravity =

Clay Lumps (CL) and Friable Particles (FP) - USBR 4142

Size / Mass	1½-3 inch (37.5-75 mm)	¾-1½ inch (19.0-37.5 mm)	⅜-¾ inch (9.5-19.0 mm)	No.4-⅜ inch (4.75-9.5 mm)	Sand +No. 16 (1.18 mm)
Gravel Grading					——
Original Sample		NOT	RUN		
Sample After Test					
Plus No.200 (75 μm) *					
Minus No.200 (75 μm) **					
CL/FP					
% CL/FP					
% FP					
% CL					
Weighted % CL/FP					——
* FP ** CL	Gravel CL/FP Total Weighted Percent =				——

Moisture Content of Aggregate - USBR 4566

Size / Mass	1½-3 inch (37.5-75 mm)	¾-1½ inch (19.0-37.5 mm)	⅜-¼ inch (9.5-19.0 mm)	No.4-⅜ inch (4.75-9.5 mm)	Sand
Original Sample					
Oven-Dry Sample					
Water					
Content, % Total					
Content, % Surface					

Physical Properties, Standard Concrete Freeze-Thaw Durability Mix - USBR 4666

30-Minute Specific Gravity and Absorption - USBR 4127

Gravel Nominal Size Fraction Inches	~~mm~~	B SSD Mass in Air, grams	C SSD Mass in Water, grams	$B-C$ Displaced Mass of Water, grams	A Oven-Dry Mass, grams	$B-A$ Absorption Mass of Water, grams	$\frac{B-A}{A}(100)$ Absorption, percent	$\frac{B}{B-C}$ SSD Bulk Specific Gravity
⅜-¼	9.5-19.0	1820	1116	704	1794	26	1.45	2.59
No.4-⅜	4.75-9.5	1401	863	538	1384	17	1.23	2.60

	Average	Weighted
Specific Gravity	2.595	2.59
Absorption	1.34	1.35

Standard Grading - USBR 4666

Gravel Size Fraction	%
⅜-¼ inch (9.5-19.0 mm)	60
No.4-⅜ inch (4.75-9.5 mm)	40
Total	100

Sand Sieve Size	%
No.8 (2.36 mm)	15
No.16 (1.18 mm)	15
No.30 (600 μm)	25
No.50 (300 μm)	24
No.100 (150 μm)	16
Pan	5
Total	100

FM = 2.74

SAND Material Passing No. 200 (75-μm) Sieve USBR 4117

Test Sample Mass
Dry (B) = 800.0
Washed (C) = 793.0
Minus No. 200 (75 μm)
($B-C$) = 7.0
Passing No. 200 (75 μm)
$\frac{B-C}{B}(100)$ = 0.88 %

30-Minute Specific Gravity and Absorption - USBR 4128

Specific Gravity
Jar No. ____ Water Temp. =
SSD Sample Mass (B) =
Jar Calib. Mass (E) =
Total Mass ($B+E$) =
Jar Sample, Water (F) =
Displacement ($B+E-F$) =
Specific Gravity
$\left(\frac{B}{B+E-F}\right)$ = 2.71 (From Sh. 1)

Absorption
Sample Mass
SSD (B) = 895.1
Dry (A) = 882.6
Absorption,
Water ($B-A$) = 12.5
Absorption
$\frac{B-A}{A}(100)$ = 1.42 %

Net Absorption (at time of mix), percent
% Net Abs. = % Abs. - % RM (Residual Moisture)

Size Fraction	% Abs.	% RM	% Net Abs.
⅜-¾ inch (9.5-19.0 mm)			
No.4-⅜ inch (4.75-9.5 mm)			
Weighted Gravel			
Sand (FM = 2.74)			

Freeze-Thaw Specimens - Date Cast ________

Strength, lbf/in² (MPa)	Mass Loss, percent	Cycles

Remarks:

Figure 2. - Physical properties of concrete aggregate and/or riprap (sheet 2 of 2).

Project CENTRAL ARIZONA	Ownership: FOREST SERVICE	Compiled by R.N. HESS Date 1989
Feature ROOSEVELT DAM	Location:	Checked by N.R. JOHNSON Date 1989
Date Letter Transmitted AUGUST 1989	Section ___ Township 3N	Reviewed by G.W. DEPUY Date 1989
Branch File No. C-1416B	Range 13E Meridian GILA & SALT RIVER	Submitted by J.S. PIERCE Date 8-89

QUALITY EVALUATION

☑ Concrete Aggregate ☐ Riprap ☐ Filter Material

State ARIZONA Region LC Source No. ~ Latitude 33°N Longitude 110°W

Sample No. M- 7724* Date Received 9-5-85 Material SAND & GRAVEL Max. Size Sampled 3 inches ~~(mm)~~

Visual Estimate of Plus 3 -inch ~~(mm)~~ 15% MAX. SIZE ENCOUNTERED 20 TO 30 INCHES

Source Name ______ Overburden NOT GIVEN Volume PLUS 1 MILLION** yd³ ~~(m³)~~

Remarks:
*COMPOSITE OF MATERIAL FROM TP-111, -112, -113, AND -114.
**BASED ON AVERAGE DEPTH OF 17 FEET.

TEST RESULTS

Sieve Analysis - USBR 4117 and 4136				
	Sieve Size, No., inch, or mm	Cumulative Percent Retained: Gravel, As Rec'd.	Sand, Unwashed	Sand, Washed
GRAVEL				
	3-inch	0		
	1½-inch	27		
	¾-inch	53		
	⅜-inch	74		
	No.4	100	0	0
SAND	No.8		17	17
	No.16		39	38
	No.30		65	63
	No.50		88	86
	No.100		97	97
	No.200			
	PAN		100	100
Fineness Modulus		7.54	3.06	
Percent Sand			54	
Percent Fines				3.5

Washed Sand: ☑ Plain Water ☑ Ovendried ☐ Wetting Agent ______ ☐ Rapid Drying

Nominal Sieve Size Fractions No., inches, or mm			3-1½ inch	1½-¾ inch	¾-⅜ inch	⅜-No.4	Fine Agg.	Washed Fine Agg.
Organic Impurities USBR 4040	—	—	—	—	—	—	No.1	
Low Density Pieces Specific Gravity - USBR 4123								
Specific Gravity USBR 4127, 4128			2.66	2.67	2.62	2.60		2.71
Absorption, percent USBR 4127, 4128			1.2	1.0	1.6	1.4		1.1
Clay Lumps and Friable Particles, percent - USBR 4142			NOT	TESTED				
Sodium Sulfate Soundness ☑ USBR 4088 ☐ ASTM C88 Solution: ☑ Fresh ☐ Reused No. of cycles 5						9	—	6

Effect of Organic Impurities on Strength of Mortar - USBR 4087

Grading: ☐ Standard ☐ Other	Average Strength Ratio of Fine Aggregate for Untreated to Treated Condition

Compressive Strength, lbf/in² (kPa)	___ Day		NOT TESTED
	7-Day		
	___ Day		
	28-Day		

Los Angeles Abrasion

USBR 4131	Grading A	B	C	D	USBR 4535	Grading 1	2	3
100 Rev.	5				200 Rev.			
500 Rev.	24				1000 Rev.			

Remarks:

Potential Alkali Reactivity of Cement-Aggregate Combinations - USBR 4227

	Sand 100	Sand 100	Sand 50	Sand 25	Gravel 100	Gravel 100	Gravel 50	Gravel 25	Sample No. M-	Type or Class	% K₂O	% Na₂O	% Na₂O Equiv.
Test Agg., %													
Neutral Agg., %													
	Low Alkali	High Alkali			Low Alkali	High Alkali							
Cement No. 1													
Cement No. 2													
Pozzolan													
Expansion, % Avg. of 4													
___ months									NOT TESTED				
6 months													
12 months													
___ months													

Resistance of Concrete to Rapid Freezing and Thawing - USBR 4666

Concrete: ☑ Cylinder ☐ Core Size: 3 BY 6-inch

Fresh: W/(C + P)	Slump, inches ~~mm~~	Meter Air Content, %	Density lbm/yd³ kg/m³	Water lbm/yd³ ~~kg/m³~~	Hardened: Density lbm/yd³ kg/m³	Air Content %	28-Day Comp. Str. lbf/in² ~~kPa~~	Mass Loss, %	No. of Cycles	Riprap Size: Density lbm/yd³ kg/m³	Mass Loss, %	No. of Cycles
0.51	2.6	6.0	NOT GIVEN	266	NOT DETERMINED		3980	25	1020			

INFORMATION SHOWN ON THIS DATA SHEET REGARDING COMMERCIAL PRODUCTS MAY NOT BE USED FOR ADVERTISING OR PROMOTIONAL PURPOSES, AND IS NOT TO BE CONSTRUED AS AN ENDORSEMENT OF ANY PRODUCT BY THE BUREAU OF RECLAMATION. APPROVAL OF DEPOSITS BY THE CONTRACTING OFFICER SHALL NOT BE CONSTRUED AS CONSTITUTING THE APPROVAL OF ALL OR ANY SPECIFIC MATERIALS FROM THE DEPOSIT.

Figure 3. - Typical reporting form for quality evaluation of concrete aggregate, riprap, and filter material (sheet 1 of 2).

Petrographic Summary - USBR 4295 Memo. No. 85-108 Date 12-3-85 By C.A. BECHTOLD

The gravel, primarily subrounded in shape with about 29 percent flat and/or elongated particles and about 2 percent calcium carbonate and sand grain coated particles, is composed primarily of granite and quartzose sandstone with lesser amounts of altered volcanics, gabbro, glassy volcanics, basalt, chert, and limestone. About 2 percent physically unsound material and 11 percent potentially alkali-reactive chert and glassy volcanic particles are present. The sand, subrounded to angular in shape, is composed of decreasing amounts of the rock types found in the gravel and increasing amounts of monomineralic grains of quartz, feldspar, amphibole, pyroxene, mica, chlorite, magnetite, zircon, calcite, and iron oxides with a few miscellaneous detrital minerals in the finer sizes. About 2 percent physically unsound material and 4 percent potentially alkali-reactive chert and glassy volcanic particles are present in the coarse sand.

Conclusions: Aggregate comparable to sample No. M-7724 is suitable for use in concrete provided the sand is washed to remove excess silt, proper gradings are obtained, and low-alkali cement is used.

Figure 3. - Typical reporting form for quality evaluation of concrete aggregate, riprap, and filter material (sheet 2 of 2).

Project CENTRAL ARIZONA	Ownership: NOT GIVEN	Compiled by J. JACOB Date 4-7-80
Feature GRANITE REEF AQUEDUCT-REACH 2	Location:	Checked by R. HESS Date 4-10-80
Date Letter Transmitted 1-14-77	Section 13 / 12 Township 6N / 6N	Reviewed by G. DEPUY Date 4-11-80
Branch File No. C- NOT ASSIGNED	Range 15W / 14W Meridian GILA & SALT RIVER	Submitted by J. PIERCE Date 4-12-80

MISCELLANEOUS PHYSICAL PROPERTIES OF MINERAL AGGREGATE

☑ Concrete Aggregate ☐ Filter Material ☐ Subbase Course ☐ Base Course ☐ Asphaltic Concrete Aggregate ☐ Other

State ARIZONA Region LC Source No. ~ Latitude NOT GIVEN Longitude NOT GIVEN

Sample No. M- 6764 Date Received 4-5-80 Material PIT-RUN S&G Max. Size Sampled 3 inches ~~(mm)~~

Visual Estimate of Plus 3 -inch ~~(mm)~~ NOT GIVEN

Source Name BIG GRANITE WASH Overburden NOT GIVEN Volume NOT GIVEN yd³ (m³)

Remarks:

TEST RESULTS

Sieve Analysis of Fine and Coarse Aggregates - USBR 4136

Materials Finer Than No. 200 (75-µm) Sieve in Mineral Aggregates by Washing - USBR 4117

Washed Sample: No. 4 ~~inch (mm)~~ Thru No. 200 (~~75 µm~~) ☑ Plain Water ☐ Wetting Agent

☑ Ovendried
☐ Rapid Drying

Cumulative Percent ☑ Retained ☐ Passing

Sample Description	MSA inches ~~mm~~			1½-inch	¾-inch	⅜-inch	No. 4 ~~4.75mm~~	No. 8 ~~2.36mm~~	No. 10 ~~2.00mm~~	No. 16 ~~1.18mm~~	No. 30 ~~600µm~~	No. 50 ~~300µm~~	No.100 ~~150µm~~	No.200 ~~75µm~~	Pan
AS RECEIVED															
GRAVEL PORTION	3			3	48	80	98								100
SAND PORTION	No.4							12	—	32	56	80	96	99	100

54 % Sand ______ % Silt Fineness Modulus: Coarse 7.54 Fine: Washed 3.05 Unwashed 3.02

Remarks: 3- TO 1½-INCH SIZE NOT TESTED BECAUSE LESS THAN 10% OF SAMPLE ASSUMED TO BE SAME AS NEXT SMALLER SIEVE. WEIGHTED PERCENTAGE BASED ON RETENTION ON 3/8-INCH.

Flat and Elongated Particles in Aggregates - USBR 4903

Length-to-Width or Width-to-Thickness Ratio = 3:1	Gravel (Weighted Averages)				Sand (Weighted Averages)			
	1½ TO 3/8 inch				No. 4 (~~4.75 mm~~) to No. 100 (~~mm~~)			
3 to 1½ inches not tested because less than 5%	Particle Mass	Particle Count	Total Weighted Average		Particle Mass	Particle Count	Total Weighted Average	
Flat, %	18	17	By Mass	By No.	ND	NA	By Mass	By No.
Elongated, %	2	2			ND	NA		
Flat and Elongated, %	1	1			ND	ND		
Total Flat and/or Elongated, %			21	20			ND	6
Crushed Particles in Agg.-USBR 4904	1½ inch (mm) to No. 4 (~~4.75 mm~~)				No. 4 (~~4.75 mm~~) to No. 30 (~~mm~~)			
Single Face Fracture, %	Test not run on this sample. Sieve analysis so close that data							
Multiple Face Fracture, %	was used from figure 1a. of USBR 4904 for illustration.							
Total Fractured Aggregates, %			91	92			12	13

Sand Equivalent Value of Soils and Fine Aggregate - ASTM D 2419

$$\text{Sand Equivalent, \%} = \frac{\text{Sand Reading}}{\text{Clay Reading}}(100)$$

1	2	3	Average	1	2	3	Average
			NOT	TESTED			

Degradation of Fine Aggregate Due to Attrition - ASTM C 1137

Grading: ☐ Standard ☐ Specifications Mass of Impeller, lbm (kg): Before ______ After ______

Fineness Modulus: Before ______ After ______ Minus No. 200 (75 µm): After ______% NOT TESTED

Remarks:
ND denotes "Not Determined"
NA denotes "Not Applicable"

Figure 4. - Typical reporting form for miscellaneous physical properties of mineral aggregate.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLING AGGREGATE FROM STOCKPILES OR TRANSPORTATION UNITS

X1.1 Scope

X1.1.1 In some situations, it is mandatory to sample aggregates that have been stored in stockpiles or loaded into rail cars, barges, or trucks. In such cases, the sampling method should ensure that segregation does not introduce a serious bias into the results.

X1.2 Sampling from Stockpiles

X1.2.1 In sampling material from stockpiles, it is very difficult to ensure unbiased samples because of the segregation which often occurs when material is stockpiled; coarser particles usually roll to outside base of pile. For coarse or mixed coarse and fine aggregate, every effort should be made to use power equipment to develop a separate, small sampling pile composed of materials drawn from various levels and locations in main pile. Then, several increments may be combined to compose the field sample. If necessary to indicate degree of variability existing within main pile, separate samples should be drawn from separate areas of pile.

X1.2.2 Where power equipment is not available, samples from stockpiles should be made up of at least three increments taken from top third, midpoint, and bottom third of pile volume. A board pushed vertically into pile just above sampling point aids in preventing further segregation. In sampling stockpiles of fine aggregate, the outer layer, which may have become segregated, should be removed and sample taken from material under the outer layer. Sampling tubes of about 1-1/4 inches (30 mm) minimum diameter by about 6 feet (2 m) minimum length may be inserted into pile at random locations to extract a minimum of five increments of material to form sample.

X1.3 Sampling From Transportation Units

X1.3.1 In sampling coarse aggregates from railroad cars or barges, effort should be made to use power equipment capable of exposing the material at various levels and random locations. Where power equipment is not available, a common method requires excavation of three or more trenches across the unit at points that will, from visual appearance, give a reasonable estimate of characteristics of load. The trench bottom should be about level, and at least 1 foot (0.3 m) wide and 1 foot deep. A minimum of three increments from approximately equally spaced points along each trench should be taken by pushing a shovel down into the material. Coarse aggregate in trucks should be sampled in essentially the same manner as rail cars or barges, except for adjusting the number of increments according to size of truck. For fine aggregate in transportation units, sampling tubes, as described in section X1.2.2, may be used to extract an appropriate number of increments to form sample.

X2. EXPLORATION OF POTENTIAL AGGREGATE SOURCES

X2.1 Scope

X2.1.1 Sampling for evaluation of potential aggregate sources should be performed by responsible, trained, and experienced personnel. Because of the wide variety of conditions under which sampling may have to be done, it is not possible to describe detailed methods for all circumstances. This appendix is intended to provide general guidance and list more comprehensive references.

X2.2 Sampling Stone From Quarries or Ledges

X2.2.1 *Inspection.*-The ledge or quarry face should be inspected to determine discernible variations or strata. Differences in color and structure should be recorded.

X2.2.2 *Sampling and Size of Sample.*-Samples of at least 600 lbm (272 kg) should be obtained from each discernible stratum being investigated. The sample should not include material weathered to such an extent that it is no longer suitable for purpose intended. One or more pieces in each sample should be at least 6- by 6- by 4-inch (150- by 150- by 100-mm) size with bedding plane plainly marked, and should be free of seams or fractures.

NOTE X2.1.-In sampling stone from quarries or ledges that is intended for use as a riprap material, samples of at least 600 lbm (272 kg) should be obtained from each discernible stratum being investigated. These samples should represent proportionally the quality range from poor to medium to best as found within each stratum. The minimum volume of individual fragments should be at least 0.5 ft^3 (0.014 m^3) and preferably 1 ft^3 (0.028 m^3).

X2.2.3 *Report.*-A typical reporting form is shown on figure 3. In addition to the general information accompanying all samples, the following information should be recorded for samples taken from ledges or quarry faces:

- Approximate quantity available. If quantity is very large, this may be recorded as practically unlimited.
- Quantity and character of overburden.

- Boundaries and location of material represented by each sample.

NOTE X2.2.–A test pit log showing thickness and location of different layers is recommended for this purpose, see figure X2.1.

X2.3 Sampling Roadside or Bank-Run Sand and Gravel Deposits

X2.3.1 *Inspection.*–Potential sources of bank-run sand and gravel deposits may include previously worked pits from which there is an exposed face, or potential deposits discovered through aerial photography interpretation, geophysical exploration, or other types of terrain investigation.

X2.3.2 *Sampling.*–Samples should be chosen from each different stratum in the deposit discernible to the sampler. An estimate of the quantity of different materials should be made. If deposit is worked as an open-face bank or pit, samples should be taken by channeling the face vertically, bottom to top, so as to represent materials proposed for use. Overburden or disturbed material should not be included in sample. Test holes should be excavated or drilled at numerous locations in the deposit to determine quality of material and extent of deposit beyond exposed face, if any. The number and depth of test holes will depend upon quantity of material needed, topography of area, nature of deposit, character of material, and potential value of material in deposit. If visual inspection indicates there is considerable variation in material, individual samples should be selected from material in each well-defined stratum. If necessary, each sample should be thoroughly mixed and quartered so that field sample thus obtained will contain at least 200 lbm (90 kg) of sand, 200 lbm of 3/4-inch (19.0-mm) nominal maximum size aggregate, and 100 lbm (45 kg) each of all other nominal aggregate sizes being investigated. Figure X2.2 shows a proposed layout of samples as taken from a pit, and figure X2.3 shows a typical grading sheet from test pit samples.

X2.3.3 *Report.*–Figures 3 and 4 show typical reporting forms. In addition to the general information accompanying all samples, the following information should be recorded for samples of bank-run sand and gravel:

- Location of supply.
- Estimate of approximate quantity available.
- Quantity and character of overburden.
- Length of haul to proposed site of work.
- Character of haul (kind of road, maximum grades, etc.).
- Extent and location of material represented by each sample (note X2.2).

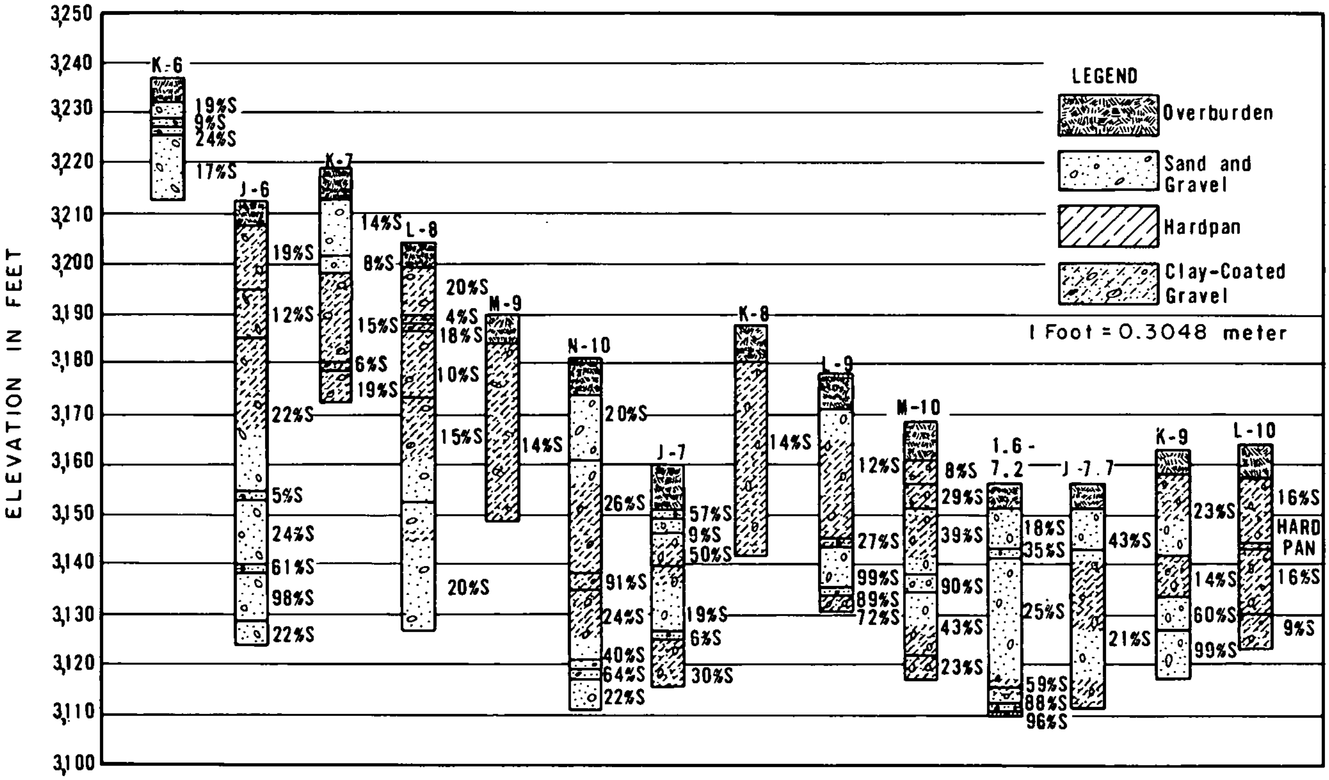
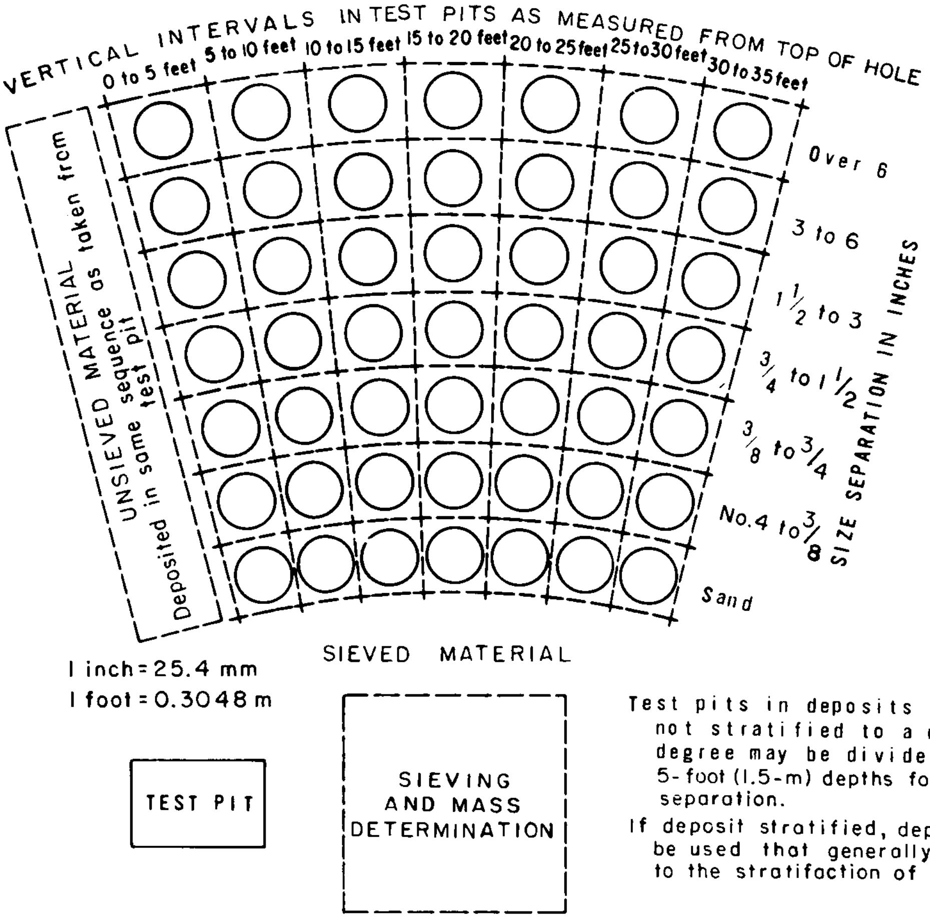


Figure X2.1. – Typical log of test pits.



1 inch = 25.4 mm
1 foot = 0.3048 m

Test pits in deposits that are not stratified to a marked degree may be divided into 5-foot (1.5-m) depths for size separation.

If deposit stratified, depths should be used that generally correspond to the stratifaction of the materials.

Figure X2.2. – Sand and gravel from a test pit stored in systematically arranged piles that facilitate sampling and inspection.

Spec. or Solic. No. PRESPECIFICATION	Structure GLEN CANYON DAM	Sampled by L.T.L., C.A.L., M.B. Date 8-20-56
Project COLORADO RIVER	Item CONCRETE AGGREGATE Location WAHWEAP CREEK DEPOSIT	Computed by Date
Feature GLEN CANYON UNIT	Station 12+50 Offset D/S LINE "D" Depth TP109 0 to 22.0 FEET	Checked by Date

GRADING AGGREGATE FROM A TEST PIT

MATERIAL REPRESENTED	SIEVE ANALYSIS, PERCENT RETAINED FOR EACH SIZE												
	SIEVE OPENINGS	DEPTH OF TEST PIT IN FEET ~~(METERS)~~											
		0 TO 4.5		4.5 TO 8.0		8.0 TO 13.0		13.0 TO 18.0		18.0 TO 22.0			
Mass of Sample, lbm ~~(kg)~~		No		1319		1985		1662		No			
Aggregate	6 inches (150 mm)	SAMPLE,		0		0		0		SAMPLE			
	3 inches (75 mm)	FINE		10		7		6					
	1½ inches (37.5 mm)	SAND		26		18		21					
	¾ inch (19.0 mm)	AND		27		29		21					
	⅜ inch (9.5 mm)	GRAVEL		20		27		30					
	No. 4 (4.75 mm)			17		19		22					
	Percent			76		62		69					
Sand	Sample No.			1	2	1	2	1	2				
	No. 8 (2.36 mm)			28	29	21	21	25	32				
	No. 16 (1.18 mm)			19	21	11	11	13	22				
	No. 30 (600 µm)			10	10	9	9	7	7				
	No. 50 (300 µm)			15	15	23	23	19	16				
	No. 100 (150 µm)			20	20	28	30	23	16				
	Pan			8	5	8	6	13	7				
	Percent			24		38		31					

NOTES:

All sieve openings to be square.

Indicate presence of organic material, soft stones, shale, clay, mud balls, boulders, coated materials, conglomerate, mica in sand, or other deleterious materials.

Indicate ground-water level and general moisture condition of the material.

Water table at 8.0 feet. Pumps used for sampling below water table.
Sampled by dragline bucket
Depth of hole was 22.0 feet.
Sond sample No. 1 was unwashed, No. 2 was washed.
Organic test OK, Silt 3%
Large sandstone boulders at 22 feet
FM of unwashed sand: 2.96, 2.50, & 2.59 FM of washed sand: 3.09, 2.52, & 3.17

Figure X2.3. - Sample of a systematic and comprehensive form for recording test pit exploration data.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4087-92

PROCEDURE FOR

EFFECT OF ORGANIC IMPURITIES IN FINE AGGREGATE ON STRENGTH OF MORTAR

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4087; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 87-83.

1. Scope

1.1 This designation covers the procedure for determination of the effect on mortar strength of the organic impurities in fine aggregate, whose presence is indicated by tests under USBR 4040. Comparison is made between compressive strengths of mortar made with fine aggregate treated to remove organic matter and fine aggregate washed in accordance with USBR 4117.

2. Applicable Documents

2.1 *USBR Procedures*:

4040 Organic Impurities in Fine Aggregates for Concrete
4075 Sampling Aggregates
4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens
4117 Materials Finer Than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
4128 Specific Gravity and Absorption of Fine Aggregate
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 87 Standard Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar[1]
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 150 Standard Specification for Portland Cement[1,3]
C 230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement[1,3]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2,3,4]

3. Summary of Procedure

3.1 The fine aggregate in a mortar compressive strength test is compared with a sample of the same aggregate that has been washed in a sodium hydroxide solution to remove organic impurities.

4. Significance and Use

4.1 This procedure is used to determine whether contamination of fine aggregate with organic material is serious enough to significantly affect its strength-producing potential in concrete.

4.2 This procedure is only applicable to those samples which, when tested in accordance with USBR 4040, have produced a supernatant liquid with a color darker than that of the reference standard color solution.

5. Terminology

5.1 Terms used in this procedure are defined in ASTM C 125.

6. Interferences

6.1 The only known interference is in the sodium hydroxide used to remove the organic material. The aggregate must be washed carefully to remove the sodium hydroxide without removing fines.

7. Apparatus

7.1 *Scales*.-Shall meet requirements of USBR 4109.

7.2 *Standard Masses*.-Shall meet requirements of USBR 4109.

7.3 *Glass Graduates*.-Shall meet requirements of USBR 4109.

7.4 *Specimen Molds*.-Shall meet requirements of USBR 4109.

7.5 *Mixer, Bowl, Paddle, and Scraper*:

7.5.1 The mixer shall be an electrically-driven, mechanical type equipped with paddle and mixing bowl, as specified in USBR 4305.

7.5.2 In the event that the fine aggregate being used includes particles so large that adjustment bracket (as described in USBR 4305) cannot provide adequate

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.
[4] *Annual Book of ASTM Standards*, vol. 04.08.

clearance, the oversized particles shall be removed by sieving on the No. 4 (4.75-mm) or No. 8 (2.36-mm) sieves. If this procedure is employed, the report shall so state and shall indicate quantity of material so removed.

NOTE 1.-*Caution*: The clearance between paddle and mixing bowl, as specified in USBR 4305, is suitable when using standard mortar made with Ottawa Sand. To permit mixer to operate freely and to avoid serious damage to paddle and bowl when coarser aggregates are used, it may be necessary to set clearance adjustment bracket to provide a greater clearance than specified. A clearance of about 4 mm is required in USBR 4305; a clearance of about 5 mm has been found to be satisfactory for this procedure when used with fine aggregate from which material retained on No. 4 (4.75-mm) sieve has been removed.

7.6 *Flow Table, Flow Mold, and Caliper*.-Shall conform to requirements of ASTM C 230.

7.7 *Tamper, Trowel, and Testing Machine*.-Shall meet requirements of USBR 4109.

8. Reagents and Materials

8.1 *Sodium Hydroxide Solution* (3 percent).-Dissolve 3 parts by mass of NaOH (sodium hydroxide) in 97 parts of water.

8.2 *Phenolphthalein or Litmus*

8.3 *Cement*.-Portland cement, Type I or II, complying with ASTM C 150.

9. Precautions

9.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

10. Sampling, Test Specimens, and Test Units

10.1 Obtain samples of fine aggregate in accordance with applicable provisions of USBR 4075, and reduce samples for test portions in accordance with USBR 4702.

10.2 Make and cure specimens as required in section 13.

11. Calibration and Standardization

11.1 Wash the fine aggregate over a No. 200 (75-µm) sieve to remove excess silt and any removable organic impurities. Dry and split the material into two parts, using one part for the reference material and the other part for the test (treated) sample. Soak and wash the test fine aggregate in sodium hydroxide and follow with a thorough rinsing in water. Repeat this treatment a sufficient number of times to obtain a washed material that, when tested in accordance with USBR 4040, produces a supernatant liquid color lighter than standard. Perform washing in such a manner as to minimize loss of fines. Check the washed and rinsed aggregate with a suitable indicator such as phenolphthalein or litmus to assure that all sodium hydroxide has been removed prior to preparation of mortar. The samples (as tested) shall normally have a standard grading (2.74 fineness modulus), as shown in table 1. If fine aggregate samples (as tested) have a nonstandard grading, the difference in the fineness modulus between the two comparative samples shall not exceed 0.10.

Table 1. - Standard sand grading.

Sieve size		Grading, percent
Passing	Retained on	
No. 4 (4.75 mm)	No. 8 (2.36 mm)	15
No. 8 (2.36 mm)	No. 16 (1.18 mm)	15
No. 16 (1.18 mm)	No. 30 (600 µm)	25
No. 30 (600 µm)	No. 50 (300 µm)	24
No. 50 (300 µm)	No. 100 (150 µm)	16
No. 100 (150 µm)	No. 200 (75 µm)	5

12. Conditioning

2.1 The temperatures of mixing water, moist closet, and storage tank shall be maintained at 73.4±3 °F (23±1.7 °C).

13. Procedure

13.1 *Preparation of Reference Fine Aggregate*.-Prepare the reference fine aggregate in accordance with the provisions of section 11.1.

13.2 *Preparation of Mortar*:

13.2.1 Mold the batches of mortar that have had the aggregate treated in sodium hydroxide and the batches with untreated aggregate on the same day. Mold six cubes from each batch, three cubes for 7-day tests and three cubes for 28-day tests.

13.2.2 Prepare mortar in a mechanical mixer in accordance with the method described in section 10 of USBR 4305, except that mortar shall be proportioned to produce a consistency of 100±5, as determined by the flow test.

13.2.3 Use water and cement in quantities that will yield a water-cement ratio of 0.6 by mass. It has been found that 600 grams of cement and 360 mL of water will usually be adequate for a six-cube batch.

13.2.4 Using fine aggregate that has been brought to a saturated-surface-dry condition as described in USBR 4128, prepare a quantity of aggregate estimated to be slightly more than needed to produce a batch of desired consistency.

NOTE 2.-If absorption has been determined in accordance with USBR 4128, aggregate may be prepared for test by adding to a known mass of dry aggregate the amount of water it will absorb, mixing thoroughly, and permitting aggregate to stand in a covered pan for 30 minutes before use.

13.2.5 After placing all mixing water in bowl, add cement to water. Start mixer and mix at the slow speed of 140±5 r/min for 30 seconds. During mixing, add a measured quantity of aggregate estimated to provide proper consistency.

NOTE 3.–The quantity of aggregate used may be determined by subtracting from a known quantity of prepared aggregate, the mass of the portion remaining after mixing.

13.2.6 Stop mixer, increase to medium speed of 285±10 r/min, and mix for an additional 30 seconds.

13.2.7 Stop mixer and let mortar stand for 1-1/2 minutes. During first 15 seconds of this interval, quickly scrape down into batch any mortar that may have collected on side of bowl; cover bowl with lid for remainder of standing period.

13.2.8 Complete procedure by mixing for 1 minute at medium speed of 285±10 r/min. If flow appears to be too high, additional sand may be added after first 30 seconds of this mixing period. If this is done, stop mixer briefly, add sand, and complete mixing.

13.2.9 In any case requiring a remixing interval, any mortar adhering to side of bowl shall be quickly scraped down into batch with scraper prior to remixing.

13.2.10 Make a determination of flow.

13.3 *Flow Test*:

13.3.1 Carefully wipe top of flow table clean and dry, and place flow mold at center of table. Immediately after completing mixing operation, place about a 1-inch (25-mm) thick layer of mortar in mold and tamp 20 times with tamper. The tamping pressure shall be just sufficient to ensure uniform filling of mold. Then, fill mold with mortar and tamp as specified for first layer. Cut off mortar to a plane surface flush with top of mold by drawing trowel straightedge (held nearly perpendicular to mold) across top of mold with a sawlike motion. Wipe top of table clean and dry, being especially careful to remove any water from around edge of flow mold. Lift mold away from mortar 1 minute after completing mixing operation. Immediately drop table through a height of 1/2 inch (12.7 mm) 10 times in 6 seconds. The flow is the resulting increase in average diameter of mortar mass, measured on at least four diameters at approximately equal angles, and expressed as a percentage of original diameter.

13.3.2 Should flow be too high, return mortar to mixing vessel, add additional sand, mix for 30 seconds at medium speed, and make another determination of flow. If more than two trials are necessary to obtain a flow of 100±5 percent, consider the mortar as a trial mortar and prepare test specimens from a new batch.

13.3.3 If mortar is too dry, discard batch.

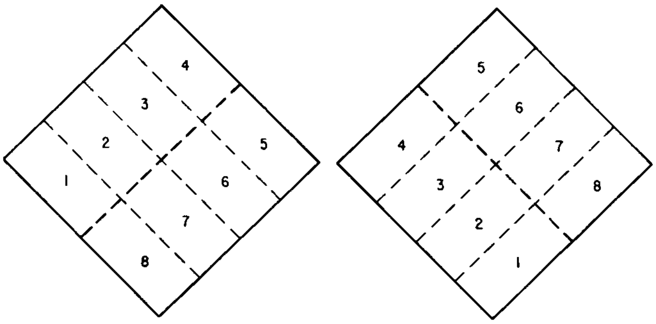
13.3.4 Determine quantity of sand used by subtracting the mass of the portion remaining after mixing from the mass of the initial sample.

13.3.5 A typical worksheet showing mix proportions is shown on figure 2.

13.4 *Molding Test Specimens*:

13.4.1 Immediately following completion of a flow test indicating acceptable consistency, return mortar from flow table to mixing bowl, scrape bowl, and then remix entire batch 15 seconds at medium speed (285±10 r/min) (note 4). Upon completion of mixing, shake excess mortar from paddle into bowl.

13.4.2 Start molding specimens within 2.5 minutes after completion of original mixing of mortar batch. Place a 1-inch (25-mm) layer of mortar, which is about half the depth of mold, in all cube compartments. Tamp mortar in each compartment 32 times in about 10 seconds over 4 rounds, with each round being at right angles to the other and consisting of 8 adjoining strokes over surface of specimen, as shown on figure 1. The tamping pressure shall be just sufficient to ensure uniform filling of molds. The 4 rounds of tamping (32 strokes) shall be completed in one cube before going to the next. When tamping of first layer in all cube compartments is completed, fill compartments with remaining mortar and then tamp again, as specified for first layer. During tamping of second layer, mortar forced out onto tops of molds after each round of tamping shall be put back into the compartments using the hands and tamper. This shall be done on completion of each round and before starting next round of tamping. On completion of tamping, tops of all cubes should protrude slightly above tops of molds. Mortar that has been forced out onto tops of molds shall be put back into the compartments using the trowel. Smooth off cubes by drawing flat side of trowel, with leading edge slightly raised, once across top of each cube at right angles to length of mold. Then, to level mortar and make mortar that protrudes above top of mold of more uniform thickness, draw flat side of trowel, with leading edge slightly raised, lightly along length of mold one time. Cut off mortar to a plane surface flush with top of mold by drawing straightedge of trowel, held nearly perpendicular to mold, with a sawing motion over length of mold.



Rounds 1 and 3

Rounds 2 and 4

Figure 1. – Order of tamping in molding of test specimens.

NOTE 4.–When a duplicate batch is to be made immediately for additional specimens, flow test may be omitted and mortar allowed to stand in mixing bowl for 90 seconds; then remixed at medium speed for 15 seconds before molding specimens.

13.5 *Testing*.–Store test specimens and determine compressive strength in accordance with USBR 4109.

14. Calculations

14.1 A typical sieve analysis work sheet and sample calculations are shown on figure 2 of USBR 4075. The fineness modulus determination is also shown on this figure as well as on figure 3 of USBR 4705.

14.2 Calculate the compressive strength of each specimen by dividing maximum load specimen carried during test by cross-sectional area of specimen. Average the strengths of three specimens from each batch. Calculate three strength ratios by dividing average strength for a batch containing sand unwashed by sodium hydroxide by average strength for corresponding (in respective order of mixing) batch containing sand washed with sodium hydroxide. Typical calculations are shown on figures 3 and 4.

15. Report

15.1 A typical reporting form is shown on figure 3 of USBR 4075. The report shall include:

- Source of fine aggregate.
- Grading analysis of companion sand materials; necessary only when nonstandard graded sands are tested.
- Fineness modulus determination of companion sand materials; necessary only when nonstandard graded sands are tested.
- Average ratio of 7-day strength for untreated fine aggregate to treated fine aggregate.
- Average ratio of 28-day strength for untreated fine aggregate to treated fine aggregate.

16. Precision and Bias

16.1 The following precision statement is applicable when a test result is the average ratio, as defined by this test procedure, of three pairs of mortar-batch strength tests with all batches mixed on same day and tested at same age.

16.2 The single laboratory coefficient of variation for the 7-day compressive strength determinations has been determined to be 5.4 percent (note 5). Therefore, results of two properly conducted tests in same laboratory should not differ from each other by more than 15.3 percent (note 5) of their average. The maximum range (difference between highest and lowest) of the three individual ratios used in calculating the average should not exceed 17 percent (note 6). The single laboratory coefficient of variation for the 28-day compressive strength determinations would not necessarily agree with this precision statement; however, 28-day determinations normally have less variation than the 7-day determinations.

NOTE 5.–These values represent, respectively, the 1S and D2S limits as described in ASTM C 670.

NOTE 6.–The precision statements are calculated as described in section 3.3.2 of ASTM C 670.

Spec. or Solic. No. DC-7080	Structure REACH 3-B	Tested by K. MITCHELL Date 3-16-77
Project PSMBP GARRISON DIVERSION	Item SAND M-6719 Location DENVER LAB	~~Computed by~~ Recorded by K. MITCHELL Date 3-16-77
Feature McCLUSKEY CANAL	Station NOT GIVEN Offset ~ Depth ~ to ~	Checked by NOT REQ'D. Date

MIX PROPORTIONS FOR COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Sand No.	Cement, grams	Sand, grams	Water, mL	Flow, percent	Specimen No. Made	Specimen Size
M-6400	15TH LAB STD. CEM.	IDEAL, DEVIL'S SLIDE, UT	II LA	M-6719	600	1560	360	100	1, 2, 3, 21, 22, & 23	2 x 2 inches
do	do	do	do	M-6719*	600	1560	360	104	11, 12, 13, 31, 32, & 33	do

NOTES:

*Sand was washed with sodium hydroxide

Figure 2. – Sample data and calculation form for mix proportions of hydraulic cement mortars.

Spec. or Solic. No. DC-7080	Structure REACH 3-B	Tested by K. MITCHELL Date 3-23-77
Project PSMBP GARRISON DIVERSION	Item SAND M-6719 Location DENVER LAB	Computed by K. MITCHELL Date 3-24-77
Feature McCLUSKEY CANAL	Station NOT GIVEN Offset ~ Depth ~ to ~	Checked by J. OWENS Date 3-30-77

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 2-INCH CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Specimen No.	Age at Test, days	Total Load, lbf	Compressive Strength, lbf/in²	Average Compressive Strength, lbf/in²
M-6400	15TH LAB STD. CEM.	IDEAL; DEVIL'S SLIDE, UT	IILA	1 UNTREATED	7	13,500	3,375	
				2		14,200	3,550	
				3		13,900	3,475	3,470
				4		14,300	3,575	
				5		13,800	3,450	
				6		14,000	3,500	3,510
				7		13,800	3,450	
				8		14,500	3,625	
				9		14,100	3,525	3,530
				11 TREATED		14,600	3,650	
				12		13,800	3,450	
				13		14,100	3,525	3,540
				14		14,300	3,575	
				15		13,900	3,475	
				16		14,000	3,500	3,520
				17		14,200	3,550	
				18		14,600	3,650	
				19		13,900	3,475	3,560

NOTES:

Treated: Washed in sodium hydroxide

$$\frac{\text{Avg. Untreated}}{\text{Avg. Treated}} = \frac{3{,}500}{3{,}540}(100) = 98.9\%$$

Figure 3. - Sample data and calculation form for compressive strength of hydraulic cement mortars using 2-inch cube specimens (sheet 1 of 2).

Spec. or Solic. No. DC-7080	Structure REACH 3-B	Tested by K. MITCHELL Date 4-14-77
Project PSMBP GARRISON DIVERSION	Item SAND M-6719 Location DENVER LAB	Computed by K. MITCHELL Date 4-15-77
Feature McCLUSKEY CANAL	Station NOT GIVEN Offset ~ Depth ~ to ~	Checked by J. OWENS Date 4-20-77

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 2-INCH CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Specimen No.	Age at Test, days	Total Load, lbf	Compressive Strength, lbf/in²	Average Compressive Strength, lbf/in²
M-6400	15TH LAB STD. CEM.	IDEAL, DEVIL'S SLIDE, UT	II LA	21 UNTREATED	28	19,750	4,940	
				22		20,000	5,000	
				23		19,800	4,950	4,960
				24		20,100	5,025	
				25		19,800	4,950	
				26		19,950	4,990	4,990
				27		20,150	5,040	
				28		19,900	4,975	
				29		20,900	5,225	5,080
				31 TREATED		20,300	5,075	
				32		19,950	4,990	
				33		19,900	4,975	5,010
				34		19,850	4,965	
				35		19,900	4,975	
				36		20,250	5,065	5,000
				37		20,300	5,075	
				38		20,450	5,115	
				39		19,850	4,965	5,050

NOTES:

Treated: Washed in sodium hydroxide

$$\frac{\text{Avg. Untreated}}{\text{Avg. Treated}} = \frac{5{,}010}{5{,}020}(100) = 99.8\,\%$$

Figure 3. – Sample data and calculation form for compressive strength of hydraulic cement mortars using 2-inch cube specimens (sheet 2 of 2).

Spec. or Solic. No. DC-6930	Structure REACH 1	Tested by W. DUFFUS Date 3-27-72
Project PSMBP GARRISON DIVERSION	Item SAND M-6363 Location DENVER LAB	Computed by W. DUFFUS Date 3-27-72
Feature McCLUSKEY CANAL	Station NOT GIVEN Offset ~ Depth ~ to ~	Checked by B. McCONNEL Date 3-30-72

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 50-mm CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Specimen No.	Age at Test, days	Total Load, kN	Compressive Strength, MPa	Average Compressive Strength, MPa
M-6400	15TH LAB STD. CEM.	IDEAL, DEVIL'S SLIDE, UT	II LA	1 UNTREATED	7	57.50	23.0	
				2		56.25	22.5	
				3		56.50	22.6	22.70
				4		57.50	23.0	
				5		58.25	23.3	
				6		58.00	23.2	23.15
				7		58.00	23.2	
				8		57.50	23.0	
				9		57.25	22.9	23.05
				11 TREATED		57.25	22.9	
				12		57.50	23.0	
				13		56.75	22.7	22.85
				14		57.75	23.1	
				15		57.00	22.8	
				16		57.25	22.9	22.95
				17		58.00	23.2	
				18		57.25	22.9	
				19		57.25	22.9	23.00

NOTES:

Treated: Washed in sodium hydroxide

$$\frac{\text{Avg. Untreated}}{\text{Avg. Treated}} = \frac{22.97}{22.95}(100) = 100.1\%$$

Figure 4. - Sample data and calculation form for compressive strength of hydraulic cement mortars using 50-mm cube specimens (sheet 1 of 2).

Spec. or Solic. No. DC-6930	Structure REACH 1	Tested by W. DUFFUS Date 4-17-72
Project PSMBP GARRISON DIVERSION	Item SAND M-6363 Location DENVER LAB	Computed by W. DUFFUS Date 4-17-72
Feature McCLUSKEY CANAL	Station NOT GIVEN Offset ~ Depth ~ to ~	Checked by B. McCONNEL Date 4-20-72

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 50-mm CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Specimen No.	Age at Test, days	Total Load, kN	Compressive Strength, MPa	Average Compressive Strength, MPa
M-6400	15TH LAB STD. CEM.	IDEAL, DEVIL'S SLIDE, UT	II LA	21 UNTREATED	28	95.00	38.0	
				22		94.75	37.9	
				23		95.75	38.3	38.05
				24		96.00	38.4	
				25		95.50	38.2	
				26		96.75	38.7	38.45
				27		95.75	38.3	
				28		96.25	38.5	
				29		95.50	38.2	38.35
				31 TREATED		95.50	38.2	
				32		95.00	38.0	
				33		95.25	38.1	38.10
				34		97.25	38.9	
				35		96.50	38.6	
				36		95.75	38.3	38.60
				37		96.00	38.4	
				38		95.25	38.1	
				39		95.75	38.3	38.25

NOTES:

Treated: Washed in sodium hydroxide

$$\frac{\text{Avg. Untreated}}{\text{Avg. Treated}} = \frac{38.28}{38.32}(100) = 99.9\%$$

Figure 4. – Sample data and calculation form for compressive strength of hydraulic cement mortars using 50-mm cube specimens (sheet 2 of 2).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4088-92

PROCEDURE FOR

SOUNDNESS OF AGGREGATES USING SODIUM SULFATE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4088; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 88-83.

1. Scope

1.1 This designation covers the procedure for the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or other applications. This is accomplished by repeated immersion in a saturated solution of sodium sulfate followed by oven drying to either partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon reimmersion, simulates the expansion of water on freezing. This procedure furnishes information that is useful in judging the soundness of aggregates when adequate information is not available from service records of the material exposed to actual weathering conditions.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 33 Standard Specification for Concrete Aggregates[1]
C 88 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,2]
E 100 Standard Specification for ASTM Hydrometers[3]
E 126 Standard Method for Inspection, Test, and Standardization of Hydrometers[3]

3. Significance and Use

3.1 This designation provides a procedure for estimating the soundness of aggregates for use in concrete and other purposes. The procedure may detect a structural weakness in an aggregate not defined by other quality testing. The values obtained may be compared with the requirements of Bureau specifications, or ASTM C 33, that are designed to indicate the suitability of aggregate proposed for use. The precision of this procedure (sec. 15) is poor; therefore, it may be suitable only for acceptance, but not rejection of aggregates without confirmation from other quality tests related to the specific service intended.

3.2 Values for the permitted-loss percentage by this procedure are usually different for fine and coarse aggregates. The data base for the standard Bureau soundness test has been developed using a sodium sulfate solution; ASTM C 88 provides for using either sodium or magnesium sulfate solutions. Attention is called to the fact that test results using these salts differ considerably, and care must be exercised in fixing proper limits in any specifications that include requirements for these tests. The test is usually more severe when magnesium sulfate is used; accordingly, limits for the allowable percent loss when magnesium sulfate is used are normally higher than the limits for sodium sulfate.

NOTE 1.-Refer to the appropriate sections in ASTM C 33 that establish the conditions for acceptance of coarse and fine aggregates which fail to meet requirements based on this test.

4. Apparatus

4.1 *Sieves*.-The sieves shall have square openings of the sizes shown in table 1 conforming to ASTM E 11 for sieving the samples in accordance with sections 7, 8, and 11.

Table 1. - Sieve sizes.

Fine series	Coarse series[1]
No. 100 (150 μm)	No. 4 (4.75 mm)
No. 50 (300 μm)	3/8 inch (9.5 mm)
No. 30 (600 μm)	3/4 inch (19.0 mm)
No. 16 (1.18 mm)	1-1/2 inches (37.5 mm)
No. 8 (2.36 mm)	*2 inches (50 mm)
No. 4 (4.75 mm)	*2-1/2 inches (63 mm)

[1] Sizes greater than 2-1/2 inches (63 mm) increase by 1/2 inch (12.5 mm).
* These sieves are not normally required for the standard Bureau soundness of aggregate test.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 14.02.
[3] *Annual Book of ASTM Standards*, vol. 14.01.

4.2 *Containers.*-Containers for immersing samples of aggregate in the solution should be corrosion resistant. Porcelain or metal (stainless steel or nickel) evaporating dishes and bowls are satisfactory. Containers, if perforated, should permit free access of solution to the sample and allow drainage of solution from sample without loss of aggregate. Baskets made of suitable wire mesh, or sieves with suitable openings, are satisfactory.

NOTE 2.-Perforated or wire mesh containers promote easier drainage of excess sulfate solution prior to sample drying, and possibly faster drying of samples for some size fractions of aggregate due to better circulation of air around aggregate particles. However, the use of proper decanting techniques with a porcelain or metal dish, or bowl type containers, provides comparable drying, prevents loss of any material during test, and minimizes any possible contamination of sodium sulfate solution. Techniques for removing aggregate samples from solution immersion prior to oven drying depend upon type of container used, and are described in section 10.2.

4.3 *Temperature Regulation.*-Suitable means for regulating the temperature of samples during immersion in the sodium sulfate solution shall be provided.

4.4 *Balances.*-For fine aggregate, a balance or scale accurate within 0.1 gram over the range required for test. For coarse aggregate, a balance or scale accurate within 0.1 percent or 1 gram, whichever is greater, over range required for test.

4.5 *Drying Oven.*-The oven shall be capable of being heated continuously at 230±9 °F (110±5 °C). The rate of evaporation, at this range of temperature, shall be at least 25 grams per hour for 4 hours, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from 1-L Griffin low-form beakers, each beaker initially containing 500 grams of water at a temperature of 70±3 °F (21±2 °C), and placed at each corner and at the center of each shelf of the oven. The evaporation requirement is to apply to all test locations when oven is empty, except for the beakers of water.

4.6 *Specific Gravity Measurement.*-Hydrometers conforming to requirements of ASTM E 100, or a suitable combination of graduated glassware and balance, capable of measuring the solution specific gravity within ±0.001.

5. Reagents and Materials

5.1 Prepare the sodium sulfate solution for immersion of test samples in accordance with 5.1.1 (note 3). The volume of the solution shall be at least five times the solid volume of all samples immersed at any one time. The solution should be kept in a covered vitreous earthenware crock or similar container not affected by the solution. It is recommended that one batch of sodium sulfate solution be used for not more than 10 cycles of test.

NOTE 3.-Some aggregates containing carbonates of calcium or magnesium are attacked chemically by the fresh sulfate solution, resulting in erroneously high-measured losses. If this condition is encountered or is suspected, repeat the test using a filtered solution that has been used previously to test the same type of carbonate rock, provided that solution meets requirements of 5.1.1 for specific gravity.

5.1.1 *Sodium Sulfate Solution.*-Prepare a saturated solution of sodium sulfate by dissolving a USP (United States Pharmacopeia), or equal grade of the salt, in water at 77 to 86 °F (25 to 30 °C). Add sufficient salt (note 4), of either the Na_2SO_4 (anhydrous) or $Na_2SO_4 \cdot 10H_2O$ (crystalline) form (note 5), to ensure not only saturation but also the presence of excess crystals when solution is ready for use in tests. Thoroughly stir mixture during the addition of the salt and stir solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep solution covered at all times when access is not needed. Allow solution to cool to 70±2 °F (21±1 °C), stir again, and allow to stand at designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake (if any) in the container, stir thoroughly, and determine specific gravity of solution. When used, solution shall have a specific gravity not less than 1.151 nor more than 1.174. Discard a discolored solution, or filter it and check for specific gravity.

NOTE 4.-For the solution, 215 grams of anhydrous salt, or 700 grams of decahydrate, per liter of water are sufficient for saturation at 71.6 °F (22 °C). However, because this salt is not completely stable and that it is desirable that an excess of crystals be present, the use of not less than 350 grams of anhydrous salt, or 750 grams of decahydrate salt, per liter of water is recommended.

NOTE 5.-The decahydrate sodium sulfate presents difficulties in compounding the required solution because of its cooling effect on the solution. A grade of sodium sulfate that is designated by the trade as "dried powder," and which may be considered as approximately anhydrous, may be the most practical and is more economically available than the anhydrous form. Bureau practice is to use reagent grade sodium sulfate (anhydrous powder) meeting the specifications of the ACS (American Chemical Society).

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Samples

7.1 The sample shall be obtained in general accordance with USBR 4075, and reduced to test portion size in accordance with USBR 4702.

7.2 *Fine Aggregate.*-Fine aggregate for the test shall be passed through a No. 4 (4.75-mm) sieve. Sample shall be of such size that it will yield for testing not less than 100 grams of each of the sizes shown in table 2 that are available in amounts of 5 percent or more.

Table 2. - Fine aggregate, 100-gram minimum sample size.

Passing Sieve	Retained on Sieve
No. 30 (600 µm)	No. 50 (300 µm)
No. 16 (1.18 mm)	No. 30 (600 µm)
No. 8 (2.36 mm)	No. 16 (1.18 mm)
No. 4 (4.75 mm)	No. 8 (2.36 mm)

7.3 *Coarse Aggregate.*-Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 sieve have been removed. Sample shall be of such size that it will yield for testing not less than the amounts of the indicated sizes shown in table 3 that are available in amounts of 5 percent or more.

7.4 When an aggregate to be tested contains appreciable amounts of both fine and coarse material that have a grading with more than 10 percent coarser than the No. 4 sieve and more than 10 percent finer than the No. 4 sieve, test separate samples of the minus No. 4 fraction and plus No. 4 fraction in accordance with the procedures for fine and coarse aggregate, respectively. Report the results separately for both the fine aggregate fraction and coarse aggregate fraction.

7.5 If the standard Bureau grading for this test is not to be used for calculating weighted percentage losses, the percentages of the individual coarse and fine aggregate fractions in initial grading shall be determined.

Table 3. - Coarse aggregate sample size.

Sieve size (square openings)	Minimum mass, grams
3/8 inch to No. 4 (9.5 to 4.75 mm)	100
3/4 to 3/8 inch (19.0 to 9.5 mm)	500
1-1/2 to 3/4 inch (37.5 to 19.0 mm)	2000
2-1/2 to 1-1/2 inches (63 to 37.5 mm)	5000
Larger sizes with a 1-inch (25-mm) spread in sieve size (each fraction)	7000

8. Preparation of Test Sample

8.1 *Fine Aggregate.*-Make a rough separation of the fine aggregate by using a nest of the standard sieves specified in table 2 to obtain about 130 grams of each size fraction to be tested. Recombine and thoroughly wash these fractions on a No. 100 (150-µm) sieve, dry to a constant mass at 230±9 °F (110±5 °C), and final sieve for 20 minutes using a mechanical sieve shaker. Prepare samples consisting of a minimum of 100 grams from each of the separated fractions after final sieving, and place in separate containers for the test.

8.2 *Coarse Aggregate.*-Make a rough separation of the coarse aggregate into the size fractions to be tested. The quantities of the different size fractions obtained should be of sufficient size to meet requirements of table 3. Thoroughly wash and then dry each size fraction to a constant mass at 230±9 °F. Final sieve each size fraction for 20 minutes using a mechanical sieve shaker. Determine and record mass of each size fraction, and place in separate containers for the test. For sizes larger than 3/4 inch (19.0 mm), record number of particles in test sample.

8.3 Particles of any fine or coarse aggregate size fraction sticking in the meshes of the sieve should not be used in preparing test samples.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

9.2 Sieves shall be calibrated to meet requirements of ASTM E 11 in accordance with USBR 1025.

9.3 Balances shall be calibrated to meet requirements of section 4.4 in accordance with USBR 1012.

9.4 Drying ovens shall be calibrated to meet requirements of section 4.5 in accordance with USBR 1020.

9.5 Hydrometers shall be calibrated to meet requirements of ASTM E 100 in accordance with ASTM E 126.

10. Procedure

10.1 *Storage of Samples in Solution.*-Immerse samples in prepared solution of sodium sulfate for not less than 16 nor more than 18 hours in such a manner that solution covers them to a depth of at least 1/2 inch (13 mm) (note 6). Cover the containers to reduce evaporation and to prevent the accidental addition of extraneous substances. Maintain samples immersed in solution at 70±2 °F (21±1 °C) for the immersion period.

NOTE 6.-Suitably weighted wire grids placed over sample in containers will permit this coverage to be achieved with very low density aggregates.

10.2 *Drying Samples After Immersion.*-Remove aggregate samples from the solution after immersion period. Allow samples in perforated or wire mesh containers to drain for 15±5 minutes before placing in drying oven. Decantation of excess solution from dish or bowl containers must be carefully performed. Decantation of coarse aggregate samples is accomplished by placing a cover fabricated of suitable wire mesh over the bowl container and draining solution from container. Fine aggregate samples in dish containers are initially decanted by very lightly tapping or vibrating the dish container by hand against a table top, carefully decanting excess solution, avoiding any loss of sample, and then placing samples in drying oven. After about 15 minutes, fine aggregate samples are removed from oven and a second decantation is performed. This second decantation may be made as before or, preferably, accomplished by using a table top vibrator to bring any solution not removed in first decantation to the sample surface, and then carefully pouring off excess solution. After second decantation, fine aggregate samples are stirred with a small 1/8-inch (3-mm) diameter rod to expedite subsequent drying by exposing a greater particle surface area. Care must be taken to prevent loss of fine aggregate particles during this stirring. Samples are then replaced in oven to complete drying. The temperature of the oven shall have been previously brought to 230±9 °F (110±5 °C). Dry samples at specified temperature until a constant mass has been achieved. Establish the time required to attain this constant mass as follows: With oven containing maximum sample load expected, check mass losses of test samples by removing and determining their mass, without cooling, at intervals of 2 to 4 hours; make enough checks to establish required drying time for the least favorable oven location (sec. 4.5) and sample condition (note 7). A constant mass will be considered to have been achieved when mass loss is less than 0.1 percent of total sample mass in 4 hours of drying. After constant mass has been achieved, allow samples to cool to room temperature, when they shall again be immersed in prepared solution as described in 10.1.

NOTE 7.-The drying time required to reach constant mass may vary considerably for several reasons. Efficiency of drying will be reduced as cycles accumulate because of salt adhering to particles and, in some cases, because of increase in surface area due to breakdown. The different size fractions of the aggregate will have differing drying rates. The smaller sizes will tend to dry more slowly because of their larger surface area and restricted interparticle voids; however, this tendency may be altered by effects of container size and shape.

10.3 *Number of Cycles.*-Repeat the process of alternate immersion and drying until required number of cycles is obtained. The data base for the standard Bureau soundness test is established for five cycles.

11. Quantitative Examination

11.1 After completion of final cycle and after sample has cooled, wash the sample free from the sodium sulfate by circulating water at 109±11 °F (43±6 °C) through the samples in their containers. This may be done by placing samples in a tank into which the hot water can be introduced near the bottom and allowed to overflow. Fine aggregate samples are washed on a No. 100 (150-μm) sieve. In the washing operation, samples shall not be subjected to impact or abrasion that may tend to break up particles. To ensure complete removal of sodium sulfate during washing, a small quantity of the wash water is obtained and a few drops of $BaCl_2$ (barium chloride) solution added. The presence of sodium sulfate is indicated by a formation of white precipitate of $BaSO_4$ (barium sulfate).

11.2 After sodium sulfate has been removed, dry each fraction of sample to a constant mass at 230±9 °F (110±5 °C). Sieve each aggregate fraction for 15 minutes over same sieve on which it was retained before test. The method of sieving shall be the same as used in preparing the test samples. No extra manipulation shall be used to break up particles or cause them to pass the sieves. Determine mass of material retained on each sieve, and record each amount. The difference between each of these amounts and the initial mass of the fraction of sample tested is the "loss" in the test, and is expressed as a percentage of initial mass.

12. Qualitative Examination

12.1 Make a qualitative examination of test samples coarser than 3/4 inch (19.0 mm) as follows (note 8):

12.1.1 Separate particles of each test sample into groups according to the action produced by the test (note 8).

12.1.2 Record number of particles showing each type of distress.

NOTE 8.-Many types of action may be expected. In general, the action may be classified as disintegration, splitting, crumbling, cracking, or flaking. While only particles larger than 3/4 inch (19.0 mm) are required to be examined qualitatively, it is recommended that examination of smaller sizes also be made to determine whether there is any evidence of excessive splitting.

13. Calculations

13.1 Refer to figure 2 of USBR 4075 for a suggested worksheet with typical calculations.

14. Report

14.1 Refer to figure 3 of USBR 4075 for a suggested reporting form. The report for this procedure shall include the following data:

14.1.1 Material from each fraction of sample finer than sieve on which fraction was retained before test, expressed as a percentage of original mass of fraction.

14.1.2 The weighted average loss, calculated from percentage of loss for each fraction and based on the standard Bureau fine or coarse aggregate sample data base grading, is shown on table 4.

Table 4. - Weighted average loss.

Fine Aggregate Sample

Size Fraction	*Standard Grading (percent)*
No. 4 to No. 8 (4.75 to 2.36 mm)	20
No. 8 to No. 16 (2.36 to 1.18 mm)	20
No. 16 to No. 30 (1.18 mm to 600 μm)	30
No. 30 to No. 50 (600 to 300 μm)	30

Coarse Aggregate Sample

Size Fraction	*Standard Grading (percent)*	
	3/4 inch (19.0 mm) max.	1-1/2 inches (37.5 mm) max.
1-1/2 to 3/4 inch (37.5 to 19.0 mm)	-	50
3/4 to 3/8 inch (19.0 to 9.5 mm)	60	30
3/8 inch to No. 4 (9.5 to 4.75 mm)	40	20

14.1.3 When sufficient material is unavailable for testing in any size fraction, that size shall not be tested. For purposes of calculating weighted test results, this untested size shall be considered to have same loss in sulfate treatment as average of next smaller and next larger size or, when one of these sizes is absent, shall be considered to have same loss as next larger or next smaller size, whichever is present.

14.2 In some specific cases (or when test results are reported in accordance with ASTM C 88), weighted average calculations in accordance with USBR 4136 from the percentage of loss for each fraction, may be based on grading of the sample as received or on the average grading of material from that portion of the supply of which sample is representative, except that:

14.2.1 For fine aggregates with less than 10 percent coarser than the No. 4 (4.75-mm) sieve, assume sizes finer than the No. 50 (300-μm) sieve to have 0 percent loss and sizes coarser than the No. 4 sieve to have same loss as next smaller size for which test data are available.

14.2.2 For coarse aggregate with less than 10 percent finer than the No. 4 sieve, assume sizes finer than the No. 4 sieve to have same loss as next larger size for which test data are available.

14.2.3 For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples as required in 7.4, compute weighted average losses separately for the minus No. 4 and plus No. 4 fractions based on recomputed gradings considering both the fine and coarse fractions as 100 percent. Report results separately giving the percentage of the minus No. 4 and plus No. 4 material in the initial grading.

14.2.4 For calculating weighted average, consider any sizes in sections 7.2 or 7.3 that contain less than 5 percent of sample to have same loss as average of next smaller and next larger size or, if one of these sizes is absent, to have same loss as next larger or next smaller size, whichever is present.

14.2.5 See figure 1 for an alternate reporting form that reports the results in accordance with ASTM C 88 based on grading of samples as received rather than the Bureau standard data base grading which is reported on figure 3 of USBR 4075.

14.3 The report shall also include the following data:

14.3.1 For particles coarser than 3/4 inch (19.0 mm): (1) number of particles in each fraction before test, and (2) number of particles affected; classified as to number disintegrating, splitting, crumbling, cracking, or flaking.

14.3.2 Whether solution was freshly prepared or previously used.

15. Precision and Bias

15.1 For coarse aggregate with weighted average sodium sulfate soundness losses in the range of 6 to 16 percent, the precision indexes are:

	Coefficient of variation (1S), percent	Difference between two tests (D2S), percent of average
Multilaboratory:		
Sodium sulfate	41	116
Single-operator:		
Sodium sulfate	24	68

Note: These values represent the (1S) and (D2S) limits as described in ASTM C 670.

15.2 The bias for this procedure has not been established.

Spec. or Solic. No. 010-0981-4071-010-38-0-0	Structure CANAL & LATERALS	Tested by N. JOHNSON Date 6-30-89
Project DOLORES	Item CONCRETE AGGREGATE Location UTE RESERV. TP1201	Computed by N. JOHNSON Date 7-15-89
Feature TOWAOC CANAL & LATERALS	Station ~ Offset ~ Depth ~ to ~	Checked by B. HESS Date 7-15-89

SOUNDNESS OF AGGREGATES USING SODIUM SULFATE

Sieve Size	Grading of Original Sample, Individual Percent Retained	Mass of Test Fraction Before Test, lbm [✓ grams]	Mass of Test Fraction After Test, lbm [✓ grams]	Mass Loss, lbm [✓ grams]	Percent Passing Sieve After Test	Weighted Loss, percent
SOUNDNESS TEST OF FINE AGGREGATE						
Minus No. 100 (–150 µm)	5.0	—	—	—	—	—
No. 50 to No. 100 (300 to 150 µm)	11.4	—	—	—	—	—
No. 30 to No. 50 (600 to 300 µm)	26.0	100	95.80	4.20	4.2	1.09
No. 16 to No. 30 (1.18 mm to 600 µm)	25.2	100	95.21	4.79	4.8	1.21
No. 8 to No. 16 (2.36 to 1.18 mm)	17.0	100	92.00	8.00	8.0	1.36
No. 4 to No. 8 (4.75 to 2.36 mm)	10.8	100	88.81	11.19	11.2	1.21
⅜ inch to No. 4 (9.5 to 4.75 mm)	4.6	—	—	—	11.2*	0.52
Totals	100.0					5.4

SOUNDNESS TEST OF COARSE AGGREGATE

Sieve Size	lbm (grams)						
2½ to 2 inches	6.23						
(63 to 50 mm)	(2825)						
2 to 1½ inches	4.32						
(50 to 37.5 mm)	(1958)						
2½ to 1½ inches		20.0	10.54(4781)	10.04(4554)	0.51(231)	4.8	0.96
(63 to 37.5 mm)							
1½ to 1 inch	2.23						
(37.5 to 25.0 mm)	(1012)						
1 to ¾ inch	1.13						
(25.0 to 19.0 mm)	(513)						
1½ to ¾ inch		45.0	3.36(1525)	3.09(1403)	0.27(122)	8.0	3.60
(37.5 to 19.0 mm)							
¾ to ½ inch	1.49						
(19.0 to 12.5 mm)	(675)						
½ to ⅜ inch	0.73						
(12.5 to 9.5 mm)	(333)						
¾ to ⅜ inch		23.0	2.22(1008)	2.01(911)	0.21(97)	9.6	2.20
(19.0 to 9.5 mm)							
⅜ inch to No. 4		12.0	0.66(298)	0.58(263)	0.07(33)	11.2	1.34
(9.5 to 4.75 mm)							
Totals		100.0					8.1

QUALITATIVE EXAMINATION OF COARSE SIZES

Sieve Size	Particles Exhibiting Distress								Total No. of Particles Before Test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
2½ to 1½ inches (63 to 37.5 mm)	2	7	—	—	2	7	—	—	29
1½ to ¾ inch (37.5 to 19.0 mm)	5	10	1	2	4	8	—	—	50

Remarks:
*This percentage loss (11.2 %) of the next smaller size was used as the percentage loss for this size because this size contains less than 5 percent of the original sample as received, see section 14.2.4.

Figure 1. – Sample form for recording test data and for the qualitative examination.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4094-92

SPECIFICATIONS FOR

READY-MIXED CONCRETE

INTRODUCTION

This specification is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. These specifications are issued under the fixed designation USBR 4094; the number immediately following the designation indicates year of original adoption or year of last revision. These specifications are a modified version of ASTM designation: C 94-83.

1. Scope

1.1 This designation covers the specifications for ready-mixed concrete manufactured and delivered to the Government in a freshly mixed and unhardened state. Requirements for the quality of concrete shall be either as stated herein or as specified in the contract. Where requirements of contract differ from these specifications, the contract shall govern. These specifications do not cover placement, consolidation, curing, or protection of concrete after delivery.

2. Applicable Documents

2.1 *USBR Procedures*:

3115 Particulate, Dissolved, or Total Matter in Water
3120 Sulfate Ion in Water
4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4191 Time-of-Setting of Hydraulic Cement by Vicat Needle
4192 Making and Curing Concrete Test Specimens in Laboratory
4211 Selecting Proportions for Concrete Mixtures
4231 Air Content of Freshly Mixed Concrete by Pressure Method

2.2 *ASTM Standards*:

C 33 Standard Specification for Concrete Aggregates[1]
C 94 Standard Specification for Ready-Mixed Concrete[1]
C 150 Standard Specification for Portland Cement[2]
C 260 Standard Specification of Air Entraining Admixtures for Concrete[1]
C 330 Standard Specification for Lightweight Aggregates for Structural Concrete[1]
C 494 Standard Specification for Chemical Admixtures for Concrete[1]
C 567 Standard Test Method for Unit Weight of Structural Lightweight Concrete[1]
C 595 Standard Specification for Blended Hydraulic Cements[2]
C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[1]
D 512 Standard Test Methods for Chloride Ion in Water[3]
D 1428 Standard Test Methods for Sodium and Potassium in Water and Water-Formed Deposits by Flame Photometry[3]

2.3 *ACI Standards*:[4]

211.1 Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete
211.2 Recommended Practice for Selecting Proportions for Structural Lightweight Concrete
214 Practice for Evaluation of Strength Test Results of Concrete
305R Hot Weather Concreting
306R Cold Weather Concreting

2.4 *National Institute of Standards and Technolgoy*[5]:

Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

3. Basis of Purchase

3.1 The basis of purchase shall be by the cubic yard or cubic meter of freshly mixed and unhardened concrete as discharged from mixer.

3.2 The volume of freshly mixed and unhardened concrete in a given batch shall be determined from total mass of batch divided by actual mass per cubic yard or per cubic meter of the concrete. The total mass of batch shall be calculated either as the sum of the masses of all materials entering batch (including water), or as net mass

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.

[3] *Annual Book of ASTM Standards*, vol. 11.01.

[4] Available from American Concrete Institute, P O Box 19150, Ledford Station, Detroit, Michigan 48219.

[5] Formerly National Bureau of Standards

of concrete in batch as delivered. The mass per cubic yard or per cubic meter shall be determined in accordance with USBR 4138 from average of at least three measurements, each on a different sample. Each sample shall be taken from midpoint of each of three different truckloads by procedure of USBR 4172.

NOTE 1.-It should be understood that volume of hardened concrete may be, or appear to be, less than expected due to waste and spillage, overexcavation, spreading forms, some loss of entrained air, or settlement of wet mixtures.

4. Materials

4.1 In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

4.1.1 *Cement.*-Cement shall conform to ASTM C 150 or C 595. The Government shall specify type or types required; however, if no type is specified, the requirements of Type II cement as prescribed in ASTM C 150 shall apply.

NOTE 2.-These different cements will produce concretes of different properties and should not be used interchangeably.

4.1.2 *Aggregates.*-Aggregates shall conform to ASTM C 33, or to ASTM C 330 if lightweight concrete is specified, or as designated in the specifications.

4.1.3 *Water*:

4.1.3.1 Mixing water shall be clear and apparently clean. If water contains quantities of substances that cause discoloration, make the odor or taste unusual or objectionable, or cause any suspicion, water shall not be used unless service records of concrete made with such water or other information indicate that water is not injurious to quality of concrete. Water of questionable quality shall be subject to acceptance criteria in table 1.

4.1.3.2 Wash water from mixer washout operations may be used for mixing concrete provided tests of wash water comply with physical tests shown in table 1. The wash water shall be tested weekly for about 4 weeks, and then monthly provided no single test exceeds applicable limit (note 3). Optional chemical tests shown in table 2 may be specified when appropriate for the construction.

NOTE 3.-When recycled wash water is used, attention should be given to effects on dosage rate and batching sequence of air-entraining and other chemical admixtures. A uniform amount should be used in consecutive batches.

4.1.4 *Admixtures.*-Admixtures shall conform to ASTM C 260, C 494, or C 618, whichever is applicable.

5. Ordering Information

5.1 In the absence of designated applicable general specifications, the Government shall specify the following:

Table 1. - Acceptance criteria for questionable water supplies.

	Limits	Test designation[1]
Compressive strength, minimum percent of control at 7 days	90%	USBR 4109
Time-of-set, deviation from control	From 30 % earlier to 30 % later	USBR 4191

[1] Comparisons shall be based on fixed proportions and same volume of test water compared to control mix using city water or distilled water.

5.1.1 Designated size, or sizes, of coarse aggregate.

5.1.2 Slump, or slumps, desired at the point of delivery. For acceptance tolerances, see table 3.

5.1.3 Air content of samples taken from transportation unit at point of discharge. For recommended air contents and tolerances, see note 4 and table 4.

NOTE 4.-In selecting the specified air content, the exposure conditions to which concrete will be subjected should be considered. Air contents less than those shown in table 4 may not give required resistance to freezing and thawing, which is primary purpose of air-entrained concrete. Air contents higher than those shown in table 4 may reduce strength without contributing any further improvement of durability.

5.1.4 Which of the alternatives described in sections 5.2, 5.3, and 5.4 should be used as a basis for determining the proportions of concrete to produce required quality.

5.1.5 When structural lightweight concrete is specified, the density as wet mass, air-dry mass, or ovendry mass shall also be specified.

NOTE 5.-The density of fresh concrete, which is the only density determinable at time of delivery, is always higher than the air-dry or ovendry mass. Definitions of and methods for determining or calculating air-dry and ovendry masses are covered in ASTM C 567.

5.2 *Alternative No. 1*:

5.2.1 When the Government assumes responsibility for proportioning the concrete mixture, the Contracting Officer shall also specify the following:

5.2.1.1 Cement content in bags or in pound mass per cubic yard (kilograms per cubic meter) of concrete.

5.2.1.2 Maximum allowable water content in gallons or in pound mass per cubic yard (kilograms per cubic meter) of concrete, including surface moisture on aggregates but excluding water of absorption (note 6) or maximum allowable water-cement plus pozzolan ratio.

5.2.1.3 The type, name, and dosage of the admixtures to be used. The cement content shall not be reduced when admixtures are used under this alternative without written approval of the Government (note 7).

NOTE 6.-In selecting requirements for which the Contracting Officer assumes responsibility, consideration should be given to requirements for workability, placeability, durability, surface

Table 2. - Chemical limitations for mix water.

Chemical requirements, maximum concentration in mixing water[1]	Limits, mg/L	Test designation or standard[2]
Chlorine as Cl:		ASTM D 512
Prestressed pipe	100	
Prestressed concrete or in bridge decks	[3]500	
Other reinforced concrete in moist environments, containing aluminum embedments, dissimilar metals, or with stay-in-place galvanized metal forms	[3]1 000	
Sulfate as SO_4	3 000	USBR 3120
Alkalies as $Na_2O + 0.658\ K_2O$	600	ASTM D 1428
Total solids	50 000	USBR 3115

[1] Wash water, reused as mixing water in concrete, may exceed the listed concentrations of chloride and sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources, does not exceed the stated limits.

[2] Other test methods that have been demonstrated to yield comparable results may be used.

[3] For conditions allowing use of $CaCl_2$ accelerator as an admixture, the chloride limitation may be waived by the Government.

Table 3. - Allowable slumps for various types of construction.[1]

Type of construction	Slump, inches (mm)	
	maximum	minimum
Footings, caissons, and substructures	3 (76)	1 (25)
Beams and reinforced walls	4 (102)	1 (25)
Sidewalls and arch in tunnel linings	4 (102)	1 (25)
Tops of walls, piers, parapets, and curbs	2 (51)	1 (25)
Pavements, slabs, and tunnel inverts[2]	2 (51)	1 (25)
Canal linings[3]	3 (76)	1 (25)
Mass concrete, mass construction	2 (51)	1 (25)
Building columns	4 (102)	1 (25)
Other structures	3 (76)	1 (25)

[1] The maximum slumps are for concrete after placement and before consolidation, and for mixes having air contents given in table 4. For certain applications, the use of a HRWRA (high-range water reducing admixture) is allowed. If mix is properly designed to prevent segregation, a HRWRA can be used to produce flowing concrete with a maximum slump of 9 inches (229 mm); however, each use or application must be allowed in the specifications or approved by contracting officer.

[2] The slump of tunnel inverts placed monolithically with sidewalls and arch may be increased to a maximum of 4 inches (102 mm).

[3] On machine-placed canal lining less than 3 inches (76 mm) thick, the slump may be increased to a maximum of 4 inches (102 mm).

texture, and density, in addition to those for structural design. The Contracting Officer is referred to USBR 4211 and ACI Standards 211.1 and 211.2 for selection of proportions that will result in concrete suitable for various types of structures and conditions of exposure. The water-cement ratio of most structural lightweight concretes cannot be determined with sufficient accuracy for use as a specification basis.

NOTE 7.-In any given instance, the required dosage of air-entraining, accelerating, and retarding admixtures will vary; therefore, a range of dosages should be specified which will permit obtaining desired effect.

5.2.2 At the request of the Government, the manufacturer shall, prior to actual delivery of concrete, furnish a statement to the Contracting Officer giving the sources, specific gravities, and sieve analyses of the aggregates; the dry mass of cement, and saturated-surface-dry masses of fine and coarse aggregates; quantities, type, and name of admixtures; and the water per cubic yard or per cubic meter of concrete that will be used in the manufacture of each class of concrete ordered.

5.3 *Alternative No. 2*:

5.3.1 When the Government requires the manufacturer to assume full responsibility for selection of proportions for the concrete mixture (note 6), the Government shall also specify the following:

5.3.1.1 The required compressive strength as determined on samples taken from transportation unit at point of discharge evaluated in accordance with section 11.4. The Government shall also specify the requirements, in terms of compressive strength, of standard specimens cured under standard laboratory conditions for moist curing

Table 4. - Recommended total air content for air-entrained concrete.[1]

Nominal maximum size, inches	(mm)	Air content, percent
3/8	(9.5)	7.0
1/2	(12.5)	6.5
3/4	(19.0)	6.0
1	(25.0)	5.5
1-1/2	(37.5)	5.0
2	(50)	4.5
3	(75)	4.0
4	(100)	4.0
6	(150)	3.5

[1] Allowable tolerances are ±1.0 percent. An air content less than shown in table may not give required resistance to freezing and thawing, which is primary purpose of using air-entrained concrete. Air contents in excess of those shown in table may reduce the strength without contributing additional protection. However, strength reductions in lean mixtures, such as mass concrete containing 3-inch (75-mm) maximum size aggregate or larger, are minimized due to reduction in quantity of paste. Because of significant improvement of workability in lean mixtures, air entrainment is recommended when durability is not a consideration.

as detailed in USBR 4031. Unless otherwise specified, the age of specimens at time of testing shall be 28 days.

5.3.1.2 The expected concrete service conditions and requirements for durability.

5.3.2 At the request of the Government the manufacturer shall, prior to actual delivery of concrete, furnish a statement to the Contracting Officer giving the dry mass of cement; saturated-surface-dry masses of fine and coarse aggregates; quantities, type, and name of admixtures; and the water per cubic yard or per cubic meter of concrete that will be used in the manufacture of each class of concrete ordered. The manufacturer shall also furnish satisfactory evidence that materials to be used and proportions selected will produce concrete of quality specified.

5.4 *Alternative No. 3*:

5.4.1 When the Government specifies a minimum allowable cement content, and requires the manufacturer to assume responsibility for selection of proportions for concrete mixture (note 6), the Contracting Officer shall also specify the following:

5.4.1.1 The required compressive strength as determined on samples taken from transporation unit at point of discharge evaluated in accordance with section 11.4. The Government shall also specify the requirements, in terms of compressive strength, of standard specimens cured under standard laboratory conditions for moist curing as detailed in USBR 4031. Unless otherwise specified, the age of specimens at time of testing shall be 28 days.

5.4.1.2 Minimum cement content in bags or in pound mass per cubic yard (kilograms per cubic meter) of concrete.

5.4.1.3 The expected concrete service conditions and requirements for durability.

NOTE 8.-Alternative No. 3 can be distinctive and useful only if designated minimum cement content is at about the same level that would ordinarily be required for the strength and durability desired considering the aggregate size and slump specified.

5.4.2 At the request of the Government the manufacturer shall, prior to actual delivery of concrete, furnish a statement to the Contracting Officer giving the dry mass of cement; saturated-surface-dry masses of fine and coarse aggregates; the quantities, types, and names of admixtures; and the water per cubic yard or per cubic meter of concrete that will be used in the manufacture of each class of concrete ordered. The manufacturer shall also furnish satisfactory evidence that materials to be used and proportions selected will produce concrete of quality specified. Whatever strengths are attained, the quantity of cement used shall not be less than the minimum specified.

5.5 The proportions arrived at by Alternative No. 1, 2, or 3 for each class of concrete and approved for use in a project shall be assigned a designation to facilitate identification of each concrete mixture delivered to project. This is the designation required in section 12.1 to supply information on concrete proportions when they are not given separately on each delivery ticket as outlined in 12.2. A certified copy of all proportions, as established in Alternatives No. 1, 2, and 3, shall be on file at batch plant.

6. Measuring Materials

6.1 Except as otherwise specifically permitted, cement and pozzolan shall be measured by mass, which shall be determined on a scale and hopper that are separate and distinct from those used for other materials. If batch plant is equipped with automatic, interlocking, sequential batching controls, the cement and pozzolan masses may be determined cumulatively with one scale and hopper, provided this determination is automatically controlled within specified tolerances and the cement mass is determined first. If batch plant is not equipped as such, the cement and pozzolan masses shall be determined separately with individual scales and hoppers. When quantity of cement exceeds 30 percent of full capacity of scale, the quantity of cement and cumulative quantity of cement plus pozzolan shall be within ±1 percent of required mass. For smaller batches to a minimum of 1 yd^3 (0.8 m^3), the quantity of cement and quantity of cement plus pozzolan used shall be not less than required amount nor more than 4 percent in excess. Under special circumstances that have been approved by the Government, cement may be measured in bags of standard mass (note 9). No fraction of a bag of cement shall be used unless mass is determined.

NOTE 9.-In the United States, the standard mass of a bag of portland cement is 94 lbm (42.6 kg) ±3 percent.

6.2 Aggregate shall be measured by mass. Batch masses shall be based on SSD (saturated-surface-dry) materials, and shall be the mass of the material plus the moisture that is contained on the surface of the aggregate that is wetter than SSD or minus the moisture that is absorbed by aggregate that is drier than SSD. The quantity of aggregate used in any batch of concrete, as indicated by the scale, shall be within ±2 percent of required mass when determined in individual aggregate batchers capable of mass determination. In a cumulative aggregate batcher, the cumulative mass after each successive determination shall be within ±1 percent of required cumulative amount when scale is used in excess of 30 percent of its capacity. For cumulative masses less than 30 percent of scale capacity, the tolerance shall be ±0.3 percent of scale capacity or ±3 percent of required cumulative mass, whichever is less.

6.3 Mixing water shall consist of water added to batch, ice added to batch, water occurring as surface moisture on aggregates, and water introduced in the form of admixtures. This added water shall be measured by mass or volume to an accuracy of 1 percent of required total mixing water. Added ice shall be measured by mass. In the case of truck mixers, any wash water retained in drum for use in next batch of concrete shall be accurately measured. If this is impractical or impossible, wash water shall be discharged prior to loading next batch. Total water including any wash water shall be measured or the mass determined to an accuracy of ±1 percent of specified total amount. Each truck mixer shall be equipped with an accurate watermeter, located between supply tank and mixer, and having a dial or digital indicator and reliable revolution counter, located near watermeter, that can be readily reset to zero for indicating total number of revolutions of drum for each batch.

6.4 Powdered admixtures shall be measured by mass, and paste or liquid admixtures by mass or volume. The accuracy of mass determination and volumetric measurement shall be within ±3 percent of total amount required.

NOTE 10.–Mechanical-type admixture dispensers capable of adjustment for variation of dosage and of simple calibration are recommended.

7. Batching Plant

7.1 Storage bins with adequate separate compartments shall be provided for fine aggregate and for each required size of coarse aggregate.

7.1.1 Coarse aggregate shall be deposited in batch bins directly over discharge gates. Aggregate larger than 3/4-inch (19.0-mm) nominal size shall be deposited in batch bins through effective rock ladders unless it can be proven to Government's satisfaction that aggregate will not otherwise be subject to breakage, degradation, and segregation beyond limits allowable in specifications.

7.1.2 Each bin compartment shall be designed and operated to discharge efficiently and freely, with minimum segregation, into the hopper for determining mass. Control shall be provided so that, as quantity desired in hopper is approached, discharging material may be shut off with precision. Hoppers shall be constructed to eliminate accumulations of materials and to discharge fully.

7.2 Separate storage bins, not containing a common wall, shall be provided for cement and pozzolan. The bins shall be dry, weathertight, and properly ventilated. Bins shall be emptied, cleaned, and inspected annually by the manufacturer. Before a concrete placement is started, sufficient cement and pozzolan shall be in storage at batch plant to complete placement.

7.3 Indicating devices shall be in full view and near enough to operator to be read accurately by operator while charging the hopper. The operator shall have convenient access to all controls.

7.4 Scales for batching concrete ingredients may be either beam or springless dial scales and shall conform to applicable sections of current edition of the National Institute of Standards and Technology's *Handbook 44*, "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices." Methods for determining mass (electric, hydraulic, load cells, etc.) other than by beam or springless dial scales that meet all tolerances are also acceptable.

7.5 Scales in use shall be accurate, when static load tested, to ±0.4 percent over the working range. Adequate standard test masses shall be available for checking accuracy. All exposed fulcrums, clevises, and similar working parts of scales shall be kept clean, and periodic static tests shall be scheduled and performed to verify accuracy of equipment. Beam scales shall be equipped with a balance indicator sensitive enough to show movement when a mass equal to 0.1 percent of nominal capacity of scale is placed in batch hopper.

7.6 The clear interval for dial scales graduations shall be not less than 0.03 inch (0.76 mm). Each scale graduation shall indicate increments no greater than 2.5 lbm (1.13 kg) for water and cementitious materials, and no greater than 10 lbm (4.54 kg) for aggregate for each cubic yard or cubic meter normally batched. Each batch mass indicator and volumetric dispenser shall be in full view of operator. Batching controls shall be interlocked so that a new batch cannot be started until hoppers have been completely emptied of last batch and scales register zero mass.

7.7 The device for measurement of added water shall be capable of delivering to the batch the quantity required within the accuracy required in section 6.3. The device shall be so arranged that measurements will not be affected by variable pressures in water supply line. Measuring tanks shall be equipped with outside taps and valves to provide for checking their calibration unless other means are provided for readily and accurately determining amount of water in tank.

NOTE 11.–The scale accuracy limitations of the National Ready Mixed Concrete Association Plant Certification meet the requirements of USBR 4094.

8. Mixers and Agitators

8.1 Mixers may be stationary mixers or truck mixers. Agitators may be truck mixers or truck agitators.

8.1.1 Stationary mixers shall be equipped with a metal plate or plates on which are plainly marked the mixing speed of drum or paddles and maximum capacity, in terms of volume, of mixed concrete. When used for the complete mixing of concrete, stationary mixers shall be equipped with an acceptable timing device that will not permit batch to be discharged until specified mixing time has elapsed.

8.1.2 Each truck mixer or agitator shall have, attached in a prominent place, a metal plate or plates on which are plainly marked the gross volume of drum, capacity of drum or container in terms of volume of mixed concrete, and the minimum and maximum mixing rotational speed of drum, blades, or paddles. When concrete is truck mixed as described in 9.5 or shrink mixed as described in 9.4, the volume of mixed concrete shall not exceed 63 percent of total volume of drum or container. When concrete is central mixed as described in 9.3, the volume of concrete in truck mixer or agitator shall not exceed 80 percent of total volume of drum or container. The mixing speed shall not be less than 12 nor more than 22 r/min. Truck mixers and agitators shall be equipped such that the number of revolutions of drum, blades, or paddles may be readily verified.

8.2 All stationary and truck mixers shall be capable of combining the ingredients of the concrete, within specified time or within number of revolutions specified in 8.5, into a thoroughly mixed and uniform mass and of discharging the concrete so that not less than five of the six requirements shown in table X2.1 of appendix X2 shall have been met.

NOTE 12.–The sequence or method of charging the mixer has an important effect on uniformity of concrete.

8.3 The agitator shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as defined in appendix X2.

8.4 Slump tests on individual samples taken after discharge of about 15 and 85 percent of load may be made for a quick check of probable degree of uniformity (note 13). These two slump tests shall be obtained within an elapsed time of not more than 15 minutes. If slumps differ by more than that specified in table X2.1 (app. X2), the mixer or agitator shall not be used unless condition is corrected, except as provided in section 8.5.

NOTE 13.–No samples should be taken before 10 percent or after 90 percent of batch has been discharged. Because of the difficulty in determining actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not at the start or end of the load.

8.5 Use of the equipment may be permitted when operation with a longer mixing time, a smaller load, or a more efficient charging sequence will permit requirements of appendix X2 to be met.

8.6 Mixers and agitators shall be examined routinely and as frequently as necessary to detect changes in condition due to accumulations of hardened concrete or mortar and the wear of blades. When such changes are extensive enough to affect mixer performance, the proof-tests described in appendix X2 shall be performed to show whether correction of deficiencies is required.

9. Mixing and Delivery

9.1 Ready-mixed concrete shall be mixed and delivered to the point designated by the Government by one of the following combinations of operations:

- Central-Mixed Concrete
- Shrink-Mixed Concrete
- Truck-Mixed Concrete

9.2 Mixers and agitators shall be operated within limits of capacity and speed of rotation designated by manufacturer of equipment.

9.3 *Central-Mixed Concrete.*–Concrete that is mixed completely in a stationary mixer and transported to point of delivery in a truck agitator, a truck mixer operating at agitating speed, or in nonagitating equipment approved by the Government and meeting requirements of section 10, shall conform to the following: Mixing time shall be counted from time all materials are in the drum. The batch shall be so charged into mixer that some water will enter before cement and aggregate, and all water shall be in drum by end of first one-fourth of specified mixing time, with the exception that about 5 percent of total water may be withheld until just prior to placement.

9.3.1 When no mixer performance tests have been made, the minimum acceptable mixing time shall not be less than 2-1/2 minutes.

9.3.2 Where mixer performance tests have been made on given concrete mixtures in accordance with testing program set forth in the following sections and mixers have been charged to their rated capacity, the acceptable mixing time may be reduced for those particular circumstances to a point at which satisfactory mixing, as defined in 9.3.3, shall have been accomplished. For air-entrained concrete, when shortened mixing time (9.3.3) is the acceptable minimum mixing time, the maximum mixing time shall not exceed the minimum mixing time by more than 60 seconds.

9.3.3 *Sampling for Uniformity Tests of Stationary Mixers.*–Samples of concrete for comparative purposes shall be obtained immediately after one of the arbitrarily designated mixing times described in the following procedures:

9.3.3.1 *Alternative Procedure 1.*–Mixer shall be stopped and required concrete samples removed at approximately equal distances from front and back of drum.

9.3.3.2 *Alternative Procedure 2.*–As mixer is being emptied, individual samples shall be taken after discharge of about 15 and 85 percent of load. Any appropriate method of sampling may be used provided samples are representative of widely separated portions and not from start or end of load (note 13).

9.3.3.3 Samples shall be tested in accordance with USBR 4039, and any differences in test results between the two samples shall not exceed the limits shown in appendix X2. Mixer performance tests shall be repeated whenever appearance of concrete or the coarse aggregate content of samples selected as outlined in this section indicates that adequate mixing has not been accomplished.

9.4 *Shrink-Mixed Concrete.*–Concrete that is first partially mixed in a stationary mixer and then mixed completely in a truck mixer, shall conform to the following: The time of partial mixing shall be the minimum required to intermingle the ingredients. After transfer to a truck mixer, amount of mixing time at designated mixing speed will be that necessary to meet requirements for uniformity as stated in appendix X2. Tests to confirm such performance may be made in accordance with sections 9.3.3 and 9.3.3.3. Additional turning of mixer, if any, shall be at a designated speed.

9.5 *Truck-Mixed Concrete.*–Truck-mixed concrete is concrete that is completely mixed in a truck mixer for 70 to 100 revolutions at mixing speed designated by manufacturer to produce uniformity of concrete as indicated in appendix X2. Concrete uniformity tests may be made in accordance with 9.5.1. If requirements for uniformity (app. X2) are not met with 100 revolutions of mixing after all ingredients, with the exception of about 5 percent of the water (sec. 9.3), are in drum, the mixer shall not be used until condition is corrected, except as provided in 8.5. When satisfactory performance is found with one truck mixer, the performance of other mixers of same design and condition of blades may be regarded as satisfactory. Additional revolutions of mixer exceeding the number found to produce required uniformity shall be at a designated speed.

9.5.1 *Sampling for Uniformity of Concrete Produced in Truck Mixers.*–The concrete shall be discharged at normal operating rate for mixer being tested, using care not to obstruct or retard the discharge by a partially opened gate or seal. Samples, each of about 2 ft^3 (0.06 m^3), shall be taken after discharge of about 15 and 85 percent of load (note 13). These samples shall be obtained within an elapsed time of not more than 15 minutes. Samples shall be secured in accordance with USBR 4172; however, they shall be kept separate to represent specific points in batch rather than combined to form a composite sample. Between samples, when necessary to maintain slump, the mixer may be turned in the mixing direction at agitating speed. During sampling, the receptacle shall receive the full discharge of the chute. Sufficient personnel should be available to perform the required tests promptly. Segregation during sampling and handling should be held to the minimum practicable and each sample should be remixed the minimum amount to ensure uniformity before the specimens are molded for a particular test.

9.5.2 When bulk cementitious materials and aggregates are dry batched and hauled to placement, each batch shall be protected during transit to prevent spillage or wind loss and to limit prehydration of the cementitious materials. Separate compartments with suitable covers shall be provided to protect cementitious materials, or they should be completely enfolded in or covered by aggregates to prevent wind loss. If cementitious materials are enfolded in moist aggregates or otherwise exposed to moisture, and delays occur between batching and mixing; the contractor shall, at his own expense, add extra cement and pozzolan to each batch in accordance with table 5.

Table 5. – Additional cementitious materials requirements.

Hours of contact between cementitious materials and wet aggregate[1]	Percentage of additional cementitious materials required
0 to 2	0
2 to 3	5
3 to 4	10
4 to 5	15
5 to 6	20
Over 6	Batch shall be rejected

[1] The Government reserves the right to require the addition of cementitious materials for shorter periods of contact during hot weather, and contractor shall be entitled to no additional compensation for such an addition.

9.6 When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed in a stationary mixer, any turning during transportation shall be at speed designated by manufacturer of equipment as agitating speed.

9.7 When a truck mixer or agitator is approved for mixing or delivery of concrete, no water from truck water system or elsewhere shall be added after initial introduction of mixing water for the batch except when, on arrival at jobsite, the slump of the concrete is less than specified. Then, such additional water to bring slump within required limits (tempering water withheld in accordance with 9.3) shall be injected into mixer under such pressure and direction of flow that requirements for uniformity (app. X2) are met; provided, that in no case shall design water content be exceeded. The drum or blades shall be turned an additional 30 revolutions or more, at mixing speed, until uniformity of concrete is within these limits. Water shall not be added to the batch at any later time. Discharge of the concrete shall be completed before the drum has revolved 300 revolutions, or within 1-1/2 hours after introduction of mixing water and cementitious materials. These limitations may be waived by the Government if concrete is of such slump, after the 1-1/2-hour time limit has been reached, that concrete can be placed without the addition of water to the batch. In hot weather, or under conditions contributing to quick stiffening of the concrete, a time limit less than 1-1/2 hours may be specified by the Government.

9.8 Fresh concrete shall be placed at the temperature specified in the contract. Temperature will be determined by placing a thermometer in the concrete immediately after sampling at placement site. Then, temperature of concrete at batch plant shall be adjusted to assure that specified concrete temperature is attained at placement.

9.8.1 Concrete ingredients shall be heated as necessary; however, they shall not be heated to a temperature higher than necessary to keep temperature of mixed concrete, as placed, from falling below specified minimum temperature. Methods of heating concrete ingredients shall be subject to approval.

9.8.2 The contractor shall use effective means, such as precooling of aggregates and mixing water, placing at night, incorporating flake or chip ice in mix, or induction of liquid nitrogen, as necessary, to maintain temperature of concrete, as placed, below specified maximum. Methods of cooling shall be as approved or directed by the Government.

NOTE 14.–When hot water is used, rapid stiffening may occur if water is brought into direct contact with cement. Additional information on cold-weather concreting is contained in ACI 306R.

NOTE 15.-Additional information on hot-weather concreting is contained in ACI 305R.

10. Use of Nonagitating Equipment

10.1 Central-mixed concrete may be transported in suitable nonagitating equipment approved by the Government. The proportions of the concrete shall be approved by the Government, and the following limitations shall apply:

10.1.1 Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that permit control of discharge of concrete. Container covers shall be provided for weather protection, as necessary.

10.1.2 Concrete shall be delivered to worksite in a thoroughly mixed and uniform mass, and discharged with a satisfactory degree of uniformity as prescribed in appendix X2.

10.1.3 Slump tests of individual samples taken after discharge of about 15 and 85 percent of load may be made for a quick check of probable degree of uniformity (note 13). These two test samples shall be obtained within an elapsed time of not more than 15 minutes. If slumps differ by more than that specified in table X2.1 (app. X2), the nonagitating equipment shall not be used unless conditions are corrected as provided in section 10.1.4.

10.1.4 If requirements of appendix X2 are not met when nonagitating equipment is operated for maximum time of haul and concrete has been mixed for the minimum time, the equipment may still be used for shorter hauls, longer mixing times, or combinations thereof that will result in meeting the requirements of appendix X2.

11. Inspection of Materials, Production, Delivery, and Concrete

11.1 *Access.*-The manufacturer shall afford the Government all reasonable access, without charge, for making necessary checks of facilities and equipment and for securing necessary samples to verify that concrete is being produced in accordance with these specifications. Tests and inspections shall be so conducted as not to interfere unnecessarily with the manufacture and delivery of the concrete.

11.2 *Sampling Equipment.*-The contractor shall provide mechanical sampling devices for safely procuring and handling representative test samples of aggregates and other concrete materials during batching. At central-mix plants, the contractor shall also provide mechanical sampling devices for obtaining representative concrete samples from a point in the discharge stream as concrete is discharged from mixers. In addition, ample and protected working space near the batch plant site shall also be provided for conducting quality control testing.

11.3 *Slump and Air Content.*-Slump and air content tests shall be performed, as necessary, in accordance with USBR 4143 and 4173. If measured slump of air content falls outside specified limits, a check test shall be made immediately on another portion of same sample. In the event of a second failure, concrete shall be considered to have failed requirements of these specifications.

11.3.1 Concrete shall be available within the permissible range of slump and total air content for 30 minutes from time of arrival at jobsite or 30 minutes after initial slump adjustment permitted in section 9.7, whichever is later. The first and last 0.25 yd^3 (0.2 m^3) discharged are exempt from this requirement. If contractor is unprepared for discharge of concrete from vehicle, the Government shall not be responsible for the limitation of minimum slump and air content after the 30-minute time limit has elapsed.

11.3.2 Uniformity in concrete consistency from batch to batch is required. To maintain concrete at proper consistency, the amount of water and sand batched for concrete shall be adjusted to compensate for variations in moisture content or grading of aggregates as they enter mixer. Also, the amount of air-entraining admixture shall be adjusted to obtain specified total air content.

11.3.3 *Slump Test.*-Unless other tolerances are included in project specifications, the allowable slump shall be as shown in table 3. The Government reserves the right to require a lesser slump whenever concrete of such lesser slump can be consolidated readily into place by vibration.

11.3.3.1 The use of buckets, chutes, hoppers, pumps, transit-mix trucks, or other equipment which will not readily handle and place concrete of specified slump will not be permitted.

11.3.3.2 Addition of water to compensate for stiffening of concrete after mixing, known as retempering, will not be permitted.

11.3.3.3 The maximum allowable slump loss from time concrete has been mixed until placement is 2 inches (51 mm).

11.3.4 *Air Content Test.*-Unless other tolerances are included in project specifications, the allowable total air content shall be as shown in table 4.

11.4 *Strength.*-When strength is used as a basis for acceptance of concrete, standard specimens shall be made in accordance with USBR 4031. The specimens shall be cured under standard moisture and temperature conditions in accordance with sections 9.5.2 and 9.5.3 of USBR 4031.

11.4.1 Strength tests, as well as slump and air content tests, shall generally be made with the frequency shown in section 4.1.1 of USBR 4031 or note 5 of USBR 4192.

11.4.2 A strength test is defined as "the average strength of all specimens of same age fabricated from a sample taken from a single batch of concrete, or from opposite ends of mixer when performing concrete uniformity tests for acceptability of mixers or agitators." For the strength test, a minimum of two standard test specimens shall be made from a sample obtained as required in sections 9.3, 9.4, and 9.5. The test shall be the average of strengths of two specimens tested at age specified in 5.3.1 or 5.4.1 (note 16). If either specimen shows definite evidence, other than low strength, of improper sampling, molding, handling, curing, or testing, specimen shall be discarded and the strength of remaining specimen shall be considered to be the test result.

NOTE 16.-Additional tests may be made at other ages to obtain information on adequacy of strength development or to check adequacy of curing and protection of the concrete. Specimens made to check adequacy of curing and protection should be cured in accordance with section 9.5.4 of USBR 4031.

11.4.3 The Government shall ascertain and record the delivery ticket number for the concrete and the location in the work at which each load represented by a strength test is deposited.

11.4.4 To conform to requirements of these specifications, the average of all strength tests (sec. 11.4.2) representing each class of concrete shall be sufficient to ensure that the following requirements (notes 17 and 18) are met:

11.4.4.1 For concrete in structures designed by working stress method and all construction other than that covered in 11.4.4.2, not more than 20 percent of strength tests shall have values less than specified strength, f_c', and the average of any six consecutive strength tests (note 17) shall be equal to or greater than specified strength.

11.4.4.2 For concrete in structures designed by ultimate strength method and in prestressed structures, not more than 10 percent of strength tests shall have values less than specified strength, f_c', and the average of any three consecutive strength tests (note 18) shall be equal to or greater than specified strength.

NOTE 17.-Because of variations in materials, operations, and testing, the average strength necessary to meet these requirements will be substantially higher than specified strength. The amount higher increases as these variations increase, and decreases as variations decrease. This is a function of the coefficient of variation and other factors of control as explained in ACI 214. Pertinent data are shown in tables 6 and 7.

NOTE 18.-When number of tests made of any class of concrete totals six or less, the average of all tests shall be equal to or greater than value shown in table 8.

11.4.4.3 *Failure to Meet Strength Requirements.*- If concrete tested in accordance with requirements of section 11.4 fails to meet strength requirements, the manufacturer of the concrete and the Government shall confer to determine whether agreement can be reached as to what adjustment, if any, shall be made.

12. Batch Ticket Information

12.1 The manufacturer of commercial ready-mix concrete shall furnish to the Government, with each batch of concrete before unloading at the site, a delivery ticket on which is printed, stamped, or written, information concerning the concrete as follows:

- Name of ready-mix batch plant.
- Date and serial number of ticket.
- Truck number.
- Name of purchaser.
- Specific designation of job (name and location).
- Specific class or designation of concrete in conformance with that used in job specifications.
- Amount of concrete in cubic yards (cubic meters).
- Time loaded or of first mixing of cement and aggregates.
- Water added by receiver of concrete and receiver's initials.

12.2 Additional information for certification purposes as designated by the Government and required by job specifications shall be furnished when requested; such information may include:

- Reading of revolution counter at first addition of water.
- Type, brand, and amount of cement.
- Type, brand, and amount of admixtures.
- Information necessary to calculate total mixing water added by manufacturer, which would include free water on aggregates or water absorbed by aggregates drier than SSD, water and ice batched at plant, and water added by truck operator from mixer tank.
- Maximum size of aggregate.
- Mass of fine and coarse aggregate.
- Ingredients certified as being previously approved.
- Signature or initials of ready-mix representative.

Table 6. - Values of student's t^1.

	Percentage of tests falling within limits of $\bar{x} \pm t$								
	40	50	60	70	80	90	95	98	99
	Chances of falling below lower limit								
	3 in 10	2.5 in 10	2 in 10	1.5 in 10	1 in 10	1 in 20	1 in 40	1 in 100	1 in 200
	Percentage of strength greater than design strength								
	70	75	80	85	90	95	97.50	99	99.50
[2]1									
2	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
3	.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
4	.584	.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841
5	.569	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604
6	.559	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032
7	.553	.718	.906	1.134	1.440	1.943	2.447	3.143	3.707
8	.549	.711	.896	1.119	1.415	1.895	2.365	2.998	3.499
9	.546	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355
10	.543	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250
11	.542	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169
12	.540	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106
13	.539	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055
14	.538	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012
15	.537	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977
16	.536	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947
17	.535	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921
18	.534	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898
19	.534	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878
20	.533	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861
21	.533	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845
22	.532	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831
23	.532	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819
24	.532	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807
25	.531	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797
26	.531	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787
27	.531	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779
28	.531	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771
29	.530	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763
30	.530	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756
31	.530	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750
∞	.524	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576

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[1] This table was abridged from table IV of *Statistical Methods for Research Workers*, by R. A. Fisher, published by Oliver and Boyd, Ltd., Edinburgh.

[2] This column was originally established to reflect degrees of freedom ($n - 1$), and has been shifted to reflect the actual number of cylinders (n).

[3] $\bar{x}$ = average of test results.

Table 7a. - Average strength that must be maintained to meet design requirements (inch-pound units).

Design strength (f_c') lbf/in²	Percent of strength greater than design strength	Average strength required (f_{cr}) in lbf/in² so that 75, 80, 85, or 90 percent of tests are greater than design strength (f_c')[1]				
		Coefficient of variation, percent				
		5	10	15	20	25
2,000	75	2,070	2,150	2,230	2,320	2,410
	80	2,090	2,190	2,290	2,410	2,540
	85	2,110	2,240	2,380	2,530	2,720
	90	2,140	2,300	2,490	2,710	2,980
2,500	75	2,590	2,680	2,790	2,900	3,010
	80	2,610	2,730	2,870	3,010	3,180
	85	2,640	2,790	2,970	3,170	3,400
	90	2,680	2,880	3,110	3,390	3,720
3,000	75	3,110	3,220	3,340	3,470	3,620
	80	3,130	3,280	3,440	3,620	3,810
	85	3,170	3,350	3,560	3,800	4,070
	90	3,210	3,450	3,730	4,070	4,460
3,500	75	3,620	3,760	3,900	4,050	4,220
	80	3,660	3,830	4,010	4,220	4,450
	85	3,690	3,910	4,160	4,440	4,750
	90	3,750	4,030	4,360	4,740	5,210
4,000	75	4,140	4,290	4,460	4,630	4,820
	80	4,180	4,370	4,590	4,820	5,090
	85	4,220	4,470	4,750	5,070	5,430
	90	4,280	4,600	4,980	5,420	5,950
4,500	75	4,660	4,830	5,010	5,210	5,430
	80	4,700	4,920	5,160	5,430	5,720
	85	4,750	5,030	5,350	5,700	6,110
	90	4,820	5,180	5,600	6,100	6,690
5,000	75	5,180	5,370	5,570	5,790	6,030
	80	5,220	5,470	5,730	6,030	6,360
	85	5,280	5,590	5,940	6,340	6,790
	90	5,350	5,750	6,220	6,780	7,440
5,500	75	5,690	5,900	6,130	6,370	6,630
	80	5,750	6,010	6,310	6,630	6,990
	85	5,810	6,150	6,530	6,970	7,470
	90	5,890	6,330	6,850	7,450	8,180
6,000	75	6,210	6,440	6,680	6,950	7,240
	80	6,270	6,560	6,880	7,240	7,630
	85	6,330	6,710	7,130	7,600	8,150
	90	6,420	6,910	7,470	8,130	8,930

[1] See appendix X1 for an explanation on how the f_{cr} values were calculated.

Table 7b. – Average strength that must be maintained to meet design requirements (SI-metric units).

Design strength (f_c') MPa	Percent of strength greater than design strength	Average strength required (f_{cr}) in MPa so that 75, 80, 85, or 90 percent of tests are greater than design strength (f_c')[1]				
		Coefficient of variation, percent				
		5	10	15	20	25
10	75	10.35	10.75	11.15	11.60	12.05
	80	10.45	10.95	11.45	12.05	12.70
	85	10.55	11.20	11.90	12.65	13.60
	90	10.70	11.50	12.45	13.55	14.90
15	75	15.55	16.10	16.70	17.35	18.10
	80	15.65	16.40	17.20	18.10	19.05
	85	15.85	16.75	17.80	19.00	20.35
	90	16.05	17.25	18.65	20.35	22.30
20	75	20.70	21.45	22.30	23.15	24.10
	80	20.90	21.85	22.95	24.10	25.45
	85	21.10	22.35	23.75	25.35	27.15
	90	21.40	23.00	24.90	27.10	29.75
25	75	25.90	26.85	27.85	28.95	30.15
	80	26.10	27.35	28.65	30.15	31.80
	85	26.40	27.95	29.70	31.70	33.95
	90	26.75	28.75	31.10	33.90	37.20
30	75	31.05	32.20	33.40	34.75	36.20
	80	31.35	32.80	34.40	36.20	38.15
	85	31.65	33.55	35.65	38.00	40.75
	90	32.10	34.55	37.35	40.65	44.65
35	75	36.25	37.55	39.00	40.55	42.20
	80	36.55	38.25	40.15	42.20	44.50
	85	36.95	39.15	41.60	44.35	47.55
	90	37.45	40.30	43.55	47.45	52.05
40	75	41.40	42.95	44.55	46.35	48.25
	80	41.80	43.75	45.90	48.25	50.85
	85	42.25	44.70	47.50	50.70	54.35
	90	42.80	46.05	49.80	54.20	59.50
45	75	46.60	48.30	50.15	52.10	54.25
	80	47.00	49.20	51.60	54.25	57.20
	85	47.50	50.30	53.45	57.05	61.10
	90	48.15	51.80	56.00	61.00	66.95
50	75	51.75	53.65	55.70	57.90	60.30
	80	52.25	54.65	57.35	60.30	63.55
	85	52.80	55.90	59.40	63.35	67.90
	90	53.50	57.55	62.25	67.75	74.40

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[1] See appendix X1 for an explanation on how the f_{cr} values were calculated.

Table 8. - Required average strength (f_{cr}) of concrete for six or less tests.

Number of tests	Required average strength (f_{cr}) of consecutive tests[1]	
	Section 11.4.4.1	Section 11.4.4.2
1	0.85 f_c'	0.90 f_c'
2	0.92 f_c'	0.98 f_c'
3	0.95 f_c'	1.02 f_c'
4	0.97 f_c'	1.04 f_c'
5	0.99 f_c'	1.06 f_c'
6	1.00 f_c'	1.07 f_c'

[1] No explanation can be offered for the discrepancy in the factors of f_c' shown as compared to those shown in ASTM C 94.

NOTE: The following equation was furnished by the ASTM Chairman of Subcommittee C09.03.09:

$$f_{cr} = (f_c' + ts) - \frac{F(z)s}{n^{1/2}}$$

where:

$f_{cr} = \bar{x}$, which is the average strength required to ensure that a minimum of a certain percentage of tests exceed f_c',
f_c' = design strength specified,
t = student's t for infinite number of specimens,
$s = \sigma$, the standard deviation, which is obtained by dividing sum of squares of individual strengths by n, subtracting square of their average, and extracting the square root:

$$s = \frac{x_1^2 + x_2^2 + \ldots + x_n^2 - \bar{x}^2}{n}^{1/2}$$

Also, $s = V\bar{x}$, where V is the coefficient of variation expressed as a decimal equivalent. Average Bureau control is obtained when V is no more than 15 percent.

$$V \text{(percent)} = \frac{\sigma}{\bar{x}}(100), \text{ equation 3-3 of ACI 214-77, or}$$

$$= \frac{s}{f_{cr}}(100)$$

$F(z)$ = normal distribution function, which is the strength level below which the average of n tests would be expected to fall only 2 percent of the time; e.g., $F(z)$ for $z = 2.0 = 2.0/0.9772 = 2.0467$.
n = number of tests, which would generally be considered to be a minimum of two specimens; however, under section 11.4.2, could easily be one cylinder per test.

APPENDIX

X1. CALCULATION OF AVERAGE STRENGTH VALUES
(Nonmandatory Information)

X1.1 The average strengths required (f_{cr}), shown on tables 7a and 7b, were computed from equation 4-1 (ACl 214-77) using values of student's t for 30 samples from table 4.1 (ACl 214-77), and from t values extracted from the table originally produced by Fisher and Yates, "Statistical Tables for Biological Agriculture and Medical Research," refer to table 6.

X1.2 An example of the computations for f_{cr} follows.

Given:

f_c' = 3,000 lbf/in^2 (for structures designed by working stress method),
f_{cr} = strength required to ensure that 80 percent of tests exceed f_c',
V = coefficient of variation of 15 percent expressed as a decimal equivalent (0.15), and
t = a constant depending on number of tests that may fall below f_c' (the Bureau previously based this t value on 10 compressive strength values; however, we now base the t value on 30 compressive strength values). From table 6, $t = 0.854$.

Determine f_{cr}:

$$f_{cr} = \frac{f_c'}{1 - tV}$$

$$= \frac{3{,}000}{1 - (0.854)\,(0.15)} = \frac{3{,}000}{0.8719} = 3{,}441 \text{ lbf/in}^2$$

If $f_c' = 20$ MPa in this example,

$$f_{cr} = \frac{20}{1 - (0.854)\,(0.15)} = \frac{.20}{0.8719}$$
$$= 22.94 \text{ MPa}$$

The values shown in tables 7a and 7b were rounded to the nearest 10 lbf/in^2 and 0.05 MPa, respectively; therefore, these example values would be rounded to 3,440 lbf/in^2 and 22.95 MPa.

APPENDIX

X2. CONCRETE UNIFORMITY AND MIXER PERFORMANCE REQUIREMENTS
(Mandatory Information)

X2.1 The variation within a batch, as shown in table X2.1, shall be determined for each property listed as the difference between the highest and lowest value, or from averages obtained from different portions of same batch. For this determination, the comparison will be between two samples, representing the first and last portions of batch being tested. Test results conforming to the limits of five of the six tests listed in table X2.1 shall indicate uniformly mixed concrete within limits of these specifications.

X2.2 The coarse aggregate content, using the washout test, shall be computed as described in sections X2.2.1 and X2.2.2.

X2.2.1 Using a density container or an air meter of sufficient capacity:

$$M = \frac{c}{V}\text{ , or} \tag{1}$$

$$P = \frac{c}{b}\,(100) \tag{2}$$

where:

M = mass of coarse aggregate, in pound mass (kilograms) per cubic foot (cubic meter) of concrete;
P = mass percent of coarse aggregate in concrete;
c = saturated-surface-dry mass in air, in pound mass (kilograms), of aggregate retained on the No. 4 (4.75-mm) sieve, resulting from washing all material finer than this sieve from the fresh concrete;
b = mass of sample in air, in pound mass (kilograms), of fresh concrete in density container or air-meter pot; and
V = volume of sample, in cubic feet (cubic meters), in density container or air-meter pot (this includes the volume occupied by air).

If M is computed from a submerged mass:

$$M = M_s\left(\frac{G_1 + G_2}{(G_1 + G_2) - 1}\right) \tag{3}$$

where:

M_s = submerged mass of coarse aggregate, No. 4 to 3/4-inch (4.75- to 19.0-mm), fraction from the density container or air-meter pot, in pound mass (kilograms);
G_1 = specific gravity of the No. 4 to 3/4-inch coarse aggregate fraction multiplied by its proportional amount of coarse aggregate in concrete mix, and

Table X2.1. – Requirements for uniformity of concrete and mixer performance.

Test	Requirement expressed as maximum permissible difference in results or averages of tests of samples taken from two locations in concrete batch
1. Density calculated to an air-free basis (total mix)	1.0 lbm/ft^3 (16 kg/m^3)
2. Air content (volume percent of concrete)	1.0 percent
3. Slump:	
4 inches (102 mm) or less (average)	1.0 inch (25 mm)
4 to 6 inches (102 to 152 mm) (average)	1.5 inches (38 mm)
4. Coarse aggregate content, retained on a No. 4 (4.75-mm) sieve (total mix):	5.0 percent
5. Variation in density of air-free mortar in pound mass per cubic foot (kilograms per cubic meter) from average	0.8 percent
6. Average compressive strength at 7 days for each sample based on average strength of all comparative test specimens[1]	7.5 percent[2]

[1] Not less than three cylinders shall be molded and tested from each of the samples.

[2] Tentative approval of mixer may be granted pending results of 7-day compressive strength tests.

G_2 = specific gravity of the 3/4- to 1-1/2-inch (19.0- to 37.5-mm) aggregate fraction multiplied by its proportional amount of coarse aggregate in concrete mix.

X2.2.2 Using an air meter or density container restricted to a maximum size aggregate of 1-1/2 inches (37.5 mm) and wet-screening sample to remove coarse aggregate larger than 1-1/2 inches, mass of total coarse aggregate per cubic foot or per cubic meter is:

$$M = \frac{c + \left(\frac{S-T}{T}\right) b}{V + \left(\frac{S-T}{T}\right)\left(\frac{b}{62.4\,G_3}\right)} \quad \text{(inch-pound units)} \quad (4)$$

$$M = \frac{c + \left(\frac{S-T}{T}\right) b}{V + \left(\frac{S-T}{T}\right)\left(\frac{b}{1000\,G_3}\right)} \quad \text{(SI-metric units)} \quad (5)$$

where:

S = mass of total sample, in pound mass (kilograms), before wet screening;

T = mass of portion of sample, in pound mass (kilograms), passing through the 1-1/2-inch (37.5-mm) sieve;

G_3 = specific gravity of the plus 1-1/2-inch (+37.5-mm) material, and

Other terms as previously defined.

NOTE X2.1.–The term $(S - T/T)\ b$ in equations (4) and (5) is the mass of coarse aggregate larger than 1-1/2 inches (37.5 mm) required in density container or air-meter pot samples to represent original concrete. The density of full mix can be computed by dividing total mass of density container or air-meter pot sample and mass of plus 1-1/2-inch material required to represent original samples, by volume of density container or air-meter pot sample and volume of plus 1-1/2-inch material computed from its mass and specific gravity.

X2.3 The density of the air-free mortar shall be calculated:

$$D = \frac{b-c}{V - \left(\frac{VA}{100} + \frac{c}{62.4G_4}\right)} \quad \text{(inch-pound units)} \quad (6)$$

$$D = \frac{b-c}{V - \left(\frac{VA}{100} + \frac{c}{1000G_4}\right)} \quad \text{(SI-metric units)} \quad (7)$$

where:

D = density of air-free mortar, in pound mass per cubic foot (kilograms per cubic meter);

A = air content of concrete, in percent, measured in accordance with USBR 4173 or 4231 on sample being tested;

G_4 = $G_1 + G_2 + G_3$ (computed specific gravity of total coarse aggregate); and

Other terms as previously defined.

X2.4 *Calculations and Report.*–Calculations are covered under this appendix. Figure X2.1 shows a typical calculation and reporting form.

Spec. or Solic. No. DC-7612	Structure DAM	Tested by D. MOOTER Date 7-9-85
Project PECOS RIVER	Item —— Location ——	Computed by D. MOOTER Date 7-9-85
Feature BRANTLEY DAM	Station —— Offset —— Depth —— to ——	Checked by D. ARTER Date 7-10-85

MIXER PERFORMANCE TEST

Plant: MONTEREY CONST. Mixer: #7 EAST Shift: DAY Time: 1400
Mix No.: M4-3050-2P Batch No.: NA Mixing Time, sec.: 120* MSA: 4 inches
Specific Gravity: No. 4 to 1-1/2 inches 2.76 1-1/2 to 4 inches 2.75 *90% ICE

NOTE: The percent material retained on the 1-1/2-inch sieve is based on the minus 1-1/2-inch fraction rather than on the total sample for these calculations.	Sample from front of mixer		Sample from back of mixer		Maximum variation allowed
	Mass, lbm	Volume, ft³	Mass, lbm	Volume, ft³	
(1) Mass of sample (Test Result)	155.87		155.33		
(2) Mass of material retained on a 1-1/2-inch sieve (Test Result)	45.83		39.89		
(3) Difference in mass, (1) - (2)	110.04		115.44		
(4) Material retained on 1-1/2-inch sieve, [(2)/(3)](100), percent	41.65 %		34.55 %		ok
(5) Slump, inches	1¾ inch(es)		1¾ inch(es)		0-4 in, 1.0 in 4-6 in, 1.5 in
(6) Mass and volume of samples in air meter (Test Result)	38.06	0.2495	38.60	0.2495	
(7) Air Content by meter (Test Result), percent	3.80 %		3.50 %		ok 1%
(8) Volume of Air, (7) × (6) vol.		0.0095		0.0087	
(9) Mass and volume of air-free sample, (6) mass and (6) vol. - (8)	38.06	0.2400	38.60	0.2408	
(10) Submerged mass of material retained on No. 4 sieve (Test Result)	12.17		12.12		
(11) SSD mass of material retained on No. 4 sieve, (10) × sp. gr./(sp. gr. - 1)	19.08		19.01		
(12) Solid volume of material retained on No. 4 sieve, (11)/(sp. gr. × 62.4)		0.1108		0.1104	
(13) Mass representing mortar in sample, (6) mass - (11)	18.98		19.59		
(14) Volume representing mortar in sample, (9) vol. - (12)		0.1292		0.1304	1.12
(15) Density of air-free mortar, (13)/(14), lbm/ft³	146.90 lbm/ft³		150.23 lbm/ft³		0.8 % from avg.
(16) Mass of material retained on 1-1/2-inch sieve for meter sample to represent a full mix, (4) × (6) mass	15.85		13.34		
(17) Solid volume of material retained on 1-1/2-inch sieve for meter sample to represent a full mix, (16)/(sp. gr. × 62.4)		0.0924		0.0777	
(18) Density of full mix, (6) mass + (16)/(6) vol. + (17), lbm/ft³	157.68 lbm/ft³		158.74 lbm/ft³		
(19) Total coarse aggregate in meter sample and plus 1-1/2-inch sieve material to represent full mix, (11) + (16)	34.93		32.35		
(20) Total coarse aggregate per cubic foot of concrete, vol. (19)/(6) + (17)	102.16		98.87		
(21) Mass of coarse aggregate in concrete, [(20)/(18)] × 100, percent	64.79 %		62.28 %		ok 5 %
(22) Density calculation to an air-free basis, (18)/(1.00 - (7)), lbm/ft³	163.91 lbm/ft³		164.50 lbm/ft³		ok 1 lbm/ft³
(23) Compressive strength at 7 days, lbf/in²	2,650	2,740	2,680	2,665	7.5 % from avg.
	2,735	Avg. 2,710	2,715	Avg. 2,690	ok 0.37

Figure X2.1a. - Data for mixer efficiency determination (inch-pound units).

Spec. or Solic. No. DC-7612	Structure DAM	Tested by D. MOOTER Date 7-17-85
Project PECOS RIVER	Item ~ Location ~	Computed by D. MOOTER Date 7-17-85
Feature BRANTLEY DAM	Station ~ Offset ~ Depth ~ to ~	Checked by D. ARTER Date 7-18-85

MIXER PERFORMANCE TEST

Plant: MONTEREY CONST. Mixer: #2 WEST Shift: DAY Time: 1515
Mix No.: M4-3050-2P Batch No.: NA Mixing Time, sec.: 120* MSA: 102 mm
Specific Gravity: 4.75 to 37.5 mm 2.76 37.5 to 102 mm 2.75 *90% ICE

NOTE: The percent material retained on the 37.5-mm sieve is based on the minus 37.5-mm fraction rather than on the total sample for these calculations.	Sample from front of mixer		Sample from back of mixer		Maximum variation allowed
	Mass, kg	Volume, m^3	Mass, kg	Volume, m^3	
(1) Mass of sample (Test Result)	70.79		69.42		
(2) Mass of material retained on a 37.5-mm sieve (Test Result)	13.91		18.77		
(3) Difference in mass, (1) - (2)	56.88		50.65		
(4) Material retained on 37.5-mm sieve, [(2)/(3)](100), percent	24.45 %		37.06 %		
(5) Slump, mm	38.1 mm		63.5 mm		0-102 mm, OK 25 mm 102-152 mm, 38 mm
(6) Mass and volume of samples in air meter (Test Result)	17.57	0.007065	17.23	0.007065	
(7) Air Content by meter (Test Result), percent	2.80 %		3.50 %		1% OK
(8) Volume of Air, (7) × (6) vol.		0.000198		0.000247	
(9) Mass and volume of air-free sample, (6) mass and (6) vol. - (8)	17.57	0.006867	17.23	0.006818	
(10) Submerged mass of material retained on 4.75-mm sieve (Test Result)	6.20		5.42		
(11) SSD mass of material retained on 4.75-mm sieve, (10) × sp. gr./(sp. gr. - 1)	9.72		8.50		
(12) Solid volume of material retained on 4.75-mm sieve, (11)/(sp. gr. × 1000)		0.003522		0.003080	
(13) Mass representing mortar in sample, (6) mass - (11)	7.85		8.73		
(14) Volume representing mortar in sample, (9) vol. - (12)		0.003345		0.003738	
(15) Density of air-free mortar, (13)/(14), kg/m^3	2347 kg/m^3		2335 kg/m^3		0.26 OK 0.8 % from avg.
(16) Mass of material retained on 37.5-mm sieve for meter sample to represent a full mix, (4) × (6) mass	4.30		6.39		
(17) Solid volume of material retained on 37.5-mm sieve for meter sample to represent a full mix, (16)/(sp. gr. × 1000)		0.001564		0.002324	
(18) Density of full mix, (6) mass + (16)/(6) vol. + (17), kg/m^3	2534 kg/m^3		2516 kg/m^3		
(19) Total coarse aggregate in meter sample and plus 37.5-mm sieve material to represent full mix, (11) + (16)	14.02		14.89		
(20) Total coarse aggregate per cubic meter of concrete, (19)/(6) vol. + (17)	1625		1586		
(21) Mass of coarse aggregate in concrete, [(20)/(18)] × 100, percent	64.13 %		63.04%		OK 5 %
(22) Density calculation to an air-free basis, (18)/(1.00 - (7)), kg/m^3	2607 kg/m^3		2607 kg/m^3		OK 16 kg/m^3
(23) Compressive strength at 7 days, MPa	18.40	18.40	18.55	1875	7.5 % from avg.
	18.15	Avg. 18.30	18.45	Avg. 18.60	OK 0.81

Figure X2.1b. - Data for mixer efficiency determination (SI-metric).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4109-92

PROCEDURE FOR

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 2-INCH OR 50-MILLIMETER CUBE SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4109; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 109-80.

1. Scope

1.1 This designation covers the procedure for determination of the compressive strength of hydraulic cement mortar using 2-inch or 50-mm cube specimens.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1104 Load Verification of Testing Machines
4183 Sampling and Acceptance of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:

C 109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-Inch or 50-mm Cube Specimens)[1]
C 230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement[2]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[3]
C 778 Standard Specification for Standard Sand[1]

2.3 *National Institute of Standards and Technology*[4]:

Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

3. Apparatus

3.1 *Scales*.–Scales are used to determine the standard masses of the materials used for mortar mixes. For scales currently in use, the permissible variation at a load of 2000 grams shall be ±2.0 grams. For new scales, the permissible variation shall be one-half this value, or ±1.0 gram. The sensibility reciprocal[5] shall be not greater than twice the permissible variation.

3.2 *Standard Masses*.–The permissible variations on masses used in determining the standard masses of materials for mortar mixes shall be as shown in table 1.

Table 1. – Permissible variations on mass.

Mass, grams	Permissible variations on mass Currently in use, ±gram	New, ±gram
1000	0.50	0.250
900	.45	.225
750	.40	.200
500	.35	.175
300	.30	.150
250	.25	.125
200	.20	.100
100	.15	.075
50	.10	.050
20	.05	.025
10	.04	.020
5	.03	.015
2	.02	.010
1	.01	.005

3.3 *Glass Graduates*.–Graduates of suitable capacities, preferably large enough to measure the mixing water in a single operation, are required to deliver the indicated volume of water at 68 °F (20 °C). The permissible variation of the water volume is ±2 mL. These graduates shall be subdivided to at least 5 mL, except that the graduation lines may be omitted for the bottom 10 mL of a 250-mL graduate and for the bottom 25 mL of a 500-mL graduate. The main graduation lines shall encircle the graduate and shall be numbered. The least graduations shall extend at least one-seventh of the circumference of the graduate, and intermediate graduations shall extend at least one-fifth the circumference.

3.4 *Specimen Molds*.–These molds shall be tight fitting for the 2-inch or 50-mm cube specimens, shall not have more than three cube compartments, and shall be separable into no more than two parts. The parts of each mold, when assembled, shall be positively held together. The molds shall be made of a hard metal that will not be

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[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vols. 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[4] Formerly National Bureau of Standards.

[5] Generally defined, the sensibility reciprocal is the change in load required to change the position of rest of the indicating element of a nonautomatic-indicating scale a definite amount at any load. For a more complete definition, see reference [1], section 16.

chemically attacked by the cement mortar. For new molds, the Rockwell hardness number of the metal shall be not less than 55 HRB. The sides of the molds shall be sufficiently rigid to prevent spreading or warping. The interior faces of the molds shall be plane surfaces with a permissible variation of 0.001 inch (0.025 mm) for new molds, and 0.002 inch (0.051 mm) for molds currently in use. The distance between opposite faces shall be 2±0.005 inches or 50±0.13 mm for new molds, and 2±0.02 inches or 50±0.50 mm for molds currently in use. The height of the molds, measured separately for each cube compartment, shall be 2 inches or 50 mm with permissible variations of +0.01 inch (+0.25 mm) and -0.005 inch (-0.13 mm) for new molds, and +0.01 inch and -0.015 inch (-0.38 mm) for molds currently in use. The angle between adjacent interior faces, and between the interior faces and top and bottom planes of the mold, shall be 90±0.5° measured at points slightly removed from the intersection of the faces.

3.5 *Mixer, Bowl, and Paddle*.-An electrically-driven, mechanical mixer with paddle and mixing bowl is required, as specified in sections 4.1, 4.2, and 4.3 of USBR 4305.

3.6 *Flow Table and Flow Mold*.-These items shall conform to the requirements of ASTM C 230.

3.7 *Tamper*.-The tamper shall be made of a nonabsorptive, nonabrasive, nonbrittle material such as a rubber compound having a Shore A durometer hardness of 80±10, or seasoned oak wood rendered nonabsorptive by immersion for 15 minutes in paraffin at about 392 °F (200 °C). Tamper shall have a cross section of 0.5 by 1 inch (13 by 25 mm), and a convenient length of about 5 to 6 inches (120 to 150 mm). The tamping face shall be flat and at right angles to length of tamper.

3.8 *Trowel*.-The trowel shall have a steel blade 4 to 6 inches (102 to 152 mm) in length, with straight edges.

3.9 *Testing Machine*.-The testing machine shall be of either the hydraulic or screw type, with sufficient opening between the upper and lower bearing surfaces to permit use of verifying apparatus. The load applied to test specimen shall be indicated within an accuracy of ±1.0 percent. The upper bearing shall be a spherically seated, hardened metal block firmly attached at center of upper head of machine. The center of the sphere shall lie at center of surface of block in contact with specimen. The block shall be closely held in its spherical seat, but shall be free to tilt in any direction. The diagonal or diameter (note 1) of bearing surface shall be only slightly greater than the diagonal of the face of the 2-inch or 50-mm cube to facilitate accurate centering of specimen. A hardened metal bearing block shall be used beneath specimen to minimize wear of lower platen of machine. The bearing block surfaces intended for contact with specimen shall have a Rockwell hardness number of not less than 60 HRC. These surfaces shall not depart from plane surfaces by more than 0.0005 inch (0.013 mm) when the blocks are new, and shall be maintained within a permissible variation of 0.001 inch (0.025 mm).

NOTE 1.-A bearing surface diameter of 3.125 inches (79.4 mm), which is large enough for testing 3- by 6-inch (76- by 152-mm) cylinders, is satisfactory, provided that lower bearing block has a diameter slightly greater than diagonal of face of 2-inch cube but not more than 2.9 inches (73.7 mm), and is centered with respect to upper bearing block and held in position by suitable means.

4. Materials

4.1 *Graded Standard Sand*:

4.1.1 The sand used for making test specimens shall be natural silica sand conforming to the requirements of ASTM C 778 for graded standard sand (note 2).

NOTE 2.-The graded, standard sand should be handled in such a manner as to prevent segregation because variations in grading cause variations in consistency of mortar. When emptying bins or sacks, care should be exercised to prevent formation of sand mounds or craters in sand because coarser particles will roll down such formations. Bins should be of sufficient size to permit these precautions. Devices for drawing sand from bins by gravity should not be used.

5. Temperature and Humidity

5.1 *Temperature*.-The air temperature in vicinity of mixing slab, dry materials, molds, base plates, and mixing bowl shall be maintained between 68 and 81.5 °F (20 and 27.5 °C). The temperature of mixing water, moist closet or room, and water in storage tank shall be set at 73.4 °F (23.0 °C) and shall not vary from this temperature by more than ±3.0 °F (±1.7 °C).

5.2 *Humidity*.-The relative humidity of the laboratory shall not be less than 50 percent. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 95 percent.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety precautions associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Test Specimens

7.1 Three or more specimens shall be made for each test period specified.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

8.2 The calibration of scales to comply with section 3.1 shall be accomplished in accordance with USBR 1012.

8.3 Glass graduates shall be checked for compliance with section 3.3 by measuring and determining mass of water required to measure volume.

8.4 Specimen molds shall be checked for compliance with section 3.4 by measuring and by using straightedges.

8.5 The testing machine shall be calibrated to comply with section 3.9 in accordance with USBR 1104.

9. Preparation of Specimen Molds

9.1 Thinly cover interior faces of specimen molds with mineral oil or light cup grease. Thinly cover contact surfaces of each half of mold with a heavy mineral oil or light cup grease, such as petrolatum. After assembling molds, remove excess oil or grease from interior faces and from top and bottom surfaces of each mold. Set molds on plane, nonabsorptive base plates that have been thinly coated with mineral oil, petrolatum, or light cup grease. Apply a mixture of 3 parts paraffin to 5 parts rosin by mass, heated to between 230 and 248 °F (110 and 120 °C), at the outside contact lines of the molds and base plates so that watertight joints are obtained (note 3).

NOTE 3.-The paraffin-rosin mixture for sealing the joint between mold and base plate may be difficult to remove when mold is cleaned. Use of straight paraffin is permissible if a watertight joint is secured, but due to low strength of paraffin it should be used only when mold is not held to base plate by paraffin alone. A watertight joint may be obtained with paraffin alone by slightly warming mold and base plate before brushing joint. Molds so treated should be allowed to return to specified temperature before use.

10. Conditioning

10.1 Conditioning procedures are discussed in section 11.

11. Procedure

11.1 *Composition of Mortar*:

11.1.1 The proportions of materials for the standard mortar shall be 1 part cement to 2.75 parts graded standard sand by mass. Use a water-cement ratio (W/C) of 0.485 for all portland cements, and 0.460 for all air-entraining portland cements. The amount of mixing water for other than the portland cements and the air-entraining portland cements shall be such as to produce a flow of 110±5, as determined in accordance with 11.3, and shall be expressed as the mass percent of cement.

11.1.2 Quantities of materials to be mixed at one time in the batch of mortar for making six and nine test specimens shall be as shown in table 2.

Table 2. - Material quantities for six and nine test specimens.

Material	Number of specimens	
	Six	Nine
Cement, grams	500	740
Sand, grams	1375	2035
Water, mL		
Portland cement, W/C = 0.485	242	359
Air-entrained portland cement, W/C = 0.460	230	340
Other (flow of 110±5)	-	-

11.2 *Preparation of Mortar*.-Mechanically mix mortar in accordance with USBR 4305.

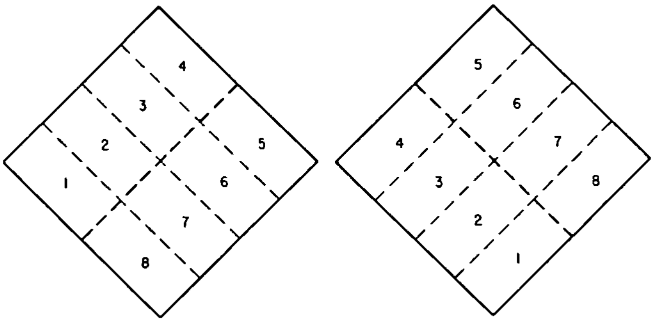
11.3 *Determination of Flow*.-Carefully wipe top of the flow table clean and dry, and place flow mold at center of table. Place a layer of mortar, about 1 inch (25 mm) thick, into mold and tamp 20 times with tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Then, finish filling the mold with a second layer of mortar and tamp as specified for first layer. Cut off mortar flush with top of mold and to a plane surface by drawing the straightedge of a trowel (held nearly perpendicular to mold) across top of mold with a sawing motion. Wipe table top clean and dry, being especially careful to remove any water from around edge of flow mold. Lift mold away from mortar 1 minute after completing mixing operation, and immediately drop table 1/2 inch (12.7 mm) 25 times within 15 seconds. The flow is the resulting increase in average base diameter of the mortar mass, measured on at least four diameters at approximately equally spaced intervals, and expressed as a percentage of original base diameter. Make trial mixes with varying percentages of water until specified flow is obtained. Use fresh mortar for each trial test. A typical worksheet on mix proportions is shown on figure 2.

11.4 *Molding Test Specimens*:

11.4.1 For portland and air-entraining portland cements, allow mortar to stand uncovered in mixing bowl for 90 seconds. During the last 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on side of bowl. Then, remix at medium speed for 15 seconds. Upon completion of mixing, mixing paddle shall be shaken to remove excess mortar from paddle into mixing bowl.

11.4.2 For other than portland and air-entraining portland cements, or when a flow test is desired on portland and air-entraining portland cements (note 4), return mortar from flow table to mixing bowl immediately following completion of flow test. Quickly scrape down into the batch any mortar that may have collected on side of bowl, and then remix entire batch at medium speed for 15 seconds. Upon completion of mixing, mixing paddle shall be shaken to remove excess mortar from paddle into mixing bowl.

11.4.3 Start molding specimens within 2.5 minutes after completion of original mixing of mortar batch. Place a 1-inch (25-mm) layer of mortar, which is about half the depth of mold, in all cube compartments. Tamp mortar in each compartment 32 times in about 10 seconds over 4 rounds, each with each round being at right angles to the other and consisting of 8 adjoining strokes over surface of specimen, as shown on figure 1. The tamping pressure shall be just sufficient to ensure uniform filling of molds. The 4 rounds of tamping (32 strokes) shall be completed in one cube before going to the next. When tamping of first layer in all cube compartments is completed, fill compartments with remaining mortar and then tamp again, as specified for first layer. During tamping of second layer,



Rounds 1 and 3

Rounds 2 and 4

Figure 1. - Order of tamping in molding of test specimens.

mortar forced out onto tops of molds after each round of tamping shall be put back into the compartments using the hands and tamper. This shall be done on completion of each round and before starting next round of tamping. On completion of tamping, tops of all cubes should protrude slightly above tops of molds. Mortar that has been forced out onto tops of molds shall be put back into the compartments using the trowel. Smooth off cubes by drawing flat side of trowel, with leading edge slightly raised, once across top of each cube at right angles to length of mold. Then, to level mortar and make mortar that protrudes above top of mold of more uniform thickness, draw flat side of trowel, with leading edge slightly raised, lightly along length of mold one time. Cut off mortar to a plane surface flush with top of mold by drawing straightedge of trowel, held nearly perpendicular to mold, over length of mold with a sawing motion.

NOTE 4.-When a duplicate batch is to be made immediately for additional specimens, flow test may be omitted and mortar allowed to stand in mixing bowl for 90 seconds; then remixed at medium speed for 15 seconds before molding specimens.

11.5 *Storage of Test Specimens*.-Immediately upon completion of molding, place test specimens in moist closet or moist room with their upper surfaces exposed to moist air but protected from dripping water for 20 to 24 hours. If specimens are removed from molds before 24 hours, keep them on shelves of moist closet or moist room until they are 24 hours old, and then immerse the specimens, except those scheduled for the 24-hour test, in saturated lime water that is in storage tanks constructed of noncorroding materials. Keep the storage lime water clean by changing as required.

11.6 *Determination of Compressive Strength*:

11.6.1 Test specimens immediately after their removal from either the moist closet (for the 24-hour specimens) or from the storage water (for all other specimens). All specimens for a given test age shall be broken within the permissible tolerance shown in table 3. If more than one specimen at a time is removed from moist closet for the 24-hour tests, keep these specimens covered with a damp cloth until time of testing. If more than one specimen at a time is removed from storage water for testing, keep these specimens completely immersed in water at a temperature of 73.4±3.0 °F (23.0±1.7 °C) until time of testing.

Table 3. - Permissible tolerances at testing age.

Test age, days	Permissible tolerance, ±hours
1	0.5
3	1
7	3
28	12

11.6.2 Wipe each specimen to a surface-dry condition, and remove any loose sand grains or incrustations from faces that will be in contact with bearing blocks of testing machine. Check these faces with a straightedge (note 5). If there is any appreciable curvature, grind to plane or discard specimen. A periodic check of the cross-sectional area of the specimens should also be made.

NOTE 5.-Values much lower than the true strength will be obtained by loading faces of a cube specimen that are not truly plane. Therefore, it is essential that specimen molds be kept very clean so that irregularities on the surfaces of the specimen will not occur. Instruments for cleaning molds should always be softer than the mold metal to prevent wear. If grinding specimen faces is necessary, it can best be accomplished by rubbing specimen on a sheet of fine emery paper or cloth glued to a plane surface, using only moderate pressure. Such grinding is tedious for more than a few thousandths of an inch (hundredths of a millimeter); therefore, it is recommended that specimen be discarded if more grinding than this is necessary.

11.6.3 Apply load to specimen faces that were in contact with true plane surfaces of mold. Carefully place specimen in testing machine below center of upper bearing block. Prior to testing each cube, it shall be ascertained that the spherically seated block is free to tilt (note 6). Use no cushioning or bedding materials. For specimens having an expected maximum load of more than 3,000 lbf (13.3 kN), an initial loading of up to one half the expected maximum load may be applied at any convenient rate. Apply no initial loading for specimens having an expected maximum load of less than 3,000 lbf. Adjust rate of load application so that remainder of load (or entire load in the case of no initial loading) is applied to failure, without interruption, at such a rate that the maximum load will be reached in not less than 20 nor more than 80 seconds from start of loading. Make no adjustment in the controls of the testing machine while a specimen is yielding before failure.

NOTE 6.-It is advisable to apply only a very light coating of a good quality, light mineral oil to the spherical seat of the upper platen.

12. Faulty Specimens and Retests

12.1 In determining the compressive strength, do not consider specimens that are obviously faulty, or those that give strengths differing by more than 10 percent from the average value of all test specimens made from the same sample and tested during the same test period (note 7). After discarding specimens or strength values, if less than two strength values are left for determining compressive strength at any given period, make a retest.

NOTE 7.–Reliable strength results depend upon careful observation of all specified requirements and procedures. Erratic results for a given test period indicate that some of the requirements and procedures have not been carefully observed; for example, not observing all of the procedures described in sections 11.6.2 and 11.6.3. Improper centering of a specimen in the testing machine can result in an oblique fracture. Lateral movement of one of the testing machine heads during loading will result in lower strength results.

13. Calculations

13.1 Record total maximum load indicated by testing machine, and calculate compressive strength in pounds force per square inch (megapascals). If cross-sectional area of specimen varies more than 1.5 percent from nominal, use actual area for calculation. The compressive strength of all acceptable test specimens (see section 12) made from same sample and tested during same test period shall be averaged and recorded to nearest 10 lbf/in^2 or 0.05 MPa. Figures 3 and 4 show typical calculation forms.

14. Report

14.1 A typical reporting form is shown on figure 5 of USBR 4183.

15. Precision and Bias

15.1 The precision statements given in this section are applicable when a test result is the average of compressive strength tests on three cubes molded from a single batch of mortar and tested at same age. The batch mortar must be of type I, II, or III cement, and cubes must be tested at 3 or 7 days. The appropriate precision limit is somewhat larger for 1-day tests, and slightly smaller for tests at ages greater than 7 days.

15.1.1 The multilaboratory coefficient of variation has been found to be 7.3 percent (note 8). Therefore, results of properly conducted tests of single batches by two different laboratories should not differ by more than 20.6 percent of their average (note 8).

15.1.2 The single-laboratory coefficient of variation has been found to be 3.8 percent (note 8). Therefore, results of two properly conducted tests of single batches of mortar made with same materials either on same day or within same week should not differ from each other by more than 10.7 percent of their average (note 8).

NOTE 8.–These numbers represent the (1S) and (D2S) limits as described in ASTM C 670.

15.2 The bias for this procedure is not known at this time.

16. Reference

[1] "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices," *Handbook 44*, National Institute of Standards and Technology.

Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 8-20-85
Project NA	Item CEMENT REF. LAB SAMPLES Location ~	Computed by K. MITCHELL Date 8-20-85
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 8-20-85

MIX PROPORTIONS FOR COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS

Sample No.	Brand Name	Plant ID	Type or Class	Sand No.	Cement, grams	Sand, grams	Water, mL	Flow, percent	Specimen No. Made	Specimen Size
CCRL -77	NI	NI	NI	GRADED STD.	500	1375	242	110	77-1 THRU 77-6	2-inch Cubes
CCRL -78	NI	NI	NI	GRADED STD.	500	1375	242	108	78-1 THRU 78-6	50-mm Cubes

NOTES:

NI = Not Identified

Figure 2. - Sample data and calculation form for mix proportions of hydraulic cement mortars.

Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 8-23-85
Project NA	Item CEMENT REF. LAB SAMPLES Location ~	Computed by K. MITCHELL Date 8-23-85
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by N. JOHNSON Date 8-23-85

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 2-INCH CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	Type or Class	Specimen No.	Age at Test, days	Total Load, lbf	Compressive Strength, lbf/in²	Average Compressive Strength, lbf/in²
CCRL -77	NI	NI	NI	77-1	3	12,050	3,012	
				77-2	3	12,350	3,087	
				77-3	3	12,400	3,100	
							9,199	3,070
				77-4	7	14,500	3,625	
				77-5	7	14,500	3,625	
				77-6	7	13,450	3,362	
							10,612	3,540

NOTES:
NI = Not Identified

Figure 3. – Sample data and calculation form for compressive strength of hydraulic cement mortars using 2-inch cube specimens.

Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 8-23-85
Project NA	Item CEMENT REF. LAB SAMPLES Location ~	Computed by K. MITCHELL Date 8-23-85
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by N. JOHNSON Date 8-23-85

COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS USING 50-mm CUBE SPECIMENS

Sample No.	Brand Name	Plant ID	Type or Class	Specimen No.	Age at Test, days	Total Load, kN	Compressive Strength, MPa	Average Compressive Strength, MPa
CCRL -78	NI	NI	NI	78-1	3	68.00	27.2	
				78-2	3	66.25	26.5	
				78-3	3	68.75	27.5	
							81.2	27.05
				78-4	7	78.25	31.3	
				78-5	7	75.75	30.3	
				78-6	7	77.25	30.9	
							92.5	30.85

NOTES:
NI = Not Identified

Figure 4. – Sample data and calculation form for compressive strength of hydraulic cement mortars using 50-mm cube specimens.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4117-92

PROCEDURE FOR

MATERIALS FINER THAN NO. 200 (75-μm) SIEVE IN MINERAL AGGREGATES BY WASHING

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4117; the number immediately following the designation indicates year of original adoption or year of last revision. This procedure is a modified version of ASTM designation: C 117-84.

1. Scope

1.1 This designation covers a procedure for the determination of the amount of material finer than a No. 200 (75-μm) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size
5330 Performing Gradation Analysis of Fines and Sand Size Fraction of Soils, Including Hydrometer Analysis

2.2 *ASTM Standards*:
C 117 Test Method for Material Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing[1,2]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2,3]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,3]

3. Summary of Procedure

3.1 A sample of the aggregate is washed in a prescribed manner and the decanted wash water containing suspended and dissolved material is passed through a No. 200 (75-μm) sieve. The loss in mass resulting from the wash treatment is calculated as a percentage of the original sample mass and reported as the percentage of material finer than a No. 200 sieve by washing.

4. Significance and Use

4.1 Material finer than the No. 200 sieve can be separated from larger particles much more efficiently and completely by wet sieving than by dry sieving. Therefore, when accurate determinations of material finer than No. 200 in fine or coarse aggregate are desired, this procedure should be used.

4.2 Occasionally, a dispersing agent will be required to assist loosening material finer than No. 200 (75-μm) sieve from the coarser material. Any dispersing agent, or liquid dishwashing detergents, which will promote separation of the finer materials, will be acceptable.

NOTE 1.–If particle size distribution of minus No. 200 (75 μm) sieve size soil is desired, the Bureau uses sodium hexametaphosphate as a dispersing agent to disperse flocculated particles (refer to USBR 5330).

5. Apparatus

5.1 *Balance.*–A balance or scale readable and accurate to 0.1 gram or 0.1 percent of test load, whichever is greater, at any point within the range of use.

5.2 *Sieves.*–A nest of two sieves, the lower being a No. 200 (75-μm) sieve and the upper a No. 16 (1.18-mm) sieve, both conforming to the requirements of ASTM E 11 for sieves with standard circular, full-height, 2-inch (51-mm); or half-height, 1-inch (25-mm), 8-inch (203-mm) diameter frames. An extra deep frame may be used for the No. 200 sieve when washing a sample that will all pass the No. 16 sieve.

NOTE 2.–The use of mechanical apparatus to perform washing operation is permitted, provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment on some samples may cause degradation of the sample.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.

5.3 *Container*.-A pan or vessel of sufficient size to contain sample covered with water and to permit vigorous agitation without loss of any part of sample or water.

5.4 *Oven*.-An oven of sufficient size and capable of maintaining a uniform temperature of 230±9 °F (110±5 °C).

NOTE 3.-For control purposes, particularly where rapid results are desired, samples may be dried at the higher temperature associated by using hotplates or gas dryers without affecting results; that is, provided steam escapes without generating pressures sufficient to fracture particles, and temperatures are not so great as to cause chemical breakdown of aggregate. Five to ten comparative samples should be dried by the above methods compared to oven-drying to assure that appreciable error is not induced by the rapid dry.

NOTE 4.-During rapid drying, to evaluate if mass has reached equilibrium, a simple check is to place a cigarette paper on the aggregate sample. If it curls, the sample is still emitting moisture.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all of the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. Sampling

7.1 Sample the aggregate in accordance with USBR 4075. If the same test sample is to be tested for sieve analysis according to USBR 4136, comply with the applicable requirements of that procedure.

7.2 Thoroughly mix the sample of aggregate to be tested and reduce the quantity to an amount suitable for testing using the applicable methods described in USBR 4702. If the same test sample is to be tested according to USBR 4136, the minimum mass shall be as described in the applicable sections of that procedure. Otherwise, the minimum mass of the test sample, after drying, shall conform with table 1. The test sample shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted.

Table 1. - Sample size for nominal, maximum size aggregate.

Nominal maximum sieve size	Minimum mass, lbm (grams)
No. 8 (2.36 mm)	0.22 (100)
No. 4 (4.75 mm)	1.10 (500)
3/8 inch (9.5 mm)	2.20 (1000)
3/4 inch (19.0 mm)	5.51 (2500)
1-1/2 inches (37.5 mm)	11.02 (5000)

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

8.2 The balance or scale shall be calibrated in accordance with USBR 1012 to meet the requirements of section 5.1.

8.3 The sieves shall be calibrated in accordance with USBR 1025 to meet the requirements of section 5.2 and ASTM E 11.

8.4 The oven shall be calibrated in accordance with USBR 1020 to meet the requirements of section 5.4.

9. Conditioning

9.1 No particular conditioning is required for this test procedure.

10. Procedure

10.1 Dry test sample to a constant mass at a temperature of 230±9 °F (110±5 °C), and determine the mass to nearest 0.1 percent of sample mass.

10.2 If a sieve analysis is to be determined according to USBR 4136, proceed as described in 10.2.1 or 10.2.2.

10.2.1 For aggregates with a nominal maximum size of No. 4 (4.75 mm) or less, first test the sample in accordance with USBR 4136, and then test the same sample as stipulated in sections 10.3 through 10.6 of this procedure.

10.2.2 For aggregates with a nominal maximum size greater than No. 4, a single test sample may be used as described in 10.2.1, or separate test samples may be used.

10.3 After drying and determining its mass, place test sample in container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate sample with sufficient vigor to result in complete separation of all particles finer than the No. 200 (75-μm) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour wash water containing the suspended and dissolved solids over the nested sieves that have been arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

10.4 Add a second charge of water to sample in container, agitate, and decant as before. Repeat this operation until wash water is clear.

10.5 *Mechanical Washing*:

10.5.1 If mechanical washing equipment is used to perform procedures described in sections 10.3 and 10.4, charging of water, agitation of sample, and decanting of wash water may be a continuous operation.

10.5.2 Fine aggregate test samples with a nominal maximum size of No. 4 (4.75 mm) or less can be washed on the nested sieves by a water spray. To prevent overloading the sieves when this method is used, the sample may be tested in a number of increments until entire sample has been washed. The mass of material on the nested sieves should not exceed 0.0085 lbm/in^2 (6.3 kg/m^2) or 4 g/in^2 of sieving surface (note 2). In no case shall the mass be so great as to cause permanent deformation of the sieve cloth. Wet sample thoroughly with a gentle stream of water. Remove nested sieves from under the spray nozzle and adjust pressure on nozzle to 10±0.5 lbf/in^2 (68.9±3.4 kPa). Return nested sieve assemblage to its position under nozzle and, moving sieves in spray with a circular motion in a horizontal plane at about one motion per second, wash sample until wash water is clear. Every portion of the sieve should be sprayed during each circular motion of the sieves. During washing, hold sieve assemblage so that bottom of spray nozzle extends 0.5 inch (13 mm) below top of sieve frame.

NOTE 5.–The 4 g/in^2 (6.3 kg/m^2) amounts to 0.43 lbm (194 g) for 8-inch (203-mm) diameter sieve.

10.6 Return all material retained on nested sieves to washed sample by flushing. Dry the washed aggregate to a constant mass at a temperature of 230±9 °F (110±5 °C), and determine its mass to nearest 0.1 percent of original sample mass.

11. Calculation

11.1 Calculate amount of material passing the No. 200 (75-μm) sieve by washing as follows:

$$A = \frac{B-C}{B}(100) \qquad (1)$$

where:

A = percentage of material finer than a No. 200 (75-μm) sieve by washing,
B = original dry mass of sample in grams, and
C = dry mass of sample in grams after washing.

11.2 A suggested calculation form is shown on figure 2 of USBR 4075.

12. Report

12.1 Report percentage of material finer than the No. 200 (75-μm) sieve by washing to nearest 0.1 percent, except if the result is 10 percent or more, report to nearest whole number. A typical reporting form is shown on figure 3 of USBR 4075.

13. Precision and Bias

13.1 The multilaboratory standard deviation has been found to be 0.22 percent for nominal 3/4-inch (19.0-mm) maximum size coarse aggregate with less than 1.5 percent passing the No. 200 (75-μm) sieve. Therefore, results of two properly conducted tests from two different laboratories on samples of the same coarse aggregate should not differ by more than 0.62 percent. The corresponding single-operator standard deviation has been found to be 0.10 percent. Therefore, results of two properly conducted tests by the same operator on the same coarse aggregate should not differ by more than 0.28 percent. See note 3.

NOTE 6.–The percentage values given in section 13 for standard deviation represent the (1S) and (D2S) limits as described in ASTM C 670.

13.2 There is no known bias for this procedure.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4123-92

PROCEDURE FOR

LOW DENSITY PIECES IN AGGREGATE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4123; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 123-83.

1. Scope

1.1 This designation covers the procedure for determination of the percentage of low density pieces in aggregate using a sink-float separation in a heavy liquid of suitable specific gravity.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:
C 123 Standard Test Method for Lightweight Pieces in Aggregate[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]
E 100 Standard Specification for ASTM Hydrometers[3]
E 126 Standard Method for Inspection, Test, and Standardization of Hydrometers[4]

3. Significance and Use

3.1 This procedure is used to determine conformance with specifications provisions pertaining to the amount of low density material in fine and coarse aggregates. A heavy liquid with a specific gravity of 2.0 is used to separate particles which may be classified as coal or lignite. Heavier liquids may be used to check the percentages of other low density pieces, such as chert, that have a specific gravity less than 2.4.

3.2 This procedure may be useful in identifying porous or otherwise unsound aggregate particles in research activities or in petrographic analyses.

3.3 This procedure can be used to determine the progressive differential spread in the specific gravity of aggregate particles. Also, the pertinent analyses of sink-float fractions resulting from heavy liquid separations will indicate any significant improvement in aggregate quality caused by the removal of low density material. Procedure is also useful in studies to evaluate the economic feasibility of any aggregate beneficiation processing method dependent upon the specific gravity relationship between an acceptable product and waste material.

3.4 Procedure serves as a specifications product quality control test for aggregate produced by beneficiation processing methods, such as heavy-media separation or hydraulic jigging, and also provides a means to monitor processing plant operating conditions to ensure optimum production efficiency.

4. Apparatus

4.1 *Balances*.–For determining mass of fine aggregates, a balance having a capacity of not less than 1.1 lbm (500 g), and sensitive to at least 0.0002 lbm (0.1 g) is required. For determining mass of coarse aggregates, a balance having a capacity of not less than 11.02 lbm (5000 g), and sensitive to at least 0.0022 lbm (1 g) is required.

4.2 *Containers*.–The containers shall be suitable for drying the aggregate sample.

4.3 *Heavy Liquid Containers*.–Stainless steel beakers are necessary for holding the heavy liquids during the sink-float separation procedure, and also for holding any required wash liquid. Beakers with about 2 quarts (2 L) capacity with pouring spouts are suitable for fine aggregate separations, which consist of minus No. 4 (–4.75-mm) material. For separation of coarse aggregate, which is the plus No. 4 material, 8- to 12-quart (8- to 12-L) capacity beakers are required.

4.4 *Sample Containers*.–The sample containers shall be baskets, with bail-type handles, fabricated from woven-wire sieve cloth conforming to requirements of ASTM E 11. Baskets shall fit snugly, but without binding, in the heavy

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.
[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.
[3] *Annual Book of ASTM Standards*, vols. 05.03, 14.01.
[4] *Annual Book of ASTM Standards*, vol. 14.01.

liquid containers. The fine aggregate sample basket shall be fabricated from No. 50 (300-μm) wire cloth, and coarse aggregate sample basket from No. 10 (2.00-mm) wire cloth. Basket construction should be suitably reinforced to maintain the basket shape without any deformation that might be caused by repeated usage.

4.5 *Skimmers.*-Saucer-shaped skimmers, with handles, fabricated from woven-wire sieve cloth conforming to requirements of ASTM E 11 are required for separating floating pieces from the heavy liquid. Fine aggregate skimmers shall be fabricated from No. 50 (300-μm) wire cloth, and coarse aggregate skimmers from No. 10 (2.00-mm) wire cloth. The skimmers for fine aggregate should be about 2 inches (50 mm) in diameter, and those for coarse aggregate about 4 inches (100 mm) in diameter.

4.6 *Sieves.*-The sieves shall be No. 30 (600μm) and No. 4 (4.75 mm), conforming to ASTM E 11.

NOTE 1.-Any sieve that may be required to obtain an aggregate sample for testing shall conform to ASTM E 11.

4.7 *Specific Gravity Measurement.*-Equipment for determining specific gravity can be hydrometers conforming to requirements of sections 4 through 10 of ASTM E 100 and with cup-top hydrometer cylinders, or a suitable combination of graduated glassware and balance capable of measuring heavy liquid specific gravities within ±0.01. Also required is a dipper or ladle for transferring, when required, the heavy liquids or the wash and rinse liquids.

4.8 *Hood.*-A downdraft-type fume hood, with safety sash. The minimum face velocity, with sash fully open, should be 100 ft/min (0.51 m/s).

4.9 *Oven.*-Forced-air ventilated oven suitable for drying the aggregate samples to a constant mass at 230±9 °F (110±5 °C).

4.10 *Aggregate Drying Trays* (optional).-Trays with legs, fabricated from No. 10 (2.00-mm) woven-wire sieve cloth conforming to ASTM E 11, may be used for rapid drying of aggregate samples retained on a No. 8 (2.36-mm) or larger sieve. Trays should be of reinforced construction to maintain their shape. The trays should be about 1 inch (25 mm) deep; dimensions of width and length may vary but should be such that test sample can be spread out on tray to a thickness of one aggregate particle. Suggested width and length dimensions range from about 12 by 18 inches (305 by 460 mm) to about 18 by 36 inches (460 by 915 mm). One side of tray should have a chute to facilitate transference of material. Use of a drying tray allows a free flow of air around aggregate particles, and expedites testing procedure when a large number of sink-float separations are to be made or when USBR 4123 is used as a quality control measure for aggregate production processing.

5. Chemicals

5.1 *Heavy Liquid.*-The heavy liquid shall consist of one of the liquids described in 5.1.1 or 5.1.2.

5.1.1 A solution of zinc chloride in water, with a specific gravity up to about 2.0. Bureau specifications for concrete aggregates limit the allowable percentage of material having a specific gravity less than 1.95±0.02. The zinc chloride liquid solution is used to make this determination. About 690 grams of the zinc chloride salt per liter of water are required to produce a solution of the required specific gravity.

5.1.2 A mixture of kerosene with 1,1,2,2-tetrabromoethane (acetylene tetrabromide), proportioned to produce the desired specific gravity. The tetrabromoethane has a specific gravity of about 2.95, while kerosene has a specific gravity of about 0.80. Approximate proportions by volume of the kerosene-tetrabromoethane mixture for the heavy liquid at various specific gravities are shown on figure 1.

5.2 The specific gravity of the heavy liquid shall be maintained within ±0.01 of specified value at all times during test. The liquids in 5.1.2 have differential rates of evaporation which will cause a progressive change in the specific gravity of mixture. Periodic checking and adjustment of the specific gravity for this heavy liquid will be necessary. The zinc chloride solution (5.1.1) is relatively stable; however, occasional specific gravity checks should be made.

NOTE 2.-*Caution*:The chemicals listed in 5.1.2 are toxic, both by absorption through the skin and by inhalation. These chemicals shall be used only in a down draft-type hood, and care shall be taken to avoid inhalation or contact with eyes or skin. There is no particular hazard from the fumes of the zinc chloride solution (5.1.1); however, this solution is caustic. Protective clothing such as gloves, aprons, and goggles should be worn to prevent contact of these chemicals with the eyes or skin.

5.3 *Rinse Liquids.*-Kerosene or denatured alcohol.

6. Effect of Aggregate Moisture Conditions

6.1 The moisture content condition of aggregate samples has a significant effect upon the results of sink-float separations. This is particularly true for fine aggregate and "pea gravel" size coarse aggregate. Deviation from the reliably reproducible and stable saturated-surface-dry moisture condition, within the time frame required for sink-float separations, will produce inaccurate test results. Low density aggregate particles in a dry or less than saturated-surface-dry condition will rapidly absorb heavy liquids, and the relative increase in particle density causes many low density "float" particles to react erroneously as high density "sink" particles. A film of free moisture around an aggregate particle not displaced by the heavy liquid may occupy a volume sufficient to significantly lessen the specific gravity of the particle and thus, a sink particle may react as a pseudo-float particle. When free water is present on aggregate particles, the high surface tension characteristics of the water will tend to cause particles to cluster or cling together after immersion in heavy liquid solution. Some sink particles will thus be captured by float particles rising to surface of heavy liquid and will be removed in float particle separation process. The presence of free moisture on aggregate particles may also dilute heavy liquid and lower its specific gravity.

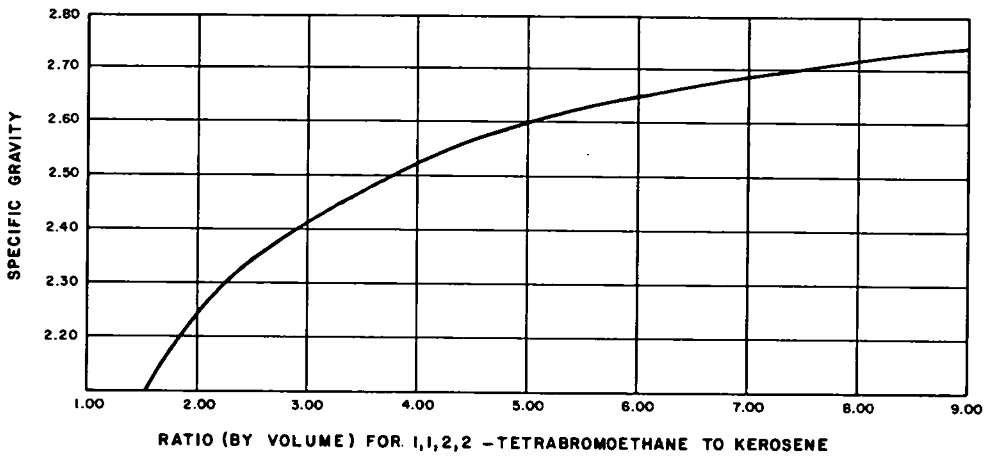


Figure 1. - Approximate proportions of kerosene-tetrabromoethane mixture for heavy liquid at various specific gravities.

7. Precautions

7.1 This test procedure, which involves hazardous materials and operations, does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7.2 Specific precautionary measures for the chemicals are given in section 5.

8. Sampling

8.1 Secure field sample of aggregate in accordance with USBR 4075, and reduce sample to test portion size in accordance with USBR 4702.

8.2 Dry the test portion size of sample to a constant mass at 230±9 °F (110±5 °C) before testing (note 3). Minimum size of test sample shall be as shown in table 1.

NOTE 3.-This test procedure is performed on aggregate samples in a saturated-surface-dry condition; therefore, "wet" samples of processed material obtained at aggregate production plants for quality control tests need not be dried to a constant mass. If necessary, these wet samples should be washed to remove any contaminating materials.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 Balances shall conform to the requirements of section 4.1 by calibration in accordance with USBR 1012.

9.3 Sieves shall conform to the requirements of section 4.6 and ASTM E 11 by calibration in accordance with USBR 1025.

9.4 The oven shall conform to the requirements of section 4.9 by calibration in accordance with USBR 1020.

9.5 Hydrometers shall conform to the requirements of section 4.7 by standardization in accordance with ASTM E 126.

10. Conditioning

10.1 The conditioning required in this procedure is primarily maintaining the specific gravity of the heavy liquid as discussed in section 5.

11. Procedure

11.1 *Preparation of Test Samples*.-Allow the dried test sample to cool to room temperature. Sieve the fine aggregate, minus No. 4 (-4.75-mm), samples over a No. 30 (600-μm) sieve, and the coarse aggregate, plus No. 4, samples over a No. 4 sieve. Sieving should continue until less than 1 percent of the retained material passes the sieve during 60 seconds of continuous sieving. The mass of the fine aggregate portion retained on the No. 30 sieve should be a minimum of 0.22 lbm (100 g) (note 4). Immerse the aggregate sample in water for 30 minutes. If aggregate samples are already saturated, this soaking period is not required. Bring sample to a saturated-surface-dry condition by the procedures specified in USBR 4128 (fine aggregate) or USBR 4127 (coarse aggregate). Determine mass of test sample to nearest 0.0002 lbm (0.1 g) for fine aggregate, and to nearest 0.0022 lbm (1 g) for coarse aggregate.

NOTE 4.-In most Bureau quality evaluation investigations, the nominal gradation separation points for coarse aggregate are No. 4, 3/8 and/or 3/4 inch, 1-1/2 inches, and 3 inches (4.75 mm, 9.5 and/or 19.0 mm, 37.5 mm, and 75 mm), and test samples are separated at these points.

Table 1. - Minimum size of sample.

Nominal maximum aggregate (sieves with square openings)	Minimum mass of sample, lbm (g)
No. 4 (4.75 mm)	0.44 (200)
3/8 inch (9.5 mm)	3.31 (1500)
3/4 inch (19.0 mm)	6.61 (3000)
1-1/2 inches (37.5 mm)	11.02 (5000)
3 inches (75 mm)	22.05 (10 000)

11.2 *Sink-Float Particle Separation.*-All subsequent heavy liquid, sink-float, separation procedures shall be performed in the fume hood. Transfer sample to sample basket container and place into heavy liquid beaker container. The volume of the heavy liquid shall be at least three times the absolute volume of the aggregate. To bring float particles to the surface of the heavy liquid, stir sample vigorously or agitate using a vertical, up-and-down, reciprocating motion of sample basket for 5 seconds. This stirring or basket agitation should be sufficiently vigorous to free the low density "float" particles surrounded and entrapped by the high density "sink" particles. Allow about 15 seconds for heavy liquid turbulence to subside, and then remove floating aggregate particles with the skimmer. Skimming depth should be just sufficient to remove only the aggregate particles floating on heavy liquid surface. Care should be taken while skimming not to create any undue currents in the heavy liquid that would disturb the settled sink material. Aggregate particles suspended in the heavy liquid mid-zone between the float and sink portions of the sample should not be removed with the float material. After skimming, allow excess heavy liquid to drain from skimmer back into beaker. Transfer skimmed float material to a wire basket container for rinsing to remove residual heavy liquid from aggregate particle surfaces. Repeat stirring or basket agitation and skimming sequence until all low density material has been removed and transferred to rinse basket. Skimming should be completed within 5 minutes from time test sample is immersed in heavy liquid.

11.2.1 After the sink-float separation has been completed, clean float particles by washing in a suitable solvent to remove residual heavy liquid from the particle surfaces. For cleaning material separated in the zinc chloride solution, thoroughly wash float particles in water. For cleaning material separated in the kerosene-tetrabromoethane mixture, immerse rinse basket containing float material in a beaker of kerosene. Then, agitate material by using a vertical up-and-down motion of rinse basket for 3 minutes. Remove basket from beaker and drain excess kerosene for 1 minute. Remove remaining kerosene by agitating basket in a beaker containing denatured alcohol for 2 minutes. Remove basket from beaker and drain excess alcohol for 1 minute. To prevent excessive contamination and to maintain their effectiveness as rinse liquids, replacement of kerosene and alcohol is recommended after 12 to 15 tests. Dry the float particles to a saturated-surface-dry condition. Determine mass of float particles to nearest 0.0002 lbm (0.1 g) for fine aggregate, and to nearest 0.0022 lbm (1 g) for coarse aggregate.

NOTE 5.-*Caution*:To minimize evaporation and the resulting lowering of specific gravity, beakers containing the 1,1,2,2-tetrabromoethane heavy liquid solutions should be covered at all times when access is not needed. To prevent dilution of heavy liquid solutions by introduction of liquids of lower specific gravity, the wire cloth baskets used for immersion of aggregate samples into the heavy liquids and the baskets used for immersion of aggregate samples into water, kerosene, or alcohol should be kept separate and not interchanged. These same precautions also apply to the wire cloth skimmers used for separation of float material from heavy liquid solutions.

11.2.2 Usually, the difference between the oven-dry mass and the saturated-surface-dry mass of an aggregate sample will not significantly affect the calculated percentage of lightweight pieces. If greater precision is required, this percentage can be determined based on the oven-dried aggregate sample mass condition for the mass values defined in section 12.

11.3 Figure 2 shows a flow diagram of the steps described in this section.

12. Calculations

12.1 Calculate the percentage of low density pieces (pieces floating on surface of heavy liquid) as follows:

For fine aggregate:

$$L = \frac{M_1}{M_2} (100) \tag{1}$$

For coarse aggregate:

$$L = \frac{M_1}{M_3} (100) \tag{2}$$

where:

L = percentage of low density pieces,
M_1 = saturated-surface-dry mass of pieces that float,
M_2 = saturated-surface-dry mass of portion of fine aggregate test sample coarser than the No. 30 (600-μm) sieve, and
M_3 = saturated-surface-dry mass of original coarse aggregate test sample.

12.2 A suggested calculation form is shown on figure 3 of USBR 4075.

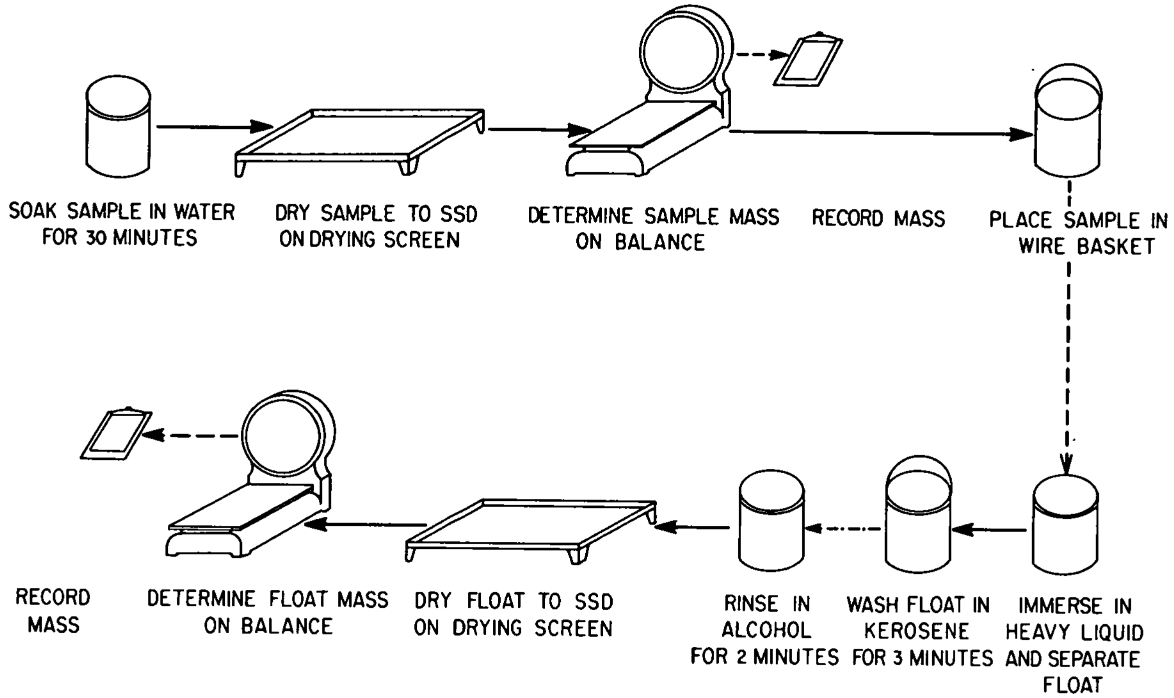
13. Report

13.1 Figure 3 of USBR 4075 also shows a typical reporting form.

14. Precision and Bias

14.1 No interlaboratory or intralaboratory studies have been conducted to determine precision indexes for this procedure. The accuracy of this procedure may be estimated by running separate specific gravity and absorption determinations on individual pieces of the separate sink or float fractions, or both.

14.2 There is no known bias.



FORMULA:

$$\text{FLOAT (PERCENT)} = \frac{\text{SSD MASS OF FLOAT}}{\text{SSD MASS OF SAMPLE}} \times 100$$

NOTE:

FLOAT IS LOW-DENSITY PARTICLES IN SAMPLE

SSD = SATURATED-SURFACE-DRY

LEGEND:

——► SAMPLE
– – – –► SAMPLE IN BASKET
–·–·–► FLOAT IN BASKET

Figure 2. – Flow diagram for separation of low-density pieces in aggregate.

UNITED STATES DEPARTMENT OF THE INTERIOR
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USBR 4127-92

PROCEDURE FOR

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4127; the number immediately following the designation indicates year of original adoption or year of last revision. This procedure is a modified version of ASTM designation: C 127-84.

1. Scope

1.1 This designation covers the procedure for the determination of specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as ovendry bulk specific gravity, SSD (saturated-surface-dry) bulk specific gravity, or apparent specific gravity. The SSD bulk specific gravity and absorption are based on aggregate that has been soaked in water at room temperature for 24 hours. This procedure is not intended to be used with lightweight aggregates.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4029 Density and Voids in Aggregate
4075 Sampling Aggregates
4128 Specific Gravity and Absorption of Fine Aggregate
4136 Sieve Analysis of Fine and Coarse Aggregates
4566 Total Moisture Content of Aggregate by Drying
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 127 Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2,3,4]
D 448 Standard Specification for Standard Sizes of Coarse Aggregate for Highway Construction[1,2,4]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,3,5,6]
E 12 Standard Definitions of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases[1,7]

2.3 *AASHTO Standards*:

T 85 Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate[8]

3. Summary of Procedure

3.1 A sample of aggregate is immersed in water for about 24 hours at room temperature to essentially fill the pores of the aggregate. The sample is then removed from the water, the water dried from the surface of the particles, and the mass determined. Subsequently, the mass is also determined while submerged in water. Finally, the sample is ovendried and the mass determined a third time. Using the three different masses obtained and the formulas given in this procedure, it is possible to calculate three different types of specific gravity and the absorption.

4. Significance and Use

4.1 The bulk specific gravity is the characteristic usually used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used to compute the voids in the aggregate in USBR 4029. The SSD specific gravity is used if the aggregate is wet; that is, if the aggregate's absorption has been satisfied. Conversely, the ovendry bulk specific gravity is used for the computations when the aggregate is dry or assumed to be dry.

4.2 Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles, but not including the pore space within the particles that is accessible to water.

4.3 Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.
[4] *Annual Book of ASTM Standards*, vol. 04.08.
[5] *Annual Book of ASTM Standards*, vol. 04.06.
[6] *Annual Book of ASTM Standards*, vol. 14.02.
[7] *Annual Book of ASTM Standards*, vol. 15.05.
[8] Available from AASHTO (American Association of State Highway and Transportation Officials), 444 North Capitol St., N.W., Suite 225, Washington DC 20001.

pore spaces within the constituent particles, as compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is the absorption obtained after submerging the dry aggregate in water for about 24 hours. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates may contain an amount of absorbed moisture less than the 24-hour soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture (dry mass basis) can be determined by deducting the absorption from the total moisture content that is determined by USBR 4566.

4.4 The general procedures described are suitable for determining the absorption of aggregates that have had conditioning other than the 24-hour soaked condition, such as boiling water or vacuum saturation. The values obtained for absorption and the SSD bulk specific gravity by other methods will be different than the values obtained by the prescribed 24-hour soaked condition.

4.5 The pores in low-density aggregates may or may not become essentially filled with water after immersion for 24 hours; many such aggregates can remain immersed in water for several days without satisfying most of the absorption potential. Therefore, this procedure is not intended for use with low-density aggregate.

5. Terminology

5.1 *Specific Gravity.*-The ratio of the mass in air of a unit volume of a material to the mass of the same volume of water at stated temperatures.

5.1.1 *Bulk Specific Gravity (Ovendry Basis).*-The ratio of the mass in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between the particles) at a stated temperature to the mass in air of an equal volume of gas-free distilled water at a stated temperature.

5.1.2 *Bulk Specific Gravity (SSD Basis).*-The ratio of the mass in air of a unit volume of aggregate (including the mass of water within the voids filled to the extent achieved by submerging in water for about 24 hours, but not including the voids between the particles) at a stated temperature to the mass in air of an equal volume of gas-free distilled water at a stated temperature.

5.1.3 *Apparent Specific Gravity.*-The ratio of the mass in air of a unit volume of the impermeable portion of the aggregate at a stated temperature to the mass in air of an equal volume of gas-free distilled water at a stated temperature.

5.2 *Absorption.*-The increase in mass of an aggregate due to water in the pores of the aggregate, but not including water adhering to the outside surfaces of the particles, expressed as a percentage of dry mass. The aggregate is considered "dry" when it has been maintained at 230±9 °F (110±5 °C) for a sufficient time to remove all uncombined water.

NOTE 1.-The terminology for specific gravity is based on terms defined in ASTM E 12, and that for absorption in ASTM C 125.

6. Apparatus

6.1 *Balance.*-A device for determining the mass that is sensitive, readable, and accurate to 0.05 percent of the sample mass at any point within the range used, or 0.001 lbm (0.5 gram), whichever is greater. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of the mass platform or pan of the balance.

6.2 *Sample Container.*-A wire basket of No. 6 (3.35 mm) or finer mesh, or a container of approximately equal breadth and height, with a 1- to 2-gallon (4- to 7-L) capacity for the 1-1/2-inch (37.5-mm) nominal maximum size aggregate or smaller, and a larger container as needed for testing the larger maximum size aggregate. Each sample container shall be constructed so as to prevent the trapping of air when container is submerged.

6.3 *Water Tank.*-A watertight tank into which the sample container may be placed while it is suspended below the balance.

6.4 *Sieves.*-A No. 4 (4.75-mm) sieve, or other sizes as needed, see sections 8.2, 8.3, and 8.4, conforming to ASTM E 11.

6.5 *Oven.*-An oven of appropriate size capable of maintaining a temperature of 230±9 °F (110±5 °C).

6.6 *Miscellaneous Equipment.*-Electric fans and various drying cloths and pans.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8. Sampling

8.1 Sample the aggregate in accordance with USBR 4075.

8.2 Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in USBR 4702. Reject all material passing a No. 4 (4.75-mm) sieve by dry sieving, and wash thoroughly to remove dust or other coatings from the aggregate surfaces. If the coarse aggregate contains a substantial quantity of material finer than the No. 4 sieve, such as the sizes 8 and 9 shown in ASTM D 448, use the No. 8 (2.36-mm) sieve instead of the No. 4 sieve. Alternatively, separate the material finer than the No. 4 sieve, and test the finer material in accordance with USBR 4128.

8.3 The minimum mass of the test sample to be used is shown in table 1. Frequently, it may be desirable to test a coarse aggregate in several separate size fractions and, if sample contains more than 15 percent retained

Table 1. - Minimum mass of test sample.

Nominal maximum size		Minimum mass of test sample	
inches	(mm)	lbm	(kg)
≤ 1/2	(12.5)	4.4	(2)
3/4	(19.0)	6.6	(3)
1	(25.0)	8.8	(4)
1-1/2	(37.5)	11	(5)
2	(50)	18	(8)
2-1/2	(63)	26	(12)
3	(75)	40	(18)
3-1/2	(90)	55	(25)
4	(100)	88	(40)
4-1/2	(112)	110	(50)
5	(125)	165	(75)
6	(150)	276	(125)

on the 1-1/2-inch (37.5-mm) sieve, tests should be made on the material larger than 1-1/2 inches in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum mass of the test sample for each fraction shall be the difference between the masses prescribed for the maximum and minimum sizes of the fraction.

8.4 If sample is tested in two or more size fractions, determine the grading of the sample in accordance with USBR 4136, including the sieves used for separating the size fractions for the determinations in this procedure. When calculating the percentage of material in each size fraction, ignore the quantity of material finer than the No. 4 (4.75-mm) sieve, or the No. 8 (2.36-mm) sieve when used in accordance with section 8.2.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

9.2 The balance shall be calibrated in accordance with USBR 1012.

9.3 The sieves shall be checked for compliance in accordance with USBR 1025 to meet the requirements of ASTM E 11.

9.4 Drying ovens shall be calibrated in accordance with USBR 1020.

10. Procedure

10.1 Dry the test sample to a constant mass at 230±9 °F (110±5 °C); and cool in air at room temperature for 1 to 3 hours, for test samples of 1-1/2-inch (37.5-mm) nominal maximum size, or longer for larger sizes until aggregate has cooled to a temperature that is comfortable to handle, about 122 °F (50 °C). Subsequently, immerse the sample in water at room temperature for 24±4 hours. Room temperature is considered to be in the range of 68 to 86 °F (20 to 30 °C) with a preferred range of 68 to 77 °F (20 to 25 °C).

NOTE 2.–When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples. The values obtained are then combined for the computations described in section 11.

10.2 When the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to a constant mass may be eliminated. If surfaces of particles in the sample have been kept continuously wet until test, the 24-hour soaking period may also be eliminated.

NOTE 3.–Values for absorption and SSD bulk specific gravity may be significantly higher for aggregate not ovendried before soaking than for the same aggregate treated in accordance with section 10.1. This is especially true of particles larger than 3 inches (75 mm) because the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

10.3 Remove test sample from water and roll sample in a large absorbent cloth until all visible films of water are removed. Then, wipe the larger particles individually. A moving stream of air may be used to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores during the surface drying. Determine mass of test sample in the SSD condition. Record this and all subsequent masses to the nearest 0.001 lbm (0.5 gram) or 0.05 percent of sample mass, whichever is greater.

10.4 After determining mass, immediately place the SSD test sample in the sample container and determine mass of sample in water. Take care to remove all entrapped air before determining the mass by shaking the container while immersed.

NOTE 4.–The container should be immersed to a depth sufficient to cover both the container and test sample during mass determination. The balance shall be tared to compensate for the mass of the empty container while it is immersed. The wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

10.5 Dry the test sample to a constant mass at 230±9 °F (110±5 °C); cool in air at room temperature for 1 to 3 hours, or until aggregate has cooled to a temperature that is comfortable to handle, about 122 °F (50 °C); and then determine mass.

10.6 This procedure, which is based on a 24-hour soaking period, determines the standard values for specific gravity and absorption. To meet the particular requirements for concrete mix design studies, the values for the SSD coarse aggregate may be determined for something other than 24-hour soaking periods, with the test procedure being identical in all other respects.

11. Calculations

11.1 Calculations for specific gravity and absorption in this section use the letters A, B, and C:

where:

A = mass of ovendry test sample in air,
B = mass of SSD (saturated-surface-dry) test sample in air, and
C = mass of SSD test sample in water.

A, B, and C are all in units of pound mass (grams).

11.1.1 *Bulk Specific Gravity (Ovendry).*-Calculate the ovendry bulk specific gravity as follows:

$$\text{Ovendry bulk sp. gr.} = \frac{A}{B-C} \qquad (1)$$

11.1.2 *Bulk Specific Gravity (SSD).*-Calculate the SSD bulk specific gravity on the basis of the mass of the SSD aggregate as follows:

$$\text{SSD Bulk sp. gr.} = \frac{B}{B-C} \qquad (2)$$

11.1.3 *Apparent Specific Gravity.*-Calculate the apparent specific gravity as follows:

$$\text{Apparent sp. gr.} = \frac{A}{A-C} \qquad (3)$$

11.2 *Average Specific Gravity Values.*-When sample is tested in separate size fractions, an average value for any of the three different bulk specific gravities can be computed as the weighted average of the values computed in 11.1 using equation (4). The derivation of this equation is given in appendix XI.

$$G = \frac{1}{\frac{P_1}{100\,G_1} + \frac{P_2}{100\,G_2} + \ldots \frac{P_n}{100\,G_n}} \qquad (4)$$

where:

G = average specific gravity (all forms of expression for specific gravity can be averaged in this manner),
$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in original sample, and
$G_1, G_2, \ldots G_n$ = appropriate specific gravity values for each size fraction depending on type of specific gravity being averaged.

NOTE 5.-Some users of this procedure may prefer to express the results of the tests in terms of density. The density may be determined by multiplying any of three specific gravity values by the density of water at 73.4 °F (23.0 °C), which is 62.27 lbm/ft^3 (997.5 kg/m^3 or 0.9975 Mg/m^3). Some authorities recommend using the density of water at 39.2 °F (4.0 °C), which is 62.43 lbm/ft^3 (1000 kg/m^3 or 1.000 Mg/m^3), as being sufficiently accurate. Whichever value is used, the results should be expressed to three significant digits. The density terminology corresponding to the three types of specific gravity has not been standardized.

11.3 *Absorption.*-Calculate the percentage of absorption as follows:

$$\text{Absorption (percent)} = \frac{B-A}{A}(100) \qquad (5)$$

11.4 *Average Absorption Value.*-When sample is tested in separate size fractions, the average absorption value is the average of the values computed in section 11.3, weighted in proportion to the mass percentages of the size fractions in the original test sample:

$$Ab = \frac{P_1 Ab_1}{100} + \frac{P_2 Ab_2}{100} + \ldots \frac{P_n Ab_n}{100} \qquad (6)$$

where:

Ab = average absorption, in percent,
$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in original sample, and
$Ab_1, Ab_2, \ldots Ab_n$ = absorption percentages for each size fraction.

11.5 Figure 1 shows a typical data and calculation form for this procedure.

12. Report

12.1 Figure 3 of USBR 4075 may be used as a reporting form for this procedure. The report shall include:

- Report specific gravity results to the nearest 0.01, and indicate which type of specific gravity is being reported.
- Report the absorption result to the nearest 0.1 percent.
- If the specific gravity and absorption values were determined without first drying the aggregate, as permitted in section 10.2, this option should be noted in the report.

13. Precision and Bias

13.1 *Precision.*-The estimates on the precision for this test procedure are shown in table 2, and are based on the results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted using ASTM C 127 and AASHTO Method T 85. The only significant difference between these two methods is that ASTM C 127 requires a saturation period of 24±4 hours while T 85 requires a minimum of 15 hours. This difference has been found to have an insignificant effect on the precision indices. The data shown in table 2 are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

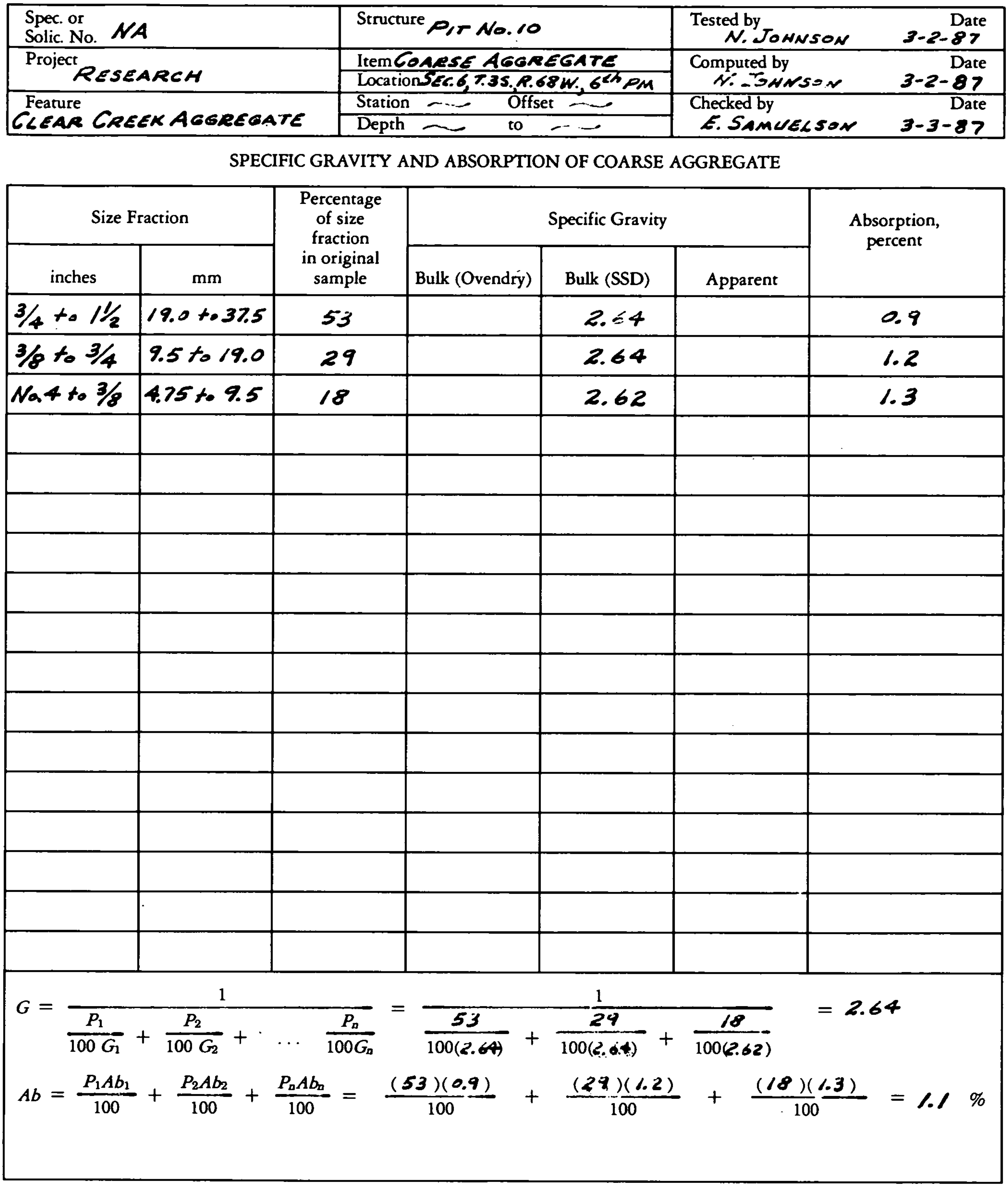
13.2 *Bias.*–The bias for this procedure has not been determined at this time.

Table 2. – Precision estimates.

	Standard Deviation (1S)[1]	Acceptable Range of Two Results (D2S)[1]
Single-Operator Precision:		
Ovendry bulk specific gravity	0.009	0.025
SSD bulk specific gravity	.007	.020
Apparent specific gravity	.007	.020
Absorption[2], percent	.088	.25
Multilaboratory Precision:		
Ovendry bulk specific gravity	.013	.038
SSD bulk specific gravity	.011	.032
Apparent specific gravity	.011	.032
Absorption[2], percent	.145	.41

[1] These numbers represent the (1S) and (D2S) limits as described in ASTM C 670. These precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15-hour minimum saturation times and other laboratories using 24±4-hour saturation times. Testing was performed on normal density aggregates, and tests were started with aggregates in ovendry condition.

[2] These precision estimates were based on aggregates with absorptions of less than 2 percent.



Spec. or Solic. No. NA	Structure PIT No. 10	Tested by N. JOHNSON — Date 3-2-87
Project RESEARCH	Item COARSE AGGREGATE Location SEC. 6, T.3S., R.68W., 6th PM	Computed by N. JOHNSON — Date 3-2-87
Feature CLEAR CREEK AGGREGATE	Station — Offset — Depth — to —	Checked by E. SAMUELSON — Date 3-3-87

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

Size Fraction		Percentage of size fraction in original sample	Specific Gravity			Absorption, percent
inches	mm		Bulk (Ovendry)	Bulk (SSD)	Apparent	
3/4 to 1 1/2	19.0 to 37.5	53		2.64		0.9
3/8 to 3/4	9.5 to 19.0	29		2.64		1.2
No. 4 to 3/8	4.75 to 9.5	18		2.62		1.3

$$G = \frac{1}{\frac{P_1}{100\,G_1} + \frac{P_2}{100\,G_2} + \cdots \frac{P_n}{100G_n}} = \frac{1}{\frac{53}{100(2.64)} + \frac{29}{100(2.64)} + \frac{18}{100(2.62)}} = 2.64$$

$$Ab = \frac{P_1Ab_1}{100} + \frac{P_2Ab_2}{100} + \frac{P_nAb_n}{100} = \frac{(53)(0.9)}{100} + \frac{(29)(1.2)}{100} + \frac{(18)(1.3)}{100} = 1.1\ \%$$

Figure 1. – Typical data and calculation form for average values of specific gravity and absorption for a coarse aggregate tested in separate size fractions.

APPENDIXES

X1. DERIVATION OF EQUATIONS

(Nonmandatory Information)

X1.1 The derivation of equation (4) in section 11.2 is apparent from the following simplified case using two solids. Solid No. 1 has a mass of M_1 in pound mass (kilograms), a volume V_1 in cubic feet (cubic meters), and a specific gravity G_1 of M_1/V_1. Similarly, solid No. 2 has a mass M_2, a volume V_2, and a G_2 of M_2/V_2. If these two solids are considered together, the specific gravity of the combination is the total mass divided by the total volume:

$$G = \frac{M_1 + M_2}{V_1 + V_2}$$

Manipulation of this equation yields:

$$G = \frac{1}{\dfrac{V_1 + V_2}{M_1 + M_2}} = \frac{1}{\dfrac{V_1}{M_1 + M_2} + \dfrac{V_2}{M_1 + M_2}}$$

$$G = \frac{1}{\dfrac{M_1}{M_1 + M_2}\left(\dfrac{V_1}{M_1}\right) + \dfrac{M_2}{M_1 + M_2}\left(\dfrac{V_2}{M_2}\right)}$$

However, the mass fractions of the two solids are:

$$\frac{M_1}{M_1 + M_2} = \frac{P_1}{100} \quad \text{and} \quad \frac{M_2}{M_1 + M_2} = \frac{P_2}{100}$$

and, $\dfrac{1}{G_1} = \dfrac{V_1}{M_1}$ and $\dfrac{1}{G_2} = \dfrac{V_2}{M_2}$

Therefore,

$$G = \frac{1}{\dfrac{P_1}{100}\left(\dfrac{1}{G_1}\right) + \dfrac{P_2}{100}\left(\dfrac{1}{G_2}\right)} = \text{Equation (4)}$$

X2. INTERRELATIONSHIPS BETWEEN SPECIFIC GRAVITIES AND ABSORPTION AS DEFINED IN USBR 4127 AND 4128

(Nonmandatory Information)

X2.1 Let:

G_d = ovendry bulk specific gravity,
G_s = SSD bulk specific gravity,
G_a = apparent specific gravity, and
Ab = absorption (percent).

X2.2 Then:

$$G_s = \left(1 + \frac{Ab}{100}\right) G_d$$

$$G_a = \frac{1}{\dfrac{1}{G_d} - \dfrac{Ab}{100}} = \frac{G_d}{1 - \dfrac{AbG_d}{100}}$$

$$G_a = \frac{1}{\dfrac{1 + \dfrac{Ab}{100}}{G_s} - \dfrac{Ab}{100}} = \frac{G_s}{1 - \left[\dfrac{Ab}{100}\,(G_s - 1)\right]}$$

$$Ab = \left(\frac{G_s}{G_d} - 1\right) 100$$

$$Ab = \left[\frac{G_a - G_s}{G_a\,(G_s - 1)}\right] 100$$

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4128-92

PROCEDURE FOR

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4128; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C128-84.

1. Scope

1.1 This designation covers the procedure for the determination of bulk and apparent specific gravity and absorption of fine aggregate.

1.2 This procedure determines, after 24 hours in water, the bulk specific gravity and the apparent specific gravity (as defined in ASTM E 12), the bulk specific gravity on the basis of mass of SSD (saturated-surface-dry) aggregate, and the absorption as defined in ASTM C 125.

NOTE 1.-The ASTM subcommittee is considering revising ASTM C 127 and C 128 for coarse and fine aggregate, respectively, to use the term "density" instead of "specific gravity."

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1030 Calibrating Specific Gravity Flasks
4029 Density and Voids in Aggregate
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4566 Total Moisture Content of Aggregate by Drying
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 70 Standard Test Method for Surface Moisture in Fine Aggregate[1]
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 127 Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate[1]
C 128 Standard Test Method for Specific Gravity and Absorption of Fine Aggregate[1,2]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2,3,4]
E 12 Definitions of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases[1,5]

2.3 *AASHTO Standard*:

T 84 Standard Method of Test for Specific Gravity and Absorption of Fine Aggregates[6]

3. Significance and Use

3.1 The bulk specific gravity is the characteristic usually used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used to compute the voids in the aggregate in USBR 4029 and the determination of moisture in the aggregate, by displacement in water, in ASTM C 70. The SSD (saturated-surface-dry) bulk specific gravity is used if the aggregate is wet; that is, if the aggregate's absorption has been satisfied. Conversely, the ovendry bulk specific gravity is used for the computations when the aggregate is dry or assumed to be dry.

3.2 Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles, but not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

3.3 Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, as compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.
[4] *Annual Book of ASTM Standards*, vol. 04.08.
[5] *Annual Book of ASTM Standards*, vol. 15.05.
[6] Available from AASHTO (American Association of State Highway and Transportation Officials), 444 North Capitol St., N.W., Suite 225, Washington DC 20001.

absorption is the absorption obtained after submerging the dry aggregate in water for about 24 hours. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates, when used, may contain an amount of absorbed moisture less than the 24-hour soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture (dry mass basis) can be determined by deducting the absorption from the total moisture content determined using USBR 4566.

4. Apparatus

4.1 *Balance.*-A balance or scale having a capacity of 1 kg or more, sensitive to 0.1 g or less, and accurate within 0.1 percent of the test load at any point within the range of use for this test. Within any 100-g range of test load, the difference between readings shall be accurate within 0.1 g.

4.2 *Pycnometer.*-A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced within ±0.1 cm^3. The volume of the container filled to mark shall be at least 50 percent greater than the space required to accommodate the test sample. A volumetric flask of 500 cm^3 capacity, or a fruit jar fitted with a pycnometer top, is satisfactory for a 500-g test sample of most fine aggregates. The Bureau-modified pycnometer, a 1-quart (0.9464-L) fruit jar with opening edge surfaces ground level and capped with a plate glass disk top, is satisfactory for a 500- to 800-g sample.

4.3 *Mold.*-A metal mold in the form of a frustum of a cone with dimensions as follows: 40±3 mm inside diameter at the top, 90±3 mm inside diameter at the bottom, and 75±3 mm in height, with the metal having a minimum thickness of 0.8 mm.

4.4 *Tamper.*-A metal tamper with a mass of 340±15 g and having a flat circular tamping face 25±3 mm in diameter.

4.5 *Storage Jar.*-A water storage jar of about 5 gallon (20 L) capacity for maintaining water at room temperature. Room temperature is considered to be in the range of 68 to 86 °F (20 to 30 °C) with a preferred range of 68 to 77 °F (20 to 25 °C).

4.6 *Pump.*-A vacuum pump or an aspirator apparatus capable of producing 20 inches (67.7 kPa) of mercury vacuum; and with the necessary pipe, connections, and gauges for removing the entrapped air from pycnometers.

NOTE 2.-Either the pump or aspirator is preferable, but not required, over the manual agitation described in section 6.6.1.

4.7 *Oven.*-An oven of appropriate size capable of maintaining a temperature of 230±9 °F (110±5 °C).

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

6.2 The balance or scale shall be calibrated in accordance with USBR 1012.

6.3 The mold shall be checked for compliance with section 4.3 by linear measuring devices and calipers meeting the requirements of USBR 1000.

6.4 The tamper shall be checked for compliance with section 4.4 by a balance and linear measuring device or outside calipers meeting the requirements of USBR 1012 and 1000, respectively.

6.5 Drying ovens shall be calibrated in accordance with USBR 1020.

6.6 The pycnometer or flask shall be calibrated in accordance with USBR 1030.

6.6.1 *Alternative to Determining Volume of Pycnometer.*-Adjusting the pycnometer and its contents to a designated temperature for each determination of fine aggregate specific gravity may require considerable time. A convenient pycnometer calibration method determines pycnometer masses, when filled to capacity with water, at the various room temperatures that will typically prevail under laboratory conditions. Pycnometers should be clean and dry prior to this calibration. Entrapped air is removed from the water by manual agitation of the pycnometer or, preferably, by application of a vacuum for 15 minutes. During vacuum application, the pycnometer may be gently rolled or tapped occasionally to aid in the removal of air bubbles. If the preferred vacuum application is not used, manually roll, invert, and agitate pycnometer until all air bubbles are eliminated. After final adjustment of the water level to pycnometer calibration capacity, dry outside of pycnometer and determine mass of the water-filled pycnometer to the nearest 0.1 g and water temperature to the nearest 1 °F (0.3 °C). Repeat this procedure for at least six different temperatures within the range of laboratory conditions. A calibration curve is then plotted through the data points obtained, using pycnometer masses as the ordinate and temperatures as the abscissa. The mass of the pycnometer, filled with water at a specific temperature, can then be selected from the curve, or from a calibration chart prepared for each 1 °F temperature interval (see fig. 1).

NOTE 3.-Some procedural differences for the calibration of volumetric flasks or fruit-jar pycnometers are: (1) *Volumetric Flask.*-Fill flask with water until lowest point of concave water meniscus is even with calibration capacity reference line on flask neck. If, after removal of entrapped air, water level is below flask reference line, adjust water level with a buret or pipet to

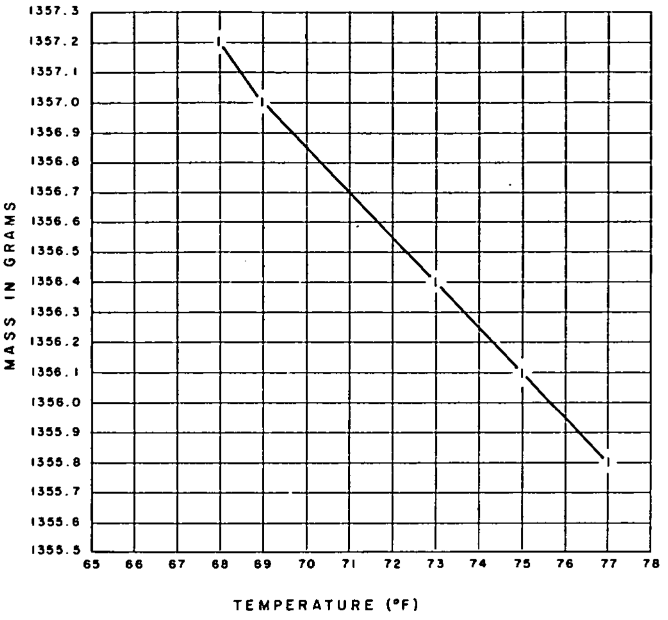

Figure 1. - Typical calibration curve for the mass of water in pycnometer at various temperatures.

reset the water meniscus at the reference line. (2) *Fruit-Jar Pycnometer* (Conical Metal Top).-Prior to calibration, the conical metal top should be screwed down snugly and permanent alignment marks scribed on top and jar to ensure that a uniform compression of the rubber gasket may always be obtained. Fill jar to top with water and remove entrapped air, then screw down conical metal top until alignment marks on top and jar match. Adjust water level to calibration capacity (cone top hole opening) with a buret or pipet. If manual agitation is used to remove air bubbles, cover the top hole with a finger while rolling jar. (3) *Fruit-Jar Pycnometer* (Modified With Glass Disk Top).-Fill jar to top with water and remove entrapped air. Add sufficient water such that a convex water meniscus forms at jar opening. Then slowly slide glass disk top horizontally with a slicing motion across the opening, taking care to avoid any entrapping of air below the disk top.

7. Sampling

7.1. Sampling shall be accomplished in general accordance with USBR 4075.

8. Preparation of Test Specimen

8.1 Obtain about 1.2 to 1.5 kg of the fine aggregate from the sample using the applicable procedures described in USBR 4702.

8.1.1 Dry the fine aggregate obtained in a suitable pan or vessel to a constant mass at 230±9 °F (110±5 °C). Allow to cool to a comfortable handling temperature, cover with water (by immersion or by the addition of at least 6 percent free moisture), and allow to condition for 24±4 hours. If sample is not completely immersed in water, the pan should be covered to prevent moisture loss.

8.1.2 As an alternative to the method described in section 8.1.1 and where the absorption and specific gravity values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for initial drying to a constant mass may be eliminated and, if surfaces of particles have been kept wet, the 24-hour soaking may also be eliminated.

NOTE 4.-Values for absorption and specific gravity in the SSD condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with section 8.1.1.

8.2 Decant excess water with care to avoid loss of fines, spread sample on a flat surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. If desired, mechanical aids such as tumbling or stirring may be used to assist in achieving the SSD condition. Continue this operation until test specimen approaches a free-flowing condition. Follow the method in 8.2.1 to determine whether surface moisture is present on the constituent fine aggregate particles. It is intended that the first trial of the cone test will be made with some surface water on the particles. Continue drying with constant stirring, and test at frequent intervals until test indicates that specimen has reached a surface-dry condition. If the first trial of the surface moisture test indicates that moisture is not present on the surface, the specimen has been dried beyond the SSD condition. In this case, thoroughly mix a few milliliters of water with the fine aggregate and permit the specimen to stand in a covered container for 30 minutes. Then, resume the process of drying and testing at frequent intervals for the onset of the surface-dry condition.

8.2.1 *Cone Test for Surface Moisture.*-Hold the mold firmly on a smooth nonabsorbent surface with large diameter of mold facing down. Place a portion of the partially dried fine aggregate loosely in the mold by filling mold to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each tamper drop should start about 0.2 inch (5 mm) above top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height of the tamper to the new surface elevation of the aggregate after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. When the fine aggregate slumps slightly, that indicates that it has reached a surface-dry condition. Some angular fine aggregate, or a material with a high proportion of fines, may not slump in the cone test when reaching a surface-dry condition. This may be the case if the fines become airborne upon dropping a handful of the sand from the cone test 4 to 6 inches (102 to 152 mm) onto a surface. For these materials, the SSD condition should be considered as the point when one side of the fine aggregate slumps slightly upon removal of the mold.

NOTE 5.-While stirring the sand during drying, visual inspection and handling of the fine aggregate will indicate the approach of the required free-flowing SSD condition. If the sand, when formed into a pile, is cut vertically with a spoon or small trowel and the cut portion of the pile remains vertical, surface moisture is still present. If the sand, when squeezed in the hand, retains the molded shape, excess surface moisture is present. During drying, most sands change from a dark (wet) to light (dry) color. Adhering wet sand particles will, as drying progresses, tend to become separate and distinct from one another when near the SSD condition.

NOTE 6.-The following criteria have also been used on materials that do not readily slump: (1) *Provisional Cone Test.*-Fill cone mold as described in 8.2.1, except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then, add aggregate two more times using 3 and 2 drops of the tamper, respectively. Level off the material even with top of mold, remove loose material from base, and lift mold vertically. (2) *Provisional Surface Test.*-If airborne fines are noted when fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand and, at onset of surface-dry condition, lightly hand pat about 100 g of the material on a flat, dry, clean, dark, or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After 1 to 3 seconds, remove the fine aggregate. If noticeable moisture shows on the test surface for more than 1 to 2 seconds, surface moisture is considered to be present on the fine aggregate. (3) Colorimetric procedures described by Kandhal and Lee [1][7]. (4) For reaching the SSD condition on a single size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

8.2.2 When the sample of sand has reached a surface-dry condition, the sample should be split into two parts using a sand splitter. One part will be used for determination of absorption and the other for specific gravity. Determine the mass of each part to the nearest 0.1 g. If bulk (dry basis) and/or apparent specific gravities are to be determined, adjust the two parts into identical mass values for the absorption and specific gravity samples.

8.3 The preparation of the test specimen, based on a 24-hour soaking period, determines standard values for specific gravity and absorption. To meet the particular requirements of concrete mix design studies, specific gravity and absorption values for SSD fine aggregate may be determined for other than the 24-hour soaking period, with the procedure being identical in all other respects.

9. Procedure

9.1 *Specific Gravity.*-Partially fill pycnometer with water at room temperature, and immediately place the SSD fine aggregate sample, prepared as described in section 8, into the pycnometer. Then, fill with additional water to about 90 percent of capacity. Entrapped air shall be removed by subjecting pycnometer contents to vacuum treatment and/or manual agitation (rolling, inverting, etc.) of the pycnometer. When entrapped air bubbles have been eliminated, bring water level in pycnometer to its calibrated capacity, and dry off outside of pycnometer. Determine and record the total mass of the pycnometer, sample specimen, and water to the nearest 0.1 g; and the temperature of water in the pycnometer to the nearest 1 °F (0.3 °C).

NOTE 7.-It normally takes about 15 to 20 minutes to eliminate air bubbles.

9.1.1 When filling pycnometer to calibrated capacity, any air bubbles that may be entrapped between the fine aggregate grains must be eliminated to obtain accurate specific gravity values. When manual agitation is used to remove entrapped air, stopper or cap the pycnometer to prevent any loss of sample. When using fruit-jar pycnometers, match the alignment marks on the conical metal top and jar and, during manual agitation of jar contents, cover top hole in jar with a finger. The glass disk top of a Bureau-modified pycnometer should be held firmly in place during agitation of the jar. When subjecting pycnometer contents to vacuum treatment by connection to an aspirator or vacuum pump, position and hold vacuum stopper or cap over pycnometer opening until reduction in air pressure is sufficient to seal stopper or cap in place; then continue to reduce air pressure until required vacuum is attained. To minimize the "boiling action" that occurs with some fine aggregate samples when subjected to the reduced air pressure, the vacuum should be applied at a slow rate. After application of the vacuum for about 15 minutes, slowly increase air pressure until vacuum seal is broken, and then add water necessary to fill pycnometer to its calibrated capacity. After sufficient water is added to the Bureau-modified fruit-jar pycnometer for a convex meniscus of water to rise above the jar opening, the glass disk top is moved horizontally across the jar opening. Firmly hold glass disk in place and manually agitate jar with a swirling motion to bring entrapped air bubbles to top of jar. Remove the glass disk top and repeat this procedure until air bubbles are no longer visible.

9.2 *Absorption.*-Dry the absorption sample to a constant mass at 230±9 °F (110±5 °C), and determine sample mass to nearest 0.1 g.

9.2.1 If a single sample is being used for both specific gravity and absorption, remove fine aggregate sample from pycnometer after determination of specific gravity, dry to a constant mass at 230±9 °F, cool in air at room temperature for 1±0.5 hour, and determine sample mass to nearest 0.1 g. Care must be used to avoid any loss of fine material during removal of fine aggregate sample from pycnometer.

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[7] Number in brackets refers to entry in Reference, section 13.

10. Calculations

10.1 *Bulk Specific Gravity (Dry-Basis)*.–Calculate the bulk specific gravity, as defined in ASTM E 12, as follows:

$$\text{Bulk sp. gr.} = \frac{A}{E + B - F} \qquad (1)$$

where:

A = mass of ovendry test specimen in air, in grams;
B = mass of SSD sample, in grams;
E = mass of pycnometer filled with water (grams) to calibration mark at temperature T; and
F = mass of pycnometer including specimen and water (grams) to calibration mark at temperature T.

10.2 *Bulk Specific Gravity (SSD)*.–Calculate the SSD bulk specific gravity on the basis of mass of SSD aggregate as follows:

$$\text{SSD Bulk sp. gr.} = \frac{B}{E + B - F} \qquad (2)$$

10.3 *Apparent Specific Gravity*.–Calculate the apparent specific gravity, as defined in ASTM E 12, as follows:

$$\text{Apparent sp. gr.} = \frac{A}{E + A - F} \qquad (3)$$

10.4 *Absorption*.–Calculate the percentage of absorption, as defined in ASTM C 125, as follows:

$$\text{Absorption (percent)} = \frac{B - A}{A}\,(100) \qquad (4)$$

10.5 Figure 2 of USBR 4075 shows a typical data and calculation form for this procedure.

11. Report

11.1 Figure 3 of USBR 4075 may be used as a reporting form for this procedure. The report shall include:

- Report specific gravity results to the nearest 0.01 and absorption to the nearest 0.1 percent. Appendix X2 in USBR 4127 shows the mathematical interrelationships among the three types of specific gravities and the absorption. This information may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.
- If the fine aggregate was tested in a naturally moist condition other than the ovendry or 24-hour soaked condition, report the source of the sample and the method used to prevent drying prior to testing.

12. Precision and Bias

12.1 *Precision*.–The estimates on the precision for this test procedure are shown in table 1, and are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted using ASTM C 128 and AASHTO Method T 84. The only significant difference between these two methods is that ASTM C 128 requires a saturation period of 24±4 hours while T 84 requires 15 to 19 hours. This difference has been found to have an insignificant effect on the precision indices. The data shown in table 1 are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

12.2 *Bias*.–The bias for this procedure has not been determined at this time.

13. Reference

[1] Kandhal and Lee, *Highway Research Record No. 307*, p. 44.

Table 1.–Precision estimates.

	Standard deviation (1S)[1]	Acceptable range of two results (D2S)[1]
Single-Operator Precision:		
Ovendry bulk specific gravity	0.011	0.032
SSD bulk specific gravity	.0095	.027
Apparent specific gravity	.0095	.027
Absorption[2], percent	.11	.31
Multilaboratory Precision:		
Ovendry bulk specific gravity	0.023	0.066
SSD bulk specific gravity	.020	.056
Apparent specific gravity	.020	.056
Absorption[2], percent	.23	.66

[1] These numbers represent the (1S) and (D2S) limits as described in ASTM C 670. These precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15- to 19-hour saturation times and other laboratories using 24±4-hour saturation times. Testing was performed on normal density aggregates, and tests were started with aggregates in the ovendry condition.

[2] These precision estimates were based on aggregates with absorptions of less than 1 percent, and may differ for manufactured fine aggregates and fine aggregates having absorption values greater than 1 percent.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4131-92

PROCEDURE FOR

RESISTANCE TO DEGRADATION OF SMALL-SIZE, COARSE AGGREGATE BY ABRASION AND IMPACT IN LOS ANGELES MACHINE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4131; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 131-81.

1. Scope

1.1 This designation covers a procedure for testing sizes of coarse aggregate smaller than 1-1/2 inches (37.5 mm) for resistance to degradation using the Los Angeles testing machine.

NOTE 1.-A procedure for testing coarse aggregate larger than 3/4 inch (19.0 mm) is covered in USBR 4535.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1025 Checking Sieves
4075 Sampling Aggregates
4136 Sieve Analysis of Fine and Coarse Aggregates
4535 Resistance to Degradation of Large-Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:
C 131 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Summary of Procedure

3.1 The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres; the number of which depends upon grading of test sample. As drum rotates, a shelf plate picks up sample and steel spheres, carrying them around until they are dropped to opposite side of drum, creating an impact-crushing effect. The contents roll within the drum with an abrading and grinding action until shelf plate impacts, and then the cycle is repeated. After the prescribed number of revolutions, contents are removed from drum and aggregate portion is sieved to measure degradation as percent loss.

4. Significance and Use

4.1 The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions; however, results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Specification limits based on this test should be assigned with extreme care in consideration of available aggregate types and their performance history concerning specific uses.

5. Apparatus

5.1 *Los Angeles Machine*.-The Los Angeles testing machine, conforming in all its essential characteristics to the design shown on figure 1, shall be used for this test procedure. The machine shall consist of a hollow steel cylinder, closed at both ends, having an inside diameter of 28±0.2 inches (711±5 mm), and an inside length of 20±0.2 inches (508±5 mm). Cylinder shall be mounted on stub shafts attached to ends of cylinder but not entering it, and shall be mounted in such a manner that it may be rotated with axis in a horizontal position within a tolerance in slope of 1 in 100. An opening shall be provided in cylinder for introduction of test sample. A suitable, dust-tight cover shall be provided for this opening with a means for bolting the cover in place. The cover shall be so designed

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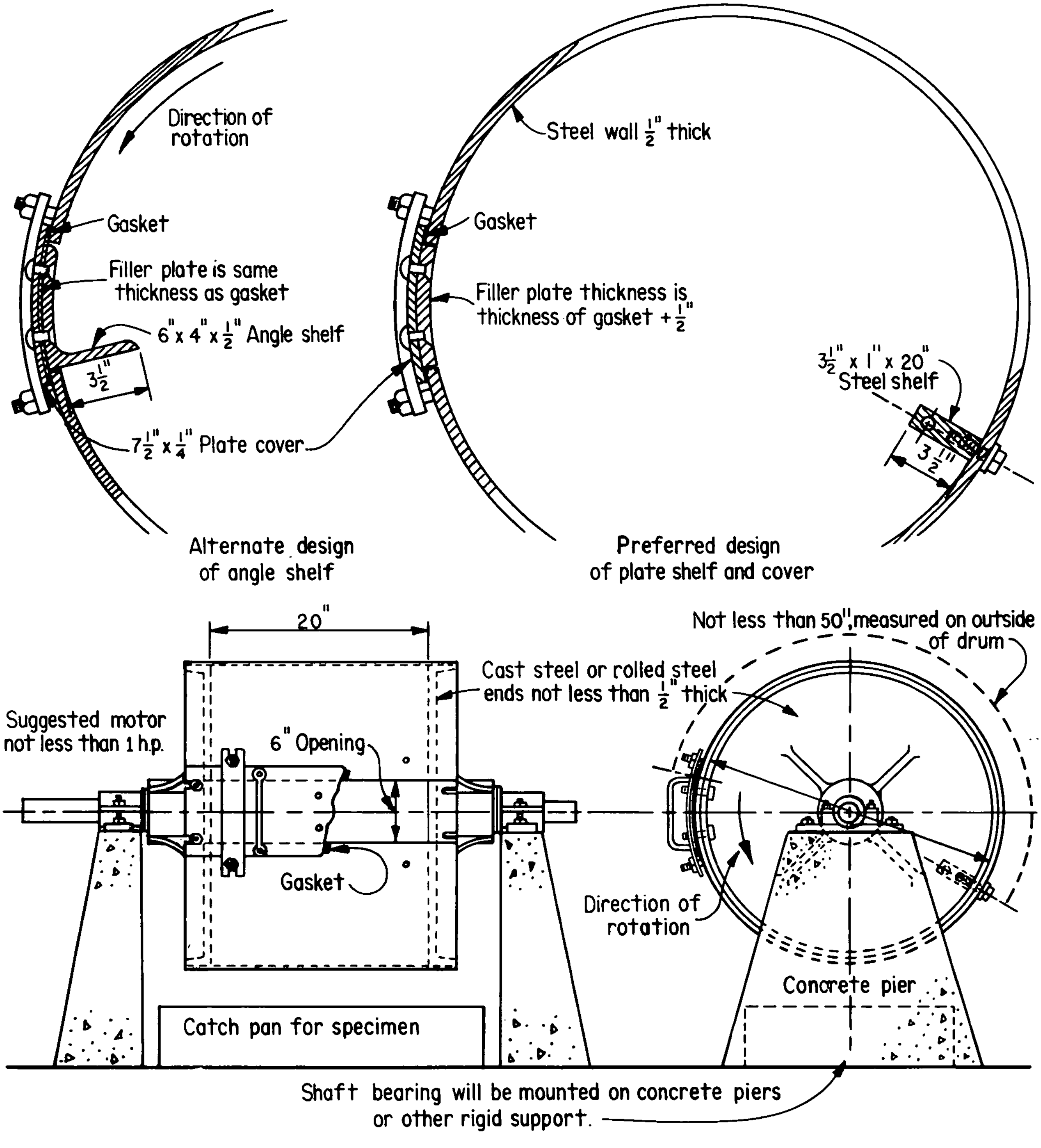
[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.03.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.



Metric Equivalents

inches	1/4	1/2	1	3 1/2	4	6	7 1/2	20	28	50
millimeters	6.4	12.8	25.4	89	102	152	190	508	711	1 270

Figure 1. – Design drawing of Los Angeles testing machine.

as to maintain the cylindrical contour of cylinder's interior surface unless shelf is so located that charge will not fall on cover or come in contact with it during test. A removable steel shelf extending the full length of the cylinder and projecting inward 3.5±0.1 inches (89±2 mm) shall be mounted on interior cylindrical surface of cylinder in such a manner that a plane centered between the large faces coincides with an axial plane. The shelf shall be of such thickness and so mounted, by bolts or other suitable means, as to be firm and rigid. Position of shelf shall be such that distance from shelf to opening, measured along outside circumference of cylinder in direction of rotation, shall be not less than 50 inches (1270 mm).

NOTE 2.–The use of a shelf of wear-resistant steel, rectangular in cross section and mounted independently of cover, is preferred. However, a shelf consisting of a section of rolled angle, properly mounted on inside of cover plate, may be used provided direction of rotation is such that charge will be caught on outside face of rolled angle. If shelf becomes distorted from its original shape to such an extent that requirements of section 6.4 are not met, shelf shall either be repaired or replaced before resuming testing.

5.1.1 The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed of from 30 to 33 r/min (note 3). If a section of rolled angle is used for shelf, direction of rotation shall be such that charge is caught on outside face of angle.

NOTE 3.–Backlash or slip in driving mechanism will probably give test results that are not duplicated by other Los Angeles machines producing constant peripheral speed.

5.1.2 The machine shall be equipped with an adjustable revolution counter that will automatically stop machine after required number of revolutions.

5.1.3 A material discharge catch pan of suitable dimensions is required to preclude any test sample loss.

5.2 *Sieves*.–Sieves shall conform to ASTM E 11.

5.3 *Balance*.–A balance or scale accurate to within 0.1 percent of test load over range required for this test is required.

5.4 *Charge*.–The charge shall consist of steel spheres averaging about 1-27/32 inches (46.8 mm) in diameter, with each sphere having a mass of between 0.86 and 0.98 lbm (390 and 445 g).

5.4.1 The charge, depending upon grading of test sample as described in section 8, shall be as follows:

Grading	Number of spheres	Mass of charge lbm (g)
A	12	11.02±0.055 (5000±25)
B	11	10.11±0.055 (4584±25)
C	8	7.34±0.044 (3330±20)
D	6	5.51±0.033 (2500±15)

NOTE 4.–Steel ball bearings 1-13/16 inches (46.0 mm) and 1-7/8 inches (47.6 mm) in diameter, with a mass of about 0.88 and 0.97 lbm (400 and 440 g) each, respectively, are readily available. Steel spheres 1-27/32 inches (46.8 mm) in diameter with a mass of about 0.93 lbm (420 g) may also be obtainable. The charge may consist of a mixture of these sizes provided the mass tolerances of sections 5.4 and 5.4.1 are met.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 Precautions on shelf distortion in machine are outlined in note 2, section 5.1.

6.3 Precautions on backlash or slip in driving mechanism of machine are outlined in note 3, section 5.1.1.

6.4 *Maintenance of Shelf*:

6.4.1 The shelf of the machine is subject to severe surface wear and impact. With use, working surface of shelf is peened by the steel spheres and tends to develop a ridge of metal parallel to and about 1-1/4 inches (32 mm) from junction of shelf and inner surface of cylinder. If shelf is made from a section of rolled angle, not only may this ridge develop, but the shelf may be bent longitudinally or transversely from its proper position.

6.4.2 Shelf should be inspected periodically to determine whether it is bent either lengthwise or from its normal radial position with respect to cylinder. If either condition exists, shelf should be repaired or replaced before further tests are made. The influence that a developed metal ridge from peening of working face of shelf has on the test results is not known; however, for uniform test conditions, it is recommended that ridge be ground off if its height exceeds 0.1 inch (2 mm).

7. Sampling

7.1 The field sample shall be obtained in accordance with USBR 4075, and reduced to test portion size in accordance with USBR 4702.

8. Conditioning of Test Sample

8.1 The test sample shall be washed and oven dried at 221 to 230 °F (105 to 110 °C) to a substantially constant mass (note 5), separated into individual size fractions, and recombined to the grading shown in table 1 that most nearly corresponds to range of aggregate sizes furnished for work. The mass of the sample prior to test shall be recorded to nearest 0.002 lbm (1 g).

NOTE 5.–If aggregate is essentially free of adherent coatings and dust, requirement for washing before and after test may be waived. Elimination of washing after test will seldom reduce the measured loss by more than about 0.2 percent of original sample mass.

Table 1. – Gradings of test samples.

Sieve size (square openings)		Mass of indicated sizes, lbm (g) Grading			
Passing	Retained on	A	B	C	D
1-1/2 inches (37.5 mm)	1 inch (25.0 mm)	2.76±0.055 (1250±25)	-	-	-
1 inch (25.0 mm)	3/4 inch (19.0 mm)	2.76±0.055 (1250±25)	-	-	-
3/4 inch (19.0 mm)	1/2 inch (12.5 mm)	2.76±0.022 (1250±10)	5.51±0.022 (2500±10)	-	-
1/2 inch (12.5 mm)	3/8 inch (9.5 mm)	2.76±0.022 (1250±10)	5.51±0.022 (2500±10)	-	-
3/8 inch (9.5 mm)	1/4 inch (6.3 mm)	-	-	5.51±0.022 (2500±10)	-
1/4 inch (6.3 mm)	No. 4 (4.75 mm)	-	-	5.51±0.022 (2500±10)	-
No. 4 (4.75 mm)	No. 8 (2.36 mm)	-	-	-	11.02±0.022 (5000±10)
	Totals	11.02±0.022 (5000±10)	11.02±0.022 (5000±10)	11.02±0.022 (5000±10)	11.02±0.022 (5000±10)

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 The Los Angeles machine shall be checked periodically for wear and to assure compliance with section 5.1.

9.3 Sieves shall be calibrated to meet requirements of ASTM E 11 in accordance with USBR 1025.

9.4 The balance or scale shall be calibrated to meet requirements of section 5.3 in accordance with USBR 1012.

9.5 The charge dimensions shall be checked to meet requirements of section 5.4 by using the linear measurement devices in accordance with USBR 1000. The mass of the charge shall meet requirements of section 5.4 by using scales calibrated in accordance with USBR 1012.

9.6 Calibration of revolution counter shall be accomplished by visual observation and by manually counting revolutions.

9.7 Speed of revolution counter shall be checked with an appropriate tachometer. This will provide the "average" rotational speed of cylinder but not the uniformity of the "peripheral" speed.

10. Procedure

10.1 Place graded test sample and charge in Los Angeles machine and rotate for 100 revolutions. Discharge material from machine and make a preliminary separation of sample on a No. 4 (4.75-mm) sieve. Sieve the finer portion on a No. 12 (1.70-mm) sieve in a manner conforming to USBR 4136. The total mass of material that would be retained on the No. 12 sieve is determined to nearest 0.002 lbm (1 g). Care should be taken to avoid loss of any part of sample. The entire sample, including the dust of abrasion and fracture, is then returned to testing machine and rotated for 400 revolutions. Discharge sample from machine and repeat previous sieving procedure. Wash material coarser than No. 12 sieve (note 5), oven dry at 221 to 230 °F (105 to 110 °C) to a substantially constant mass, and determine mass to nearest 0.002 lbm.

NOTE 6.–Valuable information concerning uniformity of sample under test may be obtained by determining loss after 100 revolutions. Ratio of loss after 100 revolutions to loss after 500 revolutions should not exceed 0.20 for material of uniform hardness. It is standard Bureau practice to determine percent loss after both 100 and 500 revolutions.

11. Calculation

11.1 Express the loss (difference between original and final mass of test sample) as a percentage of original mass of test sample. Report this value as the percent loss.

11.2 A suggested worksheet is shown on figure 2 of USBR 4075.

NOTE 7.–The percent loss determined by this procedure has no known consistent relationship to percent loss for same material when tested by USBR 4535.

12. Report

12.1 Figure 3 of USBR 4075 shows a suggested reporting form and typical data.

13. Precision and Bias[4]

13.1 For nominal 3/4-inch (19.0-mm) maximum size coarse aggregate with percent losses in a 10- to 45-percent range, the multilaboratory coefficient of variation has been found to be 4.5 percent. Therefore, results of two properly conducted tests from two different laboratories on samples of same coarse aggregates should not differ from each other by more than 12.7 percent of their average. The single-operator coefficient of variation has been found to be 2.0 percent. Therefore, results of two properly conducted tests by same operator on same coarse aggregate should not differ from each other by more than 5.7 percent of their average.

13.2 The bias for this procedure has not been determined.

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[4] These precision values represent the (1S percent) and (D2S percent) limits as described in ASTM C 670.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4136-92

PROCEDURE FOR

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4136; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 136-84.

1. Scope

1.1 This designation covers the procedure for determination of particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates that reference this procedure contain grading requirements including both coarse and fine fractions. Instructions are included for the sieve analysis of such aggregates.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4117 Materials Finer Than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[3,4]

2.3 *AASHTO Standard*:

T 27 Sieve Analysis of Fine and Coarse Aggregates[5]

3. Summary of Procedure

3.1 A determined mass of the sample of dry aggregate is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

4. Significance and Use

4.1 This procedure is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

4.2 Accurate determination of material finer than the No. 200 (75-μm) sieve cannot be achieved by use of this method alone; designation USBR 4117 for material finer than the No. 200 sieve by washing should be used.

5. Apparatus

5.1 *Balances.*-Balances or scales used in testing the fine and coarse aggregates shall have readability and accuracy as follows:

5.1.1 For fine aggregate, readable and accurate to 0.0002 lbm (0.1 g) or 0.1 percent of test load, whichever is greater, at any point within range of use.

5.1.2 For coarse aggregate or mixtures of fine and coarse aggregate, readable and accurate to 0.001 lbm (0.5 g) or 0.1 percent of test load, whichever is greater, at any point within range of use.

5.2 *Sieves.*-The sieves shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The sieves shall conform to ASTM E 11. Sieves with openings larger than 5 inches (125 mm) shall have a permissible variation in average opening of ±2 percent and shall have a nominal wire diameter of 5/16 inch (8.0 mm) or larger.

NOTE 1.-It is recommended that sieves mounted in frames larger than the standard 8-inch (203-mm) diameter frames be used for testing coarse aggregate.

5.3 *Mechanical Sieve Shaker.*-A mechanical sieve shaker, if used, shall impact a vertical, or lateral and vertical,

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.
[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.08.
[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05.
[4] *Annual Book of ASTM Standards*, vol. 14.02.
[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol Street NW., Suite 225, Washington, DC 20001.

motion to the sieve that will cause the particles thereon to bounce and turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in section 10.4 is achieved in a reasonable time period.

NOTE 2.-Use of mechanical sieve shaker is recommended when size of sample is 44 lbm (20 kg) or greater, and may also be used for smaller samples including fine aggregate. Excessive time (more than about 10 minutes) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples because the large sieving area needed for practical sieving of a large nominal size coarse aggregate could possibly result in loss of a portion of the sample if used for a small sample of fine or coarse aggregate.

5.4 *Oven.*-An oven of appropriate size that is capable of maintaining a uniform temperature of 230±9°F (110±5°C).

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Sampling

7.1 Sample aggregate in accordance with USBR 4075. The mass of field sample shall be mass shown in USBR 4075 or four times the mass required in sections 7.4 and 7.5 (except as modified in 7.6), whichever is greater.

7.2 Thoroughly mix sample and reduce it to an amount suitable for testing using applicable procedures described in USBR 4702. The sample for test shall be about the mass desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted.

NOTE 3.-Where sieve analysis, including determination of material finer than the No. 200 (75-μm) sieve, is the only testing proposed, size of sample may be reduced in field to avoid shipping excessive quantities of extra material to laboratory.

7.3 *Fine Aggregate.*-The mass of the fine aggregate, after drying, should approximate the amount shown in table 1. This amount is split into duplicate samples for sieve analysis. After splitting, resultant test samples are placed on separate nests of sieves and sieved in accordance with sections 10.2 through 10.7.

7.4 *Coarse Aggregate.*-The mass of the test sample of coarse aggregate shall conform to table 2.

7.5 *Coarse and Fine Aggregate Mixtures.*-The mass of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate (sec. 7.4).

7.6 The size of sample required for aggregates with large nominal maximum size shall be such as to preclude testing except with large mechanical sieve shakers. A large sample may be split in accordance with USBR 4702 into several suitably smaller portions, with each smaller portion then sieved and mass of each specified size fraction in that portion determined. After all portions have been sieved, total mass of each specified size fraction shall be determined and required gradation calculations made based upon mass of original large sample. However, the intent of this procedure shall be satisfied for samples of aggregate larger than 1-1/2-inch (37.5-mm) nominal maximum size if a smaller mass of sample is used, provided that criterion for acceptance or rejection of the material is based on the average of several samples, and that sample size used times number of samples averaged equals minimum mass of sample shown in section 7.4.

7.7 In the event that amount of material finer than the No. 200 (75-μm) sieve is to be determined by USBR 4117, proceed as follows:

7.7.1 For aggregates with a nominal maximum size of No. 4 (4.75 mm) or less, use the same test sample for testing by USBR 4117 and this procedure. First, test the sample in accordance with USBR 4117 through the final drying operation, and then dry sieve sample as stipulated in sections 10.2 through 10.7 of this procedure.

7.7.2 For aggregates with a nominal maximum size greater than No. 4 (4.75 mm), a single test sample may be used as described in 7.7.1, or separate test samples may be used for USBR 4117 and this procedure.

Table 1. - Fine aggreagate sample size.[1]

Minimum amount passing sieve	Minimum mass of test sample, lbm	(kg)
No. 8 (2.36 mm)	0.20	(0.10)
No. 4 (4.75 mm)	0.20	(0.10)

[1] These samples are split in accordance with USBR 4702, and the sieve analysis performed on the resultant two samples.

Table 2. - Coarse aggregate sample size.

Nominal maximum size (square openings) inches	(mm)	Minimum mass of test sample, lbm	(kg)
3/8	(9.5)	0.5	(0.25)
1/2	(12.5)	0.75	(0.30)
3/4	(19.0)	2.5	(1.1)
1	(25.0)	5.5	(2.5)
1-1/2	(37.5)	20	(10)
2	(50)	45	(20)
2-1/2	(63)	90	(40)
3	(75)	150	(70)
3-1/2	(90)	255	(115)
4	(100)	350	(160)
4-1/2	(112)	530	(240)
5	(125)	680	(310)
6	(150)	1,175	(535)

Note: The masses shown for each size are not mathematically interchangeable, each mass was rounded off to a more convenient number.

7.7.3 Where specifications require determination of total amount of material finer than the No. 200 (75-μm) sieve by washing and dry sieving, use method described in 7.7.1.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

8.2 Balances or scales shall conform to requirements of section 5.1 by calibration in accordance with USBR 1012.

8.3 Sieves shall conform to requirements of section 5.2 and ASTM E 11 by calibration in accordance with USBR 1025.

8.4 The oven shall conform to requirements of section 5.4 by calibration in accordance with USBR 1020.

9. Conditioning

9.1 The conditioning of the material is washing (if required) and ovendrying.

10. Procedure

10.1 Dry sample to a constant mass at 230±9°F (110±5°C).

NOTE 4.–For control purposes, particularly where rapid results are desired, it is generally not necessary to dry the coarse aggregate for the sieve analysis test. The results are minimumly affected by the moisture content unless (1) nominal maximum size is smaller than about No. 4 (4.75 mm), (2) coarse aggregate contains appreciable material finer than No. 4, or (3) coarse aggregate is highly absorptive, as in low density aggregate. Also, samples may be dried at the higher temperatures associated with the use of hot plates without affecting results provided steam escapes without generating pressures sufficient to fracture particles, and temperatures are not so great as to cause chemical breakdown of aggregate.

10.2 Nest sieves in decreasing size of opening from top to bottom and place sample on top sieve. Agitate sieves by hand or mechanical apparatus for a sufficient period that has been established by trial or checked by measurement on actual test sample to meet criterion for adequacy of sieving described in section 10.4.

10.3 Limit quantity of material on a given sieve so that all particles have the opportunity to reach sieve openings several times during sieving operation. For sieves with openings smaller than No. 4 (4.75 mm), the mass retained on any sieve at completion of sieving operation shall not exceed 0.0085 lbm/in^2 (6.0 kg/m^2) of sieving surfaces (note 5). For sieves with openings of No. 4 and larger, the mass in pound mass per square foot (kilograms per square meter) of sieving surface shall not exceed the product of 2.5 times the sieve opening in inches (millimeters). In no case shall the mass be so great as to cause permanent deformation of the sieve cloth.

NOTE 5.–The 0.0085 lbm/in^2 amounts to 0.428 lbm (194 g) for the standard 8-inch (203-mm) diameter sieve. The amount of material retained on a sieve may be regulated by using a sieve with larger openings immediately above the given sieve or by testing sample in a number of increments.

10.4 Continue sieving for a sufficient period and in such a manner that, after completion, not more than 1 percent of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving performed as follows: Hold individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike side of sieve sharply and with an upward motion against heel of other hand at a rate of about 150 times per minute while turning sieve about one sixth of a revolution at about every 25 strokes. In determining sufficiency of sieving for sizes larger than the No. 4 (4.75-mm) sieve, limit material on sieve to a single layer of particles. If size of mounted testing sieves makes the described sieving motion impractical, use 8-inch (203-mm) diameter sieves to verify sufficiency of sieving.

10.5 In the case of coarse and fine aggregate mixtures, portion of sample finer than the No. 4 (4.75-mm) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

10.5.1 Alternatively, the portion finer than the No. 4 sieve may be reduced in size using a mechanical splitter according to USBR 4702. If this procedure is followed, compute mass of each size increment of original sample as follows:

$$A = \left(\frac{M_1}{M_2}\right)(B) \qquad (1)$$

where:

A_1 = mass of size increment on total sample basis,
M_1 = mass of fraction finer than No. 4 (4.75-mm) sieve in total sample,
M_2 = mass of reduced portion of material finer than No. 4 sieve actually sieved, and
B = mass of size increment in reduced portion sieved.

10.5.2 Figure 2 of USBR 4075 shows a suggested worksheet and typical computations.

10.6 Unless a mechanical sieve shaker is used, hand sieve particles larger than 3 inches (75 mm) by determining smallest sieve opening through which each particle will pass. Start test on smallest sieve to be used. Rotate particles, if necessary, to determine whether they will pass through a particular opening; however, do not force particles to pass through.

10.7 Determine mass of each size increment on a scale or balance conforming to requirements in section 5.1 to nearest 0.1 percent of total original dry sample mass. The total mass of material after sieving should check closely with original mass of sample placed on sieves. If amounts differ by more than 0.3 percent, based on original dry sample mass, results should not be used for acceptance purposes.

10.8 If sample has previously been tested by USBR 4117, add the mass finer than the No. 200 (75-μm) sieve determined by USBR 4117 to the mass passing the No. 200 sieve by dry sieving of same sample in this procedure.

NOTE 6.–Careful maintenance of sieves is required for accurate sieving. Fine aggregate sieves, generally 8 inches (203 mm) in diameter, should be carefully cleaned to minimize blinding of mesh openings. A soft brass, bristle brush or a stiff, short bristle, stencil brush is satisfactory for cleaning the No. 50 (300-μm) and coarser sieves. Only a soft hair brush should be used for cleaning the No. 100 (150-μm) and finer sieves. Cleaning brushes should be gently applied to underside of sieve after each test. Harsh raking or scraping actions with cleaning brush should be avoided because the wire cloth may be damaged by too much pressure. It is neither practical nor desirable to remove all particles lodged in sieve; however, the number of blinded openings in sieve should be reduced to a reasonable minimum. With each usage, sieves should be visually inspected for wear or damage and to guard against use of sieves with broken or stretched wires. If soldering is required to repair small holes or breaks around sieve edges, a noncorrosive flux such as rosin core should be used. Battering or jolting standard sieves to dislodge aggregate particles caught in sieve openings can damage the wire mesh or deform the frame. Rims of nesting sieves should not be struck on hard surfaces such as edges of trash cans. Cuts, indentations, and other damage to rims will make it difficult to properly nest the sieves in a stack.

11. Calculations

11.1 Calculate percentages passing, total percentages retained, or percentages in various size fractions to nearest 0.1 percent on basis of total mass of initial dry sample. If same test sample was first tested by USBR 4117, include mass of material finer than the No. 200 (75-μm) size (by washing) in the sieve analysis calculation; and use the total dry sample mass (prior to washing) in USBR 4117 as the basis for calculating all percentages.

11.2 Calculate the fineness modulus, when required, by adding total percentages of material in sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing this sum by 100: No. 100 (150μm), No. 50 (300μm), No. 30 (600 μm), No. 16 (1.18 mm), No. 8 (2.36 mm), No. 4 (4.75 mm), 3/8 inch (9.5 mm), 3/4 inch (19.0 mm), 1-1/2 inches (37.5 mm), and larger, increasing in the ratio of 2 to 1.

11.3 Figure 2 of USBR 4075 shows a suggested worksheet and typical computations.

12. Report

12.1 Figure 3 of USBR 4075 shows a typical reporting form. Depending upon form of specifications for use of material under test, report shall include:

- Total percentage of material passing each sieve, total percentage of material retained on each sieve, or percentage of material retained between consecutive sieves.
- Report percentages to the nearest whole number unless percentage passing the No. 200 (75-μm) sieve is less than 10 percent, then report to nearest 0.1 percent.
- Report fineness modulus, when required, to nearest 0.01.
- Report average data for fine aggregate samples

12.2 An alternate method for reporting the sieve analysis determination is by plotting graphs, see figures 1 and 2.

13. Precision and Bias

13.1 The estimates of precision for this procedure, as shown in table 3, are based on the results from the AASHTO Materials Reference Laboratory Reference Sample Program with testing conducted by ASTM C 136 and AASHTO T 27. While there are differences in the minimum mass of test sample required for other nominal maximum sizes of aggregate, no differences entered into the testing to affect the determination of these precision indexes. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The values in table 3 are given for different ranges of percentage of aggregate passing one sieve and retained on the next finer sieve.

13.2 There is no known bias.

Table 3. - Precision values.

	Percentage of size fraction between two consecutive sieves	Coefficient of variation (1S %),* percent	Standard deviation (1S),† percent	Acceptable range of test results	
				(D2S %),* percent of average	(D2S),† percent
Coarse aggregates:††					
Single-operator precision	0 to 3	30§	-	85§	-
	3 to 10		1.4		4.0§
	10 to 20		0.95		2.7
	20 to 50		1.38		3.9
Multilaboratory precision	0 to 3	35§	-	99§	-
	3 to 10		1.06		3.0
	10 to 20		1.66		4.7
	20 to 30		2.01		5.7
	30 to 40		2.44		6.9
	40 to 50		3.18		9.0
Fine Aggregates:					
Single-operator precision	0 to 3		0.14		0.4
	3 to 10		0.43		1.2
	10 to 20		0.60		1.7
	20 to 30		0.64		1.8
	30 to 40		0.71		2.0
	40 to 50		-		-
Multilaboratory precision	0 to 3		0.21		0.6
	3 to 10		0.57		1.6
	10 to 20		0.95		2.7
	20 to 30		1.24		3.5
	30 to 40		1.41		4.0
	40 to 50		-		-

* These numbers represent, respectively, the (1S %) and (D2S %) limits as described in ASTM C 670.

† These numbers represent, respectively, the (1S) and (D2S) limits as described in ASTM C 670.

†† The precision estimates are based on coarse aggregates with a nominal maximum size of 3/4 inch (19.0 mm).

§ These values are from precision indices first included in ASTM C 136-77. Other indices were developed in 1982 from more recent AASHTO Materials Reference Laboratory sample data; however, these data did not provide sufficient information to revise the values.

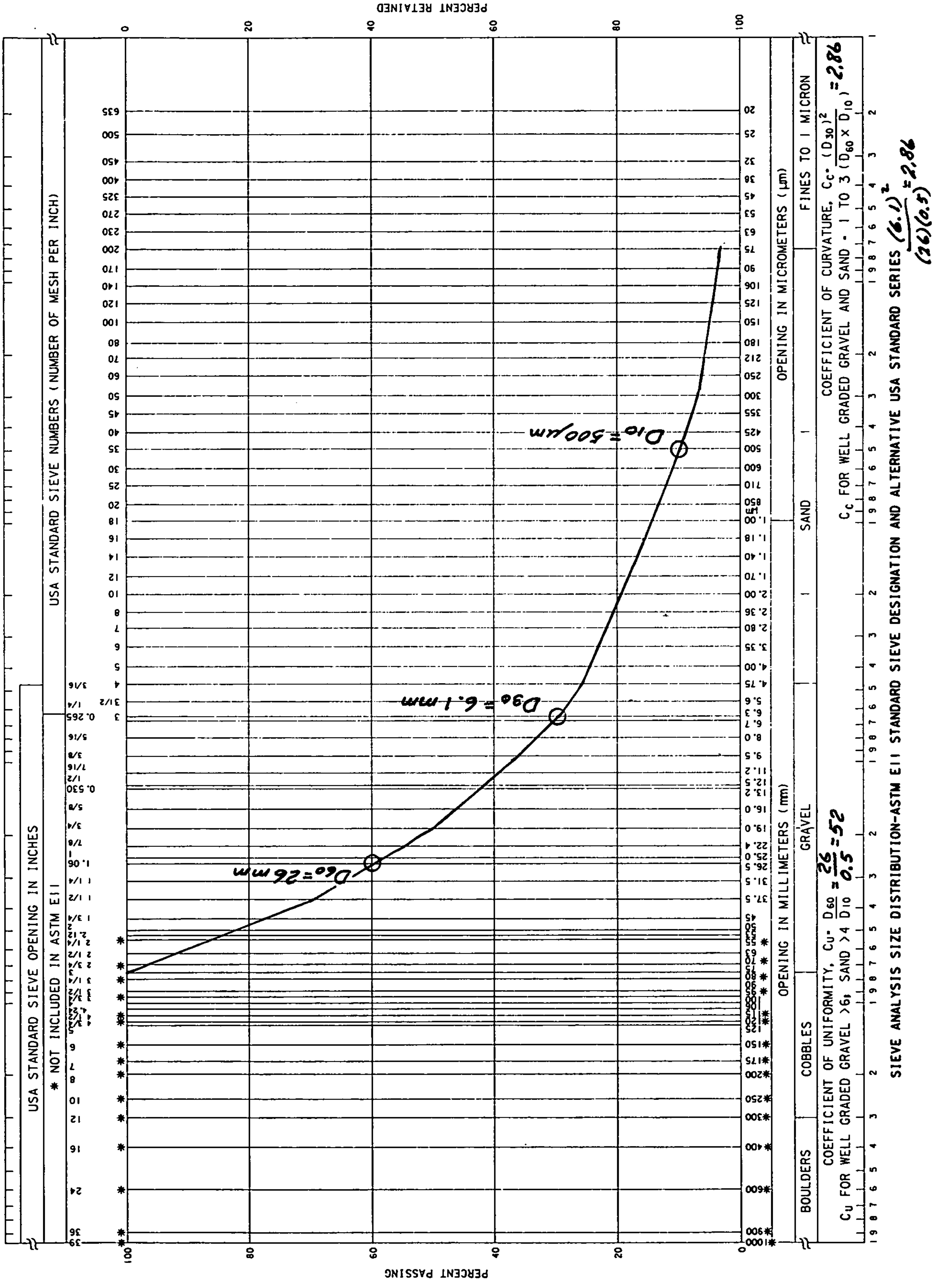

Figure 1. – Sieve analysis size distribution — ASTM E 11 standard sieve designation and alternative US standard series.

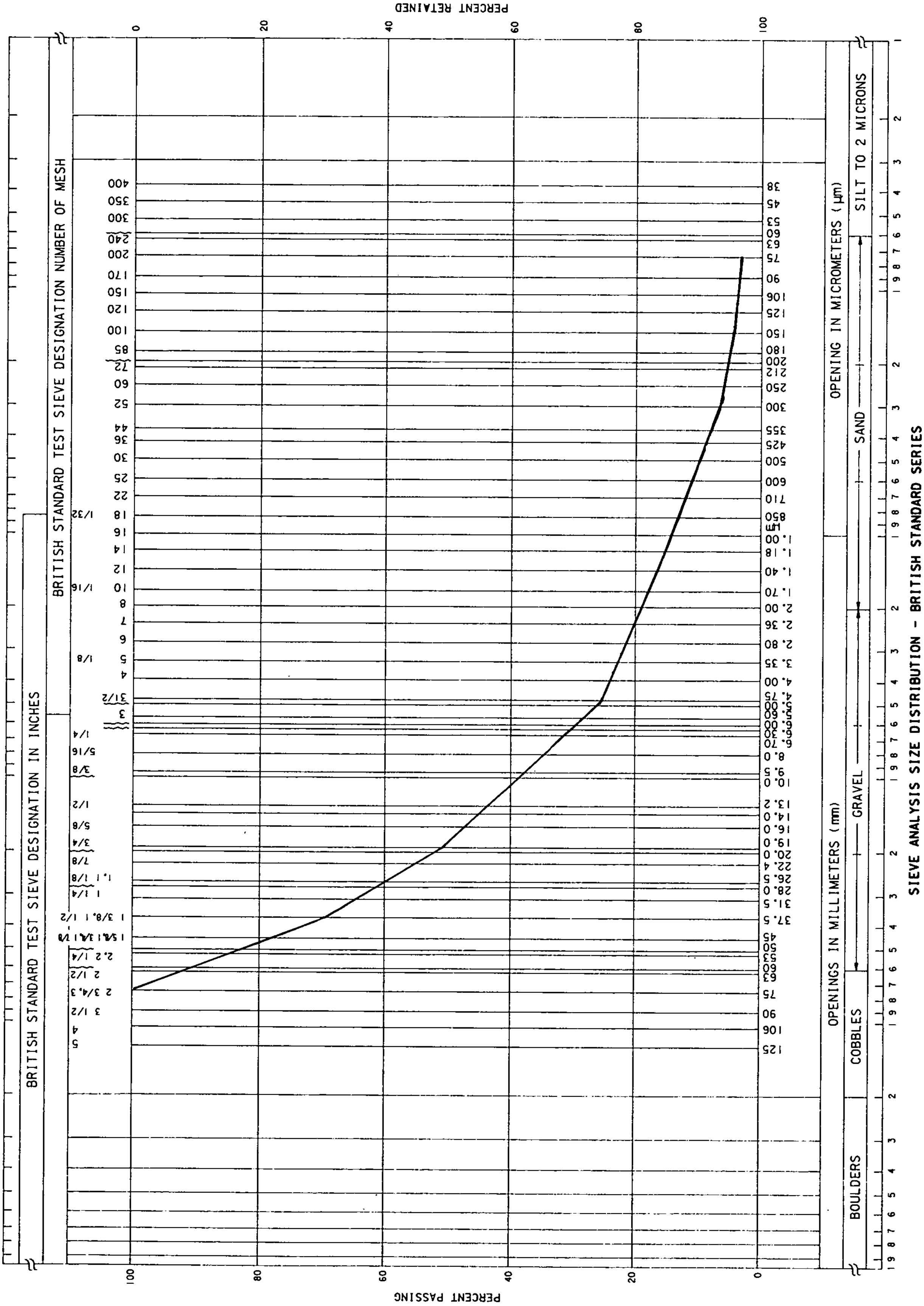

Figure 2. – Sieve analysis size distribution — British standard series.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4138-92

PROCEDURE FOR

DENSITY, YIELD, CLEAN SEPARATION, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4138; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 138-81.

1. Scope

1.1 This designation covers the procedure for determination of mass per cubic foot, per cubic yard, or per cubic meter of freshly mixed concrete; and presents formulas for calculating yield, materials content, and air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

2. Applicable Documents

2.1 *USBR Procedures*:
1011 Calibrating Measures for Sand Calibration
1012 Calibrating Balances or Scales
4029 Density and Voids in Aggregate
4031 Making and Curing Concrete Test Specimens in Field
4094 Specifications for Ready-Mixed Concrete
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4188 Density of Hydraulic Cementitious Materials
4192 Making and Curing Concrete Test Specimens in Laboratory
4211 Selecting Proportions for Concrete Mixtures
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
4905 Consistency and Density of No-Slump Concrete With Vibratory Table

2.2 *ASTM Standards*:
C 138 Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[1]
C 150 Standard Specification for Portland Cement[1,2]

3. Apparatus

3.1 *Balance*.–The balance or scale shall comply with accuracy shown in table 1. The range of use shall be considered to extend from the mass of empty measure to mass of measure plus contents at 160 lbm/ft^3 (2563 kg/m^3).

Table 1. – Minimum capacity of measures, and accuracy of scales.

Max. nominal size of aggregate		Min. capacity of measure		Required accuracy of scales	
inches	(mm)	ft^3	(m^3)	±lbm	(±kg)
No. 4	(4.75)	0.05	(0.0014)	0.01	0.005
3/8	(9.5)	0.10	(0.0028)	0.02	0.01
3/4	(19.0)	0.15	(0.0042)	0.02	0.01
1	(25.0)	0.20	(0.0057)	0.02	0.01
1-1/2	(37.5)	0.25	(0.0071)	0.02	0.01
2	(50)	0.33	(0.0093)	0.05	0.02
3	(75)	0.50	(0.0142)	0.05	0.02
4	(100)	0.75	(0.0212)	0.10	0.05
4-1/2	(115)	1.00	(0.0283)	0.10	0.05
6	(150)	3.00	(0.0850)	0.50	0.23

3.2 *Tamping Rod*.–The tamping rod shall be a round, straight, steel rod that is 5/8 inch (16 mm) in diameter and about 24 inches (610 mm) in length with the tamping end rounded to a 5/8-inch-diameter hemispherical tip.

3.3 *Internal Vibrator*.–Internal vibrators may have rigid or flexible shafts, preferably powered by electric motors. The frequency of vibration shall be 10,000 to 15,000 vibrations per minute or greater while in use. The peak amplitude, or one-half the peak-to-peak value, operating in air shall be 0.0167 to 0.030 inch (0.4 to 0.8 mm). The frequency and amplitude shall be determined by the procedure outlined in USBR 4192. The outside diameter or side dimension of the vibrating element shall be at

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

least 0.75 inch (19 mm) and not greater than 1.50 inches (38 mm). The length of the shaft shall be at least 24 inches (610 mm).

3.4 *Measure.*–The measure shall be a cylindrical container made of steel or other suitable metal (note 1). Measure shall be watertight and sufficiently rigid to retain its form and calibrated volume under rough usage. Measures that are machined to accurate dimensions on the inside and provided with handles are preferred. The minimum capacity of measure shall conform to requirements of table 1. All measures, except for measuring bowls of air meters which are also used for USBR 4138 tests, shall conform to requirements of USBR 4029. When measuring bowls of air meters are used, they shall conform to requirements of USBR 4231. The top rim of the air-meter bowls shall be smooth and plane within 0.01 inch (0.25 mm) (note 2).

NOTE 1.–The metal should not be readily subject to attack by cement paste; however, reactive materials such as aluminum alloys may be used in instances where, as a consequence of an initial reaction, a surface film is rapidly formed which protects metal against further corrosion.

NOTE 2.–The top rim is satisfactorily plane if a 0.01-inch (0.25-mm) feeler gauge cannot be inserted between rim and a piece of 1/4-inch (6-mm) or thicker plate glass laid over top of measure.

3.5 *Strike-Off Plate.*–A flat, rectangular, metal plate at least 1/4 inch (6 mm) thick or a glass or acrylic plate at least 1/2 inch (13 mm) thick with a length and width at least 2 inches (50 mm) greater than diameter of measure with which plate is to be used is required. The edges of the plate shall be straight and smooth within a tolerance of 1/16 inch (1.6 mm).

3.6 *Calibration Equipment.*–A piece of plate glass, preferably at least 1/4 inch (6 mm) thick and at least 1 inch (25 mm) larger than diameter of measure to be calibrated is required. A supply of water-pump or chassis grease that can be placed on rim of container to prevent leakage is also required.

3.7 *Mallets.*–One mallet, with a rubber or rawhide head, shall have a mass of about 1.25±0.50 lbm (0.57±0.23 kg) for use with measures of 0.5 ft^3 (0.014 m^3) or smaller. For measures larger than 0.5 ft^3, a mallet with a mass of about 2.25±0.50 lbm (1.02±0.23 kg) is required.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Calibration and Standardization

5.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

5.2 Balances or scales shall be calibrated to comply with section 3.1 in accordance with USBR 1012.

5.3 The frequency and amplitude of the vibrators shall be calibrated to comply with section 3.3 in accordance with procedure outlined in USBR 4192.

5.4 Measures shall be calibrated to comply with section 3.4 in accordance with USBR 1011.

5.5 Calibrate measure and determine factor used to convert mass in pounds or kilograms contained in measure to density in pound mass per cubic foot or kilograms per cubic meter. Follow procedure outlined in USBR 4029. Measures shall be recalibrated at least annually or whenever there is reason to question accuracy of calibration.

6. Sample

6.1 Obtain sample of freshly mixed concrete in accordance with USBR 4172.

7. Procedure

7.1 Rod concrete with a slump greater than 3 inches (76 mm), rod or vibrate concrete with a slump of 1 to 3 inches (25 to 76 mm), and vibrate concrete with a slump less than 1 inch.

NOTE 3.–Nonplastic concrete such as commonly used in manufacture of pipe, unit masonry, and roller compacted concrete is not covered by this procedure. Refer to USBR 4031, 4094, 4192, or 4905.

7.2 *Rodding.*–Place concrete in measure in three layers of approximately equal volume. Rod each layer with 25 strokes of tamping rod when 0.5-ft^3 (0.014-m^3) or smaller measures are used and 50 strokes when a 1-ft^3 (0.028-m^3) measure is used. Rod bottom layer throughout its depth, but rod shall not forcibly strike bottom of measure. Distribute strokes uniformly over cross section of measure and, for top two layers, penetrate about 1 inch (25 mm) into underlying layer. After each layer is rodded, tap sides of measure sharply 10 to 15 times with appropriate mallet (see sec. 3.7) to close any voids left by tamping rod and to release any large bubbles of air that may have been trapped.

7.3 *Internal Vibration.*–Fill and vibrate measure in two approximately equal layers. Place all concrete for each layer in measure before starting vibration of that layer. Insert vibrator at three different points for each layer. In compacting bottom layer, do not allow vibrator to rest on or touch bottom or sides of measure. In compacting final layer, vibrator shall penetrate into underlying layer about 1 inch (25 mm). Take care that vibrator is withdrawn in such a manner that no air pockets are left in specimen. The duration of vibration required will depend upon workability of concrete and effectiveness of vibrator (note 4). Continue vibration only long enough to achieve proper consolidation of concrete (note 5). Observe a constant duration of vibration for the particular kind of concrete, vibrator, and measure involved.

NOTE 4.-Usually, sufficient vibration has been applied when surface of concrete becomes relatively smooth and exhibits a shiny wet appearance, at which time vibrator is slowly withdrawn.

NOTE 5.-Overvibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

7.4 On completion of consolidation, measure must not contain a substantial excess or deficiency of concrete. An excess of concrete protruding about 1/8 inch (3 mm) above top of mold is optimum. A small quantity of concrete may be added to correct a deficiency. If measure contains a large excess of concrete at completion of consolidation, remove a representative portion of the excess concrete with a trowel or scoop immediately following completion of consolidation and before strike-off (sec. 7.5).

7.5 *Strike-Off.*-After consolidation, strike-off top surface of concrete and finish smoothly with flat strike-off plate; take care to leave measure level full. The strike-off is best accomplished by pressing strike-off plate onto top surface of measure to cover about two-thirds of surface. Then, withdraw plate with a sawing motion to finish only area originally covered. Again place plate on top of measure to cover original two-thirds of surface and advance it with a vertical pressure and sawing motion to cover entire surface of measure. Several final strokes with inclined edge of plate will produce a smooth finished surface.

7.6 *Cleaning and Determining Mass.*-After strike-off, clean all excess concrete from exterior of measure and determine net mass of concrete in measure to an accuracy consistent with requirements of section 3.1.

8. Calculations

8.1 *Density.*-Calculate net mass of concrete in pound mass or kilograms by subtracting mass of measure from gross mass. Calculate density by dividing net mass by unit volume of measure used, in accordance with USBR 4029.

8.2 *Yield.*-Calculate the yield as follows:

$$Y = \frac{M}{D} \qquad (1)$$

where:

Y = volume of concrete produced per batch in cubic yards or cubic meters;
M = total mass of all materials batched in pound mass or kilograms (note 6), and
D = density of concrete in pound mass per cubic yard or kilograms per cubic meter.

NOTE 6.-A value for Y greater than 1.00 indicates an excess of concrete being produced, whereas a value less than 1.00 indicates the batch to be "short" of its designed volume.

8.3 *Cement Content.*-Calculate actual cement content:

$$N = \frac{N_t}{Y} \qquad (2)$$

where:

N = actual cement content in pound mass per cubic yard or kilograms per cubic meter,
N_t = mass of cement in batch in pound mass or kilograms, and
Y = as previously defined.

8.4 *Air Content.*-Calculate air content:

$$A = \frac{V_d - V_f}{V_d}(100) \qquad (3)$$

where:

A = air content (percentage of voids) in concrete,
V_d = volume of concrete that batch was designed to produce in cubic yards or cubic meters, and
V_f = total absolute volume of concrete produced per batch in cubic yards or cubic meters.

NOTE 7.-The theoretical mass per cubic foot, per cubic yard, or per cubic meter is, customarily, a laboratory determination, the value for which is assumed to remain constant for all batches made using identical component ingredients and proportions. The theoretical density is calculated from the equation:

$$T = \frac{M_1}{V_f} \qquad (4)$$

where:

T = theoretical density of concrete computed on an air-free basis in pound mass per cubic foot, pound mass per cubic yard, or kilograms per cubic meter,
V_f = as defined above, and
M_1 = total mass of all materials batched corrected for moisture, and oversize and undersize in pound mass or kilograms.

The absolute volume of each ingredient in cubic feet is equal to the quotient of the mass of that ingredient divided by the product of its specific gravity times 62.4, as determined in accordance with USBR 4127 or 4128. The absolute volume of each ingredient in cubic yards is equal to the quotient of the mass of that ingredient divided by the product of its specific gravity times (27)(62.4), or 1684.8. The absolute volume of each ingredient in cubic meters is equal to the mass of that ingredient in kilograms divided by 1000 times its specific gravity. For the aggregate components, the bulk specific gravity and mass should be based on the saturated-surface-dry condition. For cement and pozzolan, the actual specific gravity should be determined by USBR 4188 (specific gravity) and 4311 (pozzolans), respectively;

a value of 3.15 may be used for cements manufactured to meet requirements of ASTM C 150; a value for pozzolans must be determined because of the extreme variability in specific gravity.

NOTE 8.-The total mass of all materials batched is the sum of the masses of the cement, fine aggregate in condition used, coarse aggregate in condition used, mixing water added to batch, and any other solid or liquid materials used. Refer to USBR 4211 for selecting proportions of concrete mixtures.

8.5 Figure 1 shows a typical calculation form for this procedure. The calculations are called "clean separation calculations" because they correct for moisture content and oversize or undersize in the aggregate. Step-by-step instructions for completing figure 1 are shown on figure 2. A computerized worksheet is also available that is called a PCQCS (Project Concrete Quality Control Sytem), example not included in this procedure

9. Report

9.1 Figure 3 shows a typical reporting form that includes a slump measurement in accordance with USBR 4143. A PCQCS form is also available (not included).

10. Precision and Bias

10.1 Data are being compiled and developed that will be suitable for use in developing precision statements for this procedure.

10.2 The bias for this procedure has not been established.

Spec. or Solic. No.* DC-6820	Structure FOUNDATION PLUG	Tested by R. BURGER Date 12-30-70
Project* FRY-ARK	Item 46: 3-inch MSA INTERIOR Location ~	Computed by R. BURGER Date 12-30-70
Feature* PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 12-30-70

CONCRETE MIX DATA WORKSHEET
(Clean Separation Calculations)

Volume of Concrete Represented*: 186 yd³; Test Cylinder Nos.: I-325 THRU I-330 W.F. HANDY Co. LADUE, MO
Type and Source of Portland Cement*: IDEAL II LA-PORTLAND Co. Class and Source of Pozzolan*: FLY ASH "F"
Percent Cementitious* 15; Brand and Source of AEA*: PROTEX; Dosage per (oz. or mL)* —
Type and Brand of Other Admixtures* WRA PDA-25; Dosage per (oz. or mL)* 1.5 mL/lbm CEMENTITIOUS
Slump* 2.00 inches; Density (D) = 147.3 [✓ lbm/ft³] or yd³; Measured Air Content* 4.0 %; Temp.* 50 °F
Date (Mo., Day, Year) and Shift* 12-30-70 (SECOND SHIFT); Inspector R. BURGER

1. Ingredients V_d = 1,000 yd³	2. Amount Actually Batched, lbm	3. Corrrection For Moisture in Aggregate: A. Percent of Moisture	B. SSD Batched Quantity, lbm	C. Batched Water in Aggregate, lbm	4. Correction for Oversize and Undersize in SSD Aggregate	A. Distrib. of Nominal Size, percent	B. Batched Quantity, lbm	C. Clean Separation Adjustment, lbm	5. Corrected Batch Quantities, lbm	6. Quantity per Cubic Yard of Concrete, lbm	7. Solid Volume per Cubic Yard, yd³	8. Coarse Aggregate Grading, percent (Based on Solid Volume)
AEA	66 mL								66 mL	66 mL*		
Cement	N_t = 254								254	N = 253*	0.047	
Pozzolan	N_t = 85								85	N = 85*	0.020	
Sand	997	4.2	957	40	Nominal Fraction	98.2	940	→	952	947	0.215	
					Oversize	1.8	17	12 →				
Coarse Aggregate: No. 4 to 3/4 inch	852	0.6	847	5	Undersize	1.4	12	17 →	859	855	0.195	* 34.2
					Nominal Fraction	96.0	813					
					Oversize	2.6	22	29 →				
3/4 to 1½ inches	961	-0.5	966	-5	Undersize	3.0	29	22 →	930	925	0.210	* 36.8
					Nominal Fraction	88.6	856	→				
					Oversize	8.4	81	52 →				
1½ to 3 inches	696	-0.8	702	-6	Undersize	7.4	52	81 →	731	727	0.165	* 29.0
					Nominal Fraction	92.6	650	→				
					Oversize	0	0	→				
__ to __ inches					Undersize			→				*
					Nominal Fraction +Oversize			→				
Water	152			34					186	185*	0.110	
Totals, M	M = 3,997		3,472				3,472		3,997	M_1 = 3,977	V_f = 0.962	
Total Aggregate	3,506											

Specific gravities: Cement 3.17 Pozzolan 2.52 Total Coarse Aggregate Volume 0.570

Sand 2.61, No. 4 to 3/4 in 2.60, 3/4 to 1½ in 2.61, Total Aggregate Volume 0.785

1½ to 3 in 2.62, ~ to ~ in ~, ~ to ~ in ~.

Yield of Batch: $Y = \frac{(3997)\ \text{lbm}}{(3977)\ \text{lbm/yd}^3} = 1.005\ \text{yd}^3$ Air Content (Gravimetric Method)*: $A = \frac{1 - 0.962\ \text{yd}^3}{1\ \text{yd}^3}(100) = 3.8\ \%$

Water-Cement Ratio*: $\frac{W}{C + P} = \frac{(185)\ \text{lbm}}{(338)\ \text{lbm}} = 0.55$ Percent Sand*: $\frac{(0.215)\ \text{yd}^3}{(0.785)\ \text{yd}^3}(100) = 27.4\ \%$

* Data to be submitted with monthly progress report (fig. 3). T = 4134 lbm/ft³, [✓ lbm/yd³]

Figure 1a.–Sample concrete mix data worksheet (inch-pound units).

Spec. or Solic. No.* DC-6820	Structure FOUNDATION PLUG	Tested by R. BURGER Date 12-30-70
Project* FRY-ARK	Item 46: 75-mm MSA INTERIOR Location ~	Computed by R. BURGER Date 12-30-70
Feature* PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 12-30-70

CONCRETE MIX DATA WORKSHEET
(Clean Separation Calculations)

Volume of Concrete Represented*: 142 m³; Test Cylinder Nos.: I-325 THRU I-330
Type and Source of Portland Cement*: IDEAL II LA-PORTLAND, CO; Class and Source of Pozzolan*: FLY ASH "F" W.F. HANDY Co. LADUE, MO
Percent Cementitious* 15; Brand and Source of AEA*: PROTEX; Dosage per (oz. or mL)* —
Type and Brand of Other Admixtures* WRA PDA-25; Dosage per (oz. or mL)* 3.3 mL/kg CEMENTITIOUS
Slump* 50.8 mm; Density (D) = 2358 kg/m³; Measured Air Content* 4.0 %; Temp.* 10 °C
Date (Mo., Day, Year) and Shift* 12-30-70 (SECOND SHIFT); Inspector R. BURGER

1. Ingredients V_d = 1.000 m³	2. Amount Actually Batched, kg	3. Corrrection For Moisture in Aggregate A. Percent of Moisture	B. SSD Batched Quantity, kg	C. Batched Water in Aggregate, kg	4. Correction for Oversize and Undersize in SSD Aggregate	A. Distrib. of Nominal Size, percent	B. Batched Quantity, kg	C. Clean Separation Adjustment, kg	5. Corrected Batch Quantities, kg	6. Quantity per Cubic Meter of Concrete, kg	7. Solid Volume per Cubic Meter, m³	8. Coarse Aggregate Grading, percent (Based on Solid Volume)
AEA	86 mL								86 mL	86 mL *		
Cement	N_t = 150								150	N = 149*	0.047	
Pozzolan	N_t = 51								51	N = 51*	0.020	
Sand	591	4.2	567	24	Nominal Fraction	98.2	557	→	564	561	0.215	
					Oversize	1.8	10	7 →				
Coarse Aggregate 4.75 mm to 19.0 mm	505	0.6	502	3	Undersize	1.4	7	10 →	509	507	0.195	* 34.2
					Nominal Fraction	96.0						
					Oversize	2.6	13	17 →				
19.0 to 37.5 mm	570	-0.5	573	-3	Undersize	3.0	17	13 →	552	549	0.210	* 36.8
					Nominal Fraction	88.6	508	→				
					Oversize	8.4	48	31 →				
37.5 to 75 mm	413	-0.8	416	-3	Undersize	7.4	31	48 →	433	431	0.165	* 29.0
					Nominal Fraction	92.6	385	→				
					Oversize	0	0	→				
___ to __ mm					Undersize			→				*
					Nominal Fraction + Oversize			→				
Water	90			21					111	110 *	0.110	
Totals, M	M = 2370		2058				2058		2370	M_1 = 2358	V_f = 0.962	

Total Aggregate 2169

Specific Gravities: Cement 3.17, Pozzolan 2.52, Sand 2.61, 4.75 to 19.0 mm 2.60, 19.0 to 37.5 mm 2.61, 37.5 to 75 mm, ~ to ~ mm ~, ~ to ~ mm ~.

Total Coarse Aggregate Volume 0.570

Total Aggregate Volume 0.785

Yield of Batch: $Y = \frac{(2370)\ \text{kg}}{(2358)\ \text{kg/m}^3} = 1.005\ \text{m}^3$ Air Content (Gravimetric Method)*: $A = \frac{1 - 0.962\ \text{m}^3}{1\ \text{m}^3}(100) = 3.8\ \%$

Water-Cement Ratio*: $\frac{W}{C+P} = \frac{(110)\ \text{kg}}{(200)\ \text{kg}} = 0.55$ Percent Sand*: $\frac{(0.164)\ \text{m}^3}{(0.600)\ \text{m}^3}(100) = 27.3\ \%$

T = 2451 kg/m³

* Data to be submitted with monthly progress report (fig. 3).

Figure 1b.–Sample concrete mix data worksheet (SI-metric units).

INSTRUCTIONS FOR USING CONCRETE MIX DATA WORKSHEETS

The portion of the worksheet above the numbered columns is self-explanatory. For the balance of the worksheet, use the following instructions.

Step 1.-In column 1, insert each nominal size range for the coarse aggregate.

Step 2.-In column 2, record (1) actual batch quantities, (2) total mass of all ingredients, and (3) total mass of all aggregates (box marked "Total Aggregate"). The liquid admixture quantities are not included for computations of totals.

Step 3.-In column 3A, record (as a percentage) the amount of free moisture or absorbed moisture from moisture tests performed on each nominal aggregate size. Use a plus (+) sign for free moisture and a minus (-) sign for absorbed moisture.

Step 4.-In column 3B, record SSD (saturated-surface-dry) mass for each aggregate size as batched:

$$\text{SSD Mass} = \frac{\text{Batch Mass (100)}}{100 \pm \text{Percent of Moisture}}$$

, where + sign indicates free moisture, - sign indicates absorbed moisture, batch from column 2, and percent of moisture from column 3A. Record the total of these values in the box marked "Totals, *M*."

Step 5.-Subtract SSD mass in column 3B from batch mass in column 2 and record difference in column 3C. This difference, if plus, is water being contributd to mix by the aggregate; if minus, it is amount of water that will be absorbed by aggregate to reach the SSD condition. The algebraic sum of these masses for all of the aggregates in column 3C should be recorded at the bottom of column 3C opposite "Water" in column 1. To verify this value, the total aggregate mass in column 2 minus the total in column 3B should be equal to the value recorded in column 3C.

Step 6.-From test results of aggregate gradation analyses, record in column 4A the percentages of oversize, undersize, and nominal fraction for each nominal size aggregate. The total percentage for each size of aggregate should be 100 percent.

Step 7.-Multiply percentage in column 4A by mass in column 3B, divide result by 100, and record value in column 4B. The total of column 4B should be equal to total of column 3B, except for occasional and insignificant round-off errors.

Step 8.-Transfer to column 4C the undersize and oversize mass values in column 4B as indicated by the small arrows shown on the dividing line between columns 4B and 4C.

Step 9.-Add combined masses in column 4C to corresponding nominal fraction in column 4B and record the resulting clean, separated, SSD batch quantities in column 5.

Step 10.-Transfer the quantities for cement, pozzolan, and admixtures from column 2 to column 5. Determine total amount of mixing water by adding mass of water in column 2 to mass of water in column 3C and record result in column 5. The total of all ingredients in column 2 should equal the total in column 5.

Step 11.-Calculate volume of batch, which is combined batch mass (total of either column 2 or column 5) divided by measured density of fresh concrete. An equation for this calculation is provided at bottom of worksheet.

Step 12.-Calculate and record in column 6 the mass of each ingredient per cubic yard (meter) of concrete by dividing each corrected batch quantity (col. 5) by volume of batch in cubic yards (meters). The toal of column 6 can be verified by mutliplying the measured density in pound mass per cubic foot by 27 or by direct comparison if density is in kilograms per cubic meter.

Step 13.-Calculate solid volume of each mix ingredient (mass in col. 6 divided by density of each ingredient) and record in column 7. At the bottom of column 7, show the total of solid volumes and also the solid volumes for coarse aggregate and total aggregate, where indicated. Record these total values to the nearest 0.001 cubic yard (or cubic meter).

Step 14.-The volume of air is equal to one minus the total solid volume of the ingredients in column 7, and the gravimetric percentage of air is equal to volume of air in cubic yards per cubic yard (cubic meters per cubic meter) of concrete times 100. An equation for this calculation is provided at bottom of worksheet. Record air content to nearest 0.1 percent.

Step 15.-Calculate percent sand:

$$\text{Sand: Percent Sand} = \left(\frac{\text{Sand Volume}}{\text{Total Aggregate Volume}} \right) (100)$$

The sand volume and total aggregate volume are obtained from column 7. An equation for this calculation is provided at bottom of worksheet.

Step 16.-Based on clean separation, calculate percentage of each nominal fraction of coarse aggregate by dividing solid volume of fraction size by total volume of coarse aggregate and then multiplying by 100. Record results in column 8.

Step 17.-Calculate water-cement ratio from masses of water and cement (plus pozzolan if used) shown in column 5. An equation for this calculation is provided at bottom of worksheet.

Figure 2.-Instructions for using concrete mix data worksheets.

Spec. or Solic. No. DC-6820	Structure FOUNDATION PLUG	Tested by R. BURGER Date 12-30-70
Project FRY-ARK	Item 46—3-INCH MSA INTERIOR Location ~	Computed by R. BURGER Date 12-30-70
Feature PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 12-30-70

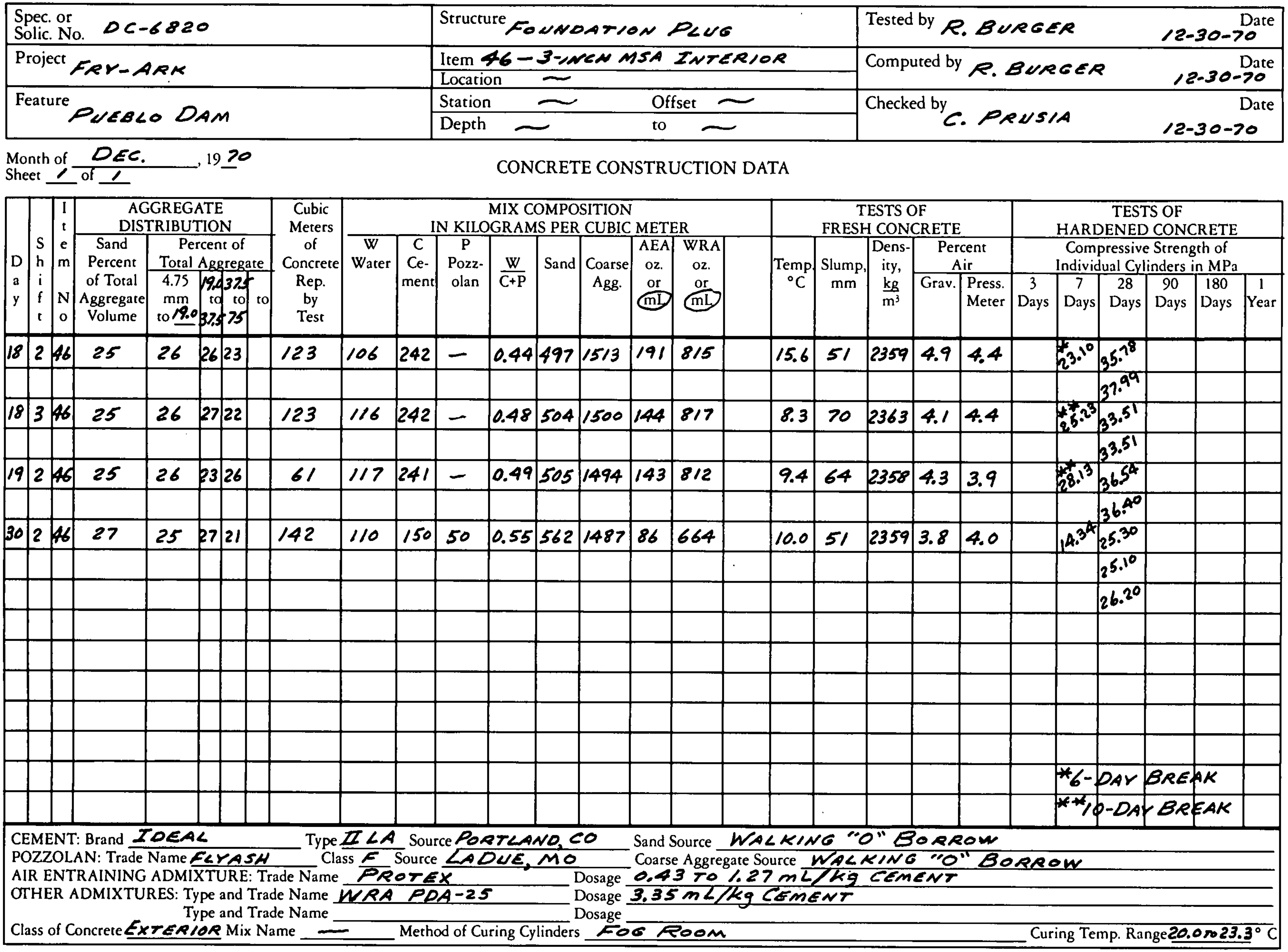
Month of DEC., 1970
Sheet 1 of 1

CONCRETE CONSTRUCTION DATA

			AGGREGATE DISTRIBUTION					Cubic Yards of Concrete Rep. by Test	MIX COMPOSITION IN POUNDS PER CUBIC YARD									TESTS OF FRESH CONCRETE					TESTS OF HARDENED CONCRETE					
				Percent of Total Aggregate																	Percent Air		Compressive Strength of Individual Cylinders in lbf/in²					
Day	Shift	Item No	Sand Percent of Total Aggregate Volume	No. 4 to 3/4"	3/4 to 1½	1½ to 3	to		W Water	C Cement	P Pozzolan	W/C+P	Sand	Coarse Agg.	AEA oz. or mL	WRA oz. or mL		Temp. °F	Slump, inches	Density, lbm/ft³	Grav.	Press. Meter	3 Days	7 Days	28 Days	90 Days	180 Days	1 Year
18	2	46	25	26	26	23		161	178	408	—	0.44	838	2552	146	623		60	2.00	147.3	4.9	4.4		*3350	5190			
																									5510			
18	3	46	25	26	27	22		161	196	408	—	0.48	850	2529	110	625		47	2.75	147.5	4.1	4.4		**3660	4860			
																									4860			
19	2	46	25	26	23	26		80	197	406	—	0.49	852	2520	109	621		49	2.50	147.2	4.3	3.9		**4080	5300			
																									5280			
30	2	46	27	25	27	21		186	185	253	85	0.55	947	2507	66	508		50	2.00	147.3	3.8	4.0		2080	3670			
																								2090	3670			
																									3640			
																									3800			
																								* 6-DAY BREAK				
																								** 10-DAY BREAK				

CEMENT: Brand IDEAL Type II LA Source PORTLAND, CO Sand Source WALKING "O" BORROW
POZZOLAN: Trade Name FLYASH Class F Source LADUE, MO Coarse Aggregate Source WALKING "O" BORROW
AIR ENTRAINING ADMIXTURE: Trade Name PROTEX Dosage 0.66 TO 1.21 OZ/cwt CEMENT
OTHER ADMIXTURES: Type and Trade Name WRA PDA-25 Dosage 1.5 mL/lbm CEMENT
Type and Trade Name ______ Dosage ______
Class of Concrete EXTERIOR Mix Name —— Method of Curing Cylinders FOG ROOM Curing Temp. Range 68 TO 74 ° F

Figure 3a.-Sample reporting form (inch-pound units).



Spec. or Solic. No. DC-6820	Structure FOUNDATION PLUG	Tested by R. BURGER — Date 12-30-70
Project FRY-ARK	Item 46—3-INCH MSA INTERIOR Location ~	Computed by R. BURGER — Date 12-30-70
Feature PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date 12-30-70

Month of DEC., 19 70
Sheet 1 of 1

CONCRETE CONSTRUCTION DATA

			AGGREGATE DISTRIBUTION					Cubic Meters of Concrete Rep. by Test	MIX COMPOSITION IN KILOGRAMS PER CUBIC METER									TESTS OF FRESH CONCRETE					TESTS OF HARDENED CONCRETE — Compressive Strength of Individual Cylinders in MPa					
Day	Shift	Item No	Sand Percent of Total Aggregate Volume	Percent of Total Aggregate 4.75 mm to 19.0	19.0 to 37.5	37.5 to 75	to		W Water	C Cement	P Pozzolan	W/C+P	Sand	Coarse Agg.	AEA oz. or [✓ mL]	WRA oz. or [✓ mL]		Temp. °C	Slump, mm	Density, kg/m³	Percent Air Grav.	Percent Air Press. Meter	3 Days	7 Days	28 Days	90 Days	180 Days	1 Year
18	2	46	25	26	26	23		123	106	242	—	0.44	497	1513	191	815		15.6	51	2359	4.9	4.4		*23.10	35.78			
																									37.99			
18	3	46	25	26	27	22		123	116	242	—	0.48	504	1500	144	817		8.3	70	2363	4.1	4.4		**25.23	33.51			
																									33.51			
19	2	46	25	26	23	26		61	117	241	—	0.49	505	1494	143	812		9.4	64	2358	4.3	3.9		**28.13	36.54			
																									36.40			
30	2	46	27	25	27	21		142	110	150	50	0.55	562	1487	86	664		10.0	51	2359	3.8	4.0		14.34	25.30			
																									25.10			
																									26.20			
																								*6-DAY BREAK				
																								**10-DAY BREAK				

CEMENT: Brand IDEAL Type II LA Source PORTLAND, CO Sand Source WALKING "O" BORROW
POZZOLAN: Trade Name FLYASH Class F Source LADUE, MO Coarse Aggregate Source WALKING "O" BORROW
AIR ENTRAINING ADMIXTURE: Trade Name PROTEX Dosage 0.43 TO 1.27 mL/kg CEMENT
OTHER ADMIXTURES: Type and Trade Name WRA PDA-25 Dosage 3.35 mL/kg CEMENT
Type and Trade Name ______ Dosage ______
Class of Concrete EXTERIOR Mix Name — Method of Curing Cylinders FOG ROOM Curing Temp. Range 20.0 to 23.3° C

Figure 3b.–Sample reporting form (SI-metric units).

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4140-92

PROCEDURE FOR

SAMPLING AND TESTING CONCRETE MASONRY UNITS

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4140; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 140-75 (Reapproved 1980).

1. Scope

1.1 This designation covers the procedure for sampling and testing concrete masonry units for compressive strength, absorption, mass, moisture content, and dimensions.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1104 Load Verification of Testing Machines
2.2 *ASTM Standards*:
C 140 Standard Methods of Sampling and Testing Concrete Masonry Units[1]
E 6 Standard Definitions of Terms Relating to Methods of Mechanical Testing[2]

3. Terminology

3.1 For definitions of terms used in this procedure, refer to ASTM E 6.

4. Precautions

4.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

SAMPLING

5. Selection of Test Specimens

5.1 For purposes of test, full-size concrete masonry units shall be selected by an authorized representative of the Government. Specimens shall be representative of the whole lot of units from which they are selected. If specimens are selected at worksite, those selected for moisture content tests shall be protected from rain and other moisture after delivery and until time of test.

6. Number of Specimens

6.1 For the strength, absorption, and moisture content determinations, 6 units shall be selected from each lot of 10,000 units or fraction thereof and 12 units from each lot of more than 10,000 and less than 100,000 units. For lots of more than 100,000 units, 6 units shall be selected from each 50,000 units or fraction thereof contained in the lot. Additional specimens may be taken at the discretion of an authorized representative of the Government.

6.2 The number of specimens prescribed in section 6.1 may be reduced by one-half when only strength tests are required.

7. Identification

7.1 Mark each specimen so that it may be identified at any time. Markings shall cover not more than 5 percent of superficial area of specimen.

7.2 Determine mass of units for moisture content tests immediately after sampling and marking.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

MEASUREMENT OF DIMENSIONS

9. Apparatus

9.1 Measure overall dimensions with a steel scale graduated in 1/32-inch (or 1-mm) divisions. Face-shell and web thicknesses shall be measured with a caliper rule

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[1] *Annual Book of ASTM Standards*, vol. 04.05.

[2] *Annual Book of ASTM Standards*, vols. 03.01, 08.03

graduated in 1/64-inch (or 0.5-mm) divisions and having parallel jaws not less than 1/2 inch (13 mm) nor more than 1 inch (25 mm) in length.

9.2 Measurement devices shall be calibrated in accordance with USBR 1000.

10. Specimens

10.1 Three full-size units shall be measured for length, width, and height. Cored units shall also be measured for minimum thicknesses of face shells and webs.

NOTE 1.-The same specimens may be used in other tests.

11. Measurements

11.1 Read individual measurements on dimensions of each unit to nearest division of scale or caliper and record the average.

11.2 Measure length L on longitudinal centerline of each face, width W across top and bottom bearing surfaces at midlength, and height H on both faces at midlength. Measure face shell and web thicknesses, FST and WT, at thinnest point of each such element 1/2 inch (13 mm) above or below mortar-bed plane. Where opposite face shells differ in thickness by less than 1/8 inch (3.2 mm), average their measurements. Disregard sash grooves, dummy joints, and similar details in the measurements.

11.3 *Calculations.*-The equivalent web thickness can be calculated as follows:

$$EWT = \frac{TWT}{L} (12^*) \qquad (1)$$

where:

EWT = equivalent web thickness in inches per linear foot (millimeters per linear meter),
TWT = total web shell thickness in inches per linear foot (millimeters per linear meter), and
L = length of unit in inches (millimeters).

* For metric units, use 1000.

11.4 Figure 1 shows a typical form for calculations and recording measurements.

12. Report

12.1 Figure 2 shows a typical reporting form. The report shall show average length, width, and height of each specimen; the minimum face-shell and web thicknesses; and the equivalent web thickness as an average for the three specimens.

ABSORPTION, MOISTURE CONTENT, AND DENSITY

13. Apparatus

13.1 The balance used shall be sensitive to within 0.5 percent of mass of smallest specimen tested, and shall be calibrated in accordance with USBR 1012.

14. Test Specimens

14.1 Three full-size units shall be used.

15. Procedure

15.1 *Saturation.*-Immerse test specimens in water at room temperature, 60 to 80 °F (15.6 to 26.7 °C), for 24 hours. Determine mass of specimens while they are suspended by a metal wire and completely submerged in water. Remove specimens from water and allow to drain for 1 minute by placing them on a 3/8-inch (9.5-mm) or coarser wire mesh, remove visible surface water with a damp cloth, and immediately determine mass.

15.2 *Drying.*-Subsequent to saturation, dry all specimens in a ventilated oven at 212 to 239 °F (100 to 115 °C) for not less than 24 hours and until two successive mass determinations at intervals of 2 hours show a decrease no greater than 0.2 percent of last previously determined mass.

16. Calculations

16.1 *Absorption.*-Calculate the absorption as follows:

$$AB = \frac{B-A}{A} (100) \qquad (2)$$

where:

AB = absorption in percent,
A = mass of oven-dry test sample in air in pound mass (kilograms), and
B = mass of saturated-surface-dry test sample in air in pound mass (kilograms).

16.2 *Moisture Content.*-Calculate the as-sampled moisture content (note 2) as follows:

$$MC = \frac{D-A}{B-A} (100) \qquad (3)$$

where:

MC = as-sampled moisture content in percent,
D = mass of sample as received, in whatever moisture condition, in pound mass (kilograms), and
A and B = as previously defined.

NOTE 2.-By definition, this is not the moisture content of the block; it is the moisture content of the block in the as-received moisture condition as a percentage of the total absorption.

16.3 *Density.*-Calculate the density as follows:

$$D_d = \frac{A}{B-C} (62.4^*) \qquad (4)$$

where:

D_d = dry density in pound mass per cubic foot (kilograms per cubic meter),
C = mass of suspended sample immersed in water in pound mass (kilograms), and
A and B = as previously defined.

* For metric units, use 1000.

16.4 Figure 1 shows a typical form for calculations and recording data.

17. Report

17.1 Report all results separately for each unit and as average for three units. Example reporting data are shown on figure 2.

COMPRESSIVE STRENGTH

18. Apparatus

18.1 *Testing Machine.*–The testing machine shall conform to requirements of USBR 1104. The machine shall be equipped with two steel-bearing blocks (note 3), one of which is a spherically seated block that will transmit load to upper surface of masonry specimen, and the other a plane rigid block on which specimen will rest. When bearing area of steel blocks is not sufficient to cover bearing area of masonry specimen, steel bearing plates meeting the requirements of section 18.2 shall be placed between bearing blocks and capped specimen after centroid of masonry bearing surface has been aligned with center of thrust of bearing blocks, see section 21.1.

NOTE 3.–It is desirable that bearing faces of blocks and plates used for compression testing of concrete masonry have a Rockwell hardness of not less than HRC 60 (BHN 620).

18.2 *Steel Bearing Blocks and Plates.*–Surfaces of steel bearing blocks and plates shall not depart from plane by more than 0.001 inch (0.025 mm) in any 6-inch (152-mm) dimension. The center of the sphere of the spherically seated upper bearing block shall coincide with center of its bearing face. If a bearing plate is used, the center of this sphere shall lie on a line passing vertically through centroid of specimen bearing face. The spherically seated block shall be held closely in its seat but shall be free to turn in any direction. The face diameter of the bearing blocks shall be at least 6 inches. When steel plates are used between bearing blocks and masonry specimen (sec. 21.1), plates shall have a thickness equal to at least one-third the distance from edge of bearing block to most distant corner of specimen. In no case shall plate thickness be less than 1/2 inch (13 mm).

19. Test Specimens

19.1 Three full-size units shall be tested within 72 hours after delivery to laboratory, during which time they shall be stored continuously in normal room air.

19.2 Units of unusual size, shape, or strength may be sawed into segments, some or all of which shall be tested individually in same manner as prescribed for full-size units. The strength of the full-size units shall be considered as that which is calculated from the average measured strength of the segments.

20. Capping Test Specimens

20.1 Cap bearing surfaces of units by one of the following methods:

20.1.1 *Sulfur and Granular Materials.*–Spread evenly on a nonabsorbent surface that has been lightly coated with oil (note 4), the proprietary or laboratory-prepared mixtures of 40 to 60 percent sulfur, by mass. The balance of the mixture shall be ground fire clay or other suitable inert material passing a No. 100 (150-μm) sieve, with or without a plasticizer. Heat the sulfur mixture in a thermostatically controlled heating pot to a temperature sufficient to maintain fluidity for a reasonable time after contact with capping surface. Take care to prevent overheating, and stir liquid in pot just before use. The capping surface shall be plane within 0.003 inch (0.08 mm) in 16 inches (406 mm) and shall be sufficiently rigid and so supported as not to be measurably deflected during capping operation. Place four 1-inch (25-mm) square steel bars on surface plate to form a rectangular mold about 1/2 inch (13 mm) greater than inside dimensions of masonry unit. Fill mold to a depth of 1/4 inch (6.4 mm) with molten sulfur material. Then, bring surface of unit to be capped quickly into contact with liquid and insert specimen, holding it so that its axis is at right angles to surface of capping liquid. Allow unit to remain undisturbed until solidification is complete. Allow caps to cool for a minimum of 2 hours before testing specimens. Patching of caps shall not be permitted. Remove imperfect caps and replace with new ones.

NOTE 4.–The use of oil on capping plates may be omitted if it is found that plate and unit can be separated without damaging cap.

20.1.2 *Gypsum Plaster Capping.*–Spread evenly on a nonabsorbent surface that has been lightly coated with oil (note 4), a neat paste of special high-strength plaster (note 5) and water. Such gypsum plaster, when mixed with water at the capping consistency, shall have a compressive strength after 2 hours of not less than 3,500 lbf/in^2 (24.1 MPa) when tested as 2-inch (50-mm) cubes. The casting surface plate shall conform to requirements described in section 20.1.1. Bring surface of unit to be capped into contact with capping paste by firmly pressing down on the specimen with a single motion, holding it so that its axis is at right angles to capping surface. The average thickness of the cap shall be not more than 1/8 inch (3.2 mm). Patching of caps shall not be permitted. Remove imperfect caps and replace with new ones. Age caps for at least 2 hours before testing specimens.

NOTE 5.-Two such high-strength plasters are "Hydrostone" and "Hydrocal White." Other plasters should not be used unless they have been certified by testing to meet the strength requirement.

21. Procedure

21.1 *Position of Specimens.*-Position test specimens with the centroid of their bearing surfaces aligned vertically with center of thrust of spherically seated steel bearing block of testing machine (note 6). Except for special units intended for use with their cores in a horizontal direction, test all hollow concrete masonry units with their cores in a vertical direction. Test masonry units that are 100 percent solid and special hollow units intended for use with their hollow cores in a horizontal direction in the same direction that they will be in when in use.

NOTE 6.-For homogeneous materials, centroid of bearing surface can be considered to be vertically above center of gravity of masonry unit.

21.2 *Speed of Testing.*-Apply load up to one-half of expected maximum load at any convenient rate. Then, adjust controls of machine as required to give a uniform rate of travel of moving head such that remaining load is applied in not less than 1 nor more than 2 minutes.

22. Calculations

22.1 Compressive strength of a concrete masonry unit shall be the maximum load in pound force (kilonewtons) divided by gross cross-sectional area of unit in square inches (square millimeters). The gross area of a unit is the total area of a section perpendicular to direction of load, including areas within cells and within reentrant spaces unless these spaces are to be occupied in the masonry by portions of adjacent masonry.

22.2 Where a minimum compressive strength on average net area as well as on gross area is specified, calculate maximum load in pound force (kilonewtons) divided by average net area, and include result in the report.

22.3 *Net Area.*-Calculate the average percentage of net area (note 7) of the unit as follows:

$$A_n = \frac{V_n}{V_g}(100) \tag{5}$$

$$V_n = \frac{A}{D_d} \tag{6}$$

$$V_g = \frac{LWH}{1728^*} \tag{7}$$

where:

A_n = average net area in percent,
V_n = net volume of unit in cubic feet (cubic meters),
V_g = gross volume of unit in cubic feet (cubic meters),
L = length of unit in inches (millimeters),
W = width of unit in inches (millimeters),
H = height of unit in inches (millimeters), and
A and D_d = as previously defined in section 16.

* For metric units, use 1×10^9.

NOTE 7.-Net area calculations are based on values obtained in the absorption, moisture content, and density portion of this procedure, sections 13 through 17.

22.4 *Compressive Strength.*-Calculate the compressive strength of a concrete masonry unit as follows:

$$S_g = \frac{P}{A_g} \tag{8}$$

$$S_n = \frac{P}{A_n A_g} \tag{9}$$

where:

P = total maximum load in pound force (kilonewtons),
S_g = compressive strength based on gross area A_g in pound force per square inch (megapascals),
S_n = compressive strength based on net area A_n in pound force per square inch (megapascals),
$A_g = LW$ = gross area in square inches (square millimeters), and
A_n, L, and W = as defined in section 22.3.

22.5 Figure 1 shows a typical form for calculations and recording data.

23. Report

Report results to nearest 10 lbf/in² or 0.05 MPa separately for each unit and as average for three units. Typical reporting data are shown on figure 2.

24. Precision and Bias

24.1 The precision and bias for this procedure have not been established.

Spec. or Solic. No.	Structure WAREHOUSE		Tested by E. DUNSTAN Date 5-3-65
Project FRY-ARK	Item 8x8x16" GRADE N, TYPE I MASONRY UNITS Location DENVER LAB		Computed by E. DUNSTAN Date 5-3-65
Feature OFFICE BUILDINGS, SALIDA, CO	Station —— Depth ——	Offset —— to ——	Checked by D. PARADY Date 5-4-65

SAMPLING AND TESTING CONCRETE MASONRY UNITS

Specimen No.	*L* Length, inches	*W* Width, inches	*H* Height, inches	*FST* Min. Face Shell Thick., inches	*WT* Min. Web Shell Thick., inches	*TWT* Total Web Shell Thick., inches	*EWT* Equiv. Web Thick. (*TWT*/*L*)(12), in/ft	*D* Mass, as received, lbm	*A* Dry Mass, lbm	*B* SSD Mass, lbm	*C* Submerged Mass, lbm
101	15 20/32	7 20/32	7 20/32								
101	15 20/32	7 20/32	7 20/32								
Average	15 20/32	7 20/32	7 20/32								
102	15 20/32	7 20/32	7 20/32								
102	15 20/32	7 20/32	7 20/32								
Average	15 20/32	7 20/32	7 20/32								
103	15 20/32	7 20/32	7 20/32								
103	15 20/32	7 20/32	7 20/32								
Average	15 20/32	7 20/32	7 20/32								
104	15 20/32	7 20/32	7 20/32	4 Meas. each side-2 Min.	3 Meas. each side-Avg of 3 Web			36.3	36.0	38.0	21.0
104	15 20/32	7 20/32	7 20/32	1 14/64-1 22/64	1- 1/64, 2/64, 3/64						
Average	15 20/32	7 20/32	7 20/32	1 18/64	1 2/64	3 6/64	2.3760				
105	15 20/32	7 20/32	7 20/32					36.3	36.0	38.1	20.9
105	15 20/32	7 20/32	7 20/32	1 15/64-1 25/64	1- 3/64, 4/64, 5/64						
Average	15 20/32	7 20/32	7 20/32	1 20/64	1 4/64	3 12/64	2.3760				
106	15 20/32	7 20/32	7 20/32					36.4	36.1	38.2	21.0
106	15 20/32	7 20/32	7 20/32	1 16/64-1 20/64	1- 1/64, 2/64, 3/64						
Average	15 20/32	7 20/32	7 20/32	1 18/64	1 2/64	3 6/64	2.3760				

Figure 1a.–Typical data and calculation form (inch-pound units).

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN Date 5-3-65
Project FRY-ARK	Item 203 x 203 x 406 mm Grade N, Type I Masonry Units Location DENVER LAB	Computed by E. DUNSTAN Date 5-3-65
Feature OFFICE BUILDING, SALIDA, CO	Station — Offset — Depth — to —	Checked by D. PARADY Date 5-4-65

SAMPLING AND TESTING CONCRETE MASONRY UNITS

Specimen No.	*L* Length, mm	*W* Width, mm	*H* Height, mm	*FST* Min. Face Shell Thick., mm	*WT* Min. Web Shell Thick., mm	*TWT* Total Web Shell Thick., mm	*EWT* Equiv. Web Thick. (*TWT*/*L*)(1000), mm/m	*D* Mass, as received, kg	*A* Dry Mass, kg	*B* SSD Mass, kg	*C* Submerged Mass, kg
101	397	194	194								
101	397	194	194								
Average	397	194	194								
102	397	194	194								
102	397	194	194								
Average	397	194	194								
103	397	194	194								
103	397	194	194								
Average	397	194	194								
104	397	194	194	4 Meas. Each Side - 2 Min.	3 Meas. Each Side - Avg. of 3 Web			16.47	16.33	17.24	9.53
104	397	194	194	30.9, 34.1	25.8, 26.2, 26.6						
Average	397	194	194	32.5	26.2	78.6					
105	397	194	194					16.47	16.33	17.28	9.48
105	397	194	194	31.3, 35.3	26.6, 27.0, 27.4						
Average	397	194	194	33.3	27.0	81.0					
106	397	194	194					16.51	16.37	17.33	9.53
106	397	194	194	30.9, 34.1	25.8, 26.2, 26.6						
Average	397	194	194	32.5	26.2	78.6					

Figure 1b.-Typical data and calculation form (SI-metric).

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN Date 5-3-65
Project FRY-ARK	Item 8x8x16" GRADE N, TYPE I, MASONRY UNITS Location DENVER LAB	Computed by E. DUNSTAN Date 5-3-65
Feature OFFICE BUILDING, SALIDA, CO	Station — Offset — Depth — to —	Checked by D. PARADY Date 5-4-65

SAMPLING AND TESTING CONCRETE MASONRY UNITS

Specimen No.	*L* Length, inches	*W* Width, inches	*H* Height, inches	*FST* Min. Face Shell Thick., inches	*WT* Min. Web Shell Thick., inches	*TWT* Total Web Shell Thick., inches	*EWT* Equiv. Web Thick. $(TWT/L)(12)$, in/ft	A_g Gross Area *LW*, in²	V_g Gross Volume $LWH/1728$, ft³	D_d Dry Density $\frac{A}{B-C}(62.4)$, lbm/ft³	V_n Net Volume A/D_d, ft³
101	15 20/32	7 20/32	7 20/32					119.1	0.5257		
102	15 20/32	7 20/32	7 20/32					119.1	0.5257		
103	15 20/32	7 20/32	7 20/32					119.1	0.5257		
Average	15 20/32	7 20/32	7 20/32					119.1	0.5257		
104	15 20/32	7 20/32	7 20/32	1 18/64	1 2/64	3 6/64	2.3760	119.1	0.5257	132	0.273
105	15 20/32	7 20/32	7 20/32	1 20/64	1 4/64	3 12/64	2.4480	119.1	0.5257	130	0.277
106	15 20/32	7 20/32	7 20/32	1 19/64	1 3/64	3 6/64	2.3760	119.1	0.5257	131	0.276
Average	15 20/32	7 20/32	7 20/32	1 19/64	1 3/64	3 8/64	2.4000	119.1	0.5257		

	A_n Avg. Net Area $\frac{V_n}{V_g}(100)$, percent	*AB* Absorption $\frac{B-A}{A}(100)$, percent	*MC* Moisture Content $\frac{D-A}{B-A}(100)$, percent	*P* Total Load, lbm	S_g Comp. Str. P/A_g, lbf/in²	S_n Comp. Str. $P/(A_nA_g)$, lbf/in²
101				204,000	1,710	3,300
102				207,500	1,740	3,300
103				209,000	1,750	3,310
Average					1,730	3,300
104	51.9	5.6	15			
105	52.7	5.8	14			
106	52.5	5.8	14			
Average						
Average						

Remarks:
Six 8x8x16-inch nominal size masonry units (full size) to represent a 10,000-unit lot.

Figure 2a. – Typical calculation and reporting form (inch-pound units).

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN Date 5-3-65
Project FRY-ARK	Item 203x 203x 406-mm Grade N, Type I Masonry Units Location DENVER LAB	Computed by E. DUNSTAN Date 5-3-65
Feature OFFICE BUILDING, SALIDA, CO	Station — Offset — Depth — to —	Checked by D. PARADY Date 5-4-65

SAMPLING AND TESTING CONCRETE MASONRY UNITS

Specimen No.	L Length, mm	W Width, mm	H Height, mm	FST Min. Face Shell Thick., mm	WT Min. Web Shell Thick., mm	TWT Total Web Shell Thick., mm kg/m³	EWT Equiv. Web Thick. $(TWT/L)(1000)$, mm/m	A_g Gross Area LW, mm²	V_g Gross Volume $LWH/10^9$, m³	D_d Dry Density $\frac{A}{B-C}$ (1000), kg/m³	V_n Net Volume A/D_d, m³
101	397	194	194					77018	0.015		
102	397	194	194					77018	0.015		
103	397	194	194					77018	0.015		
Average	397	194	194					77018	0.015		
104	397	194	194	32.5	26.2	78.6	198	77018	0.015	2120	0.0077
105	397	194	194	33.3	27.0	81.0	204	77018	0.015	2090	0.0078
106	397	194	194	32.5	26.2	78.6	198	77018	0.015	2100	0.0078
Average	397	194	194	32.8	26.5	79.4	200	77018	0.015		

	A_n Avg. Net Area $\frac{V_n}{V_g}$(100), percent	AB Absorption $\frac{B-A}{A}$(100), percent	MC Moisture Content $\frac{D-A}{B-A}$(100), percent	P Total Load, kN	S_g Comp. Str. $\frac{P/A_g}{1000}$, MPa	S_n Comp. Str. $\frac{P/(A_nA_g)}{1000}$, MPa
101				907	11.8	23
102				923	12.0	23
103				930	12.1	23
Average					12.0	23
104	51.3	5.6	15			
105	52.0	5.8	14			
106	52.0	5.8	14			
Average						
Average						

Remarks: Six 203 x 203 x 406-mm nominal size masonry units (full size) to represent a 10,000-unit lot.

Figure 2b. – Typical calculation and reporting form (SI-metric).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4142-92

PROCEDURE FOR

CLAY LUMPS AND FRIABLE PARTICLES IN AGGREGATES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4142; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 142-78 (Reapproved 1984).

1. Scope

1.1 This designation covers the procedure for the approximate determination of clay lumps and friable particles in natural aggregates.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4117 Materials Finer Than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
2.2 *ASTM Standards*:
C 142 Standard Test Method for Clay Lumps and Friable Particles in Aggregates[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]

3. Significance and Use

3.1 This procedure is of primary significance in determining the acceptability of aggregate with respect to particles strong enough to withstand concrete mixing operations, but which may later break down in hardened concrete exposed to freezing and thawing or other natural weathering actions and produce unsightly surface spalling or popouts.

4. Apparatus

4.1 *Balance.*–A balance or scale accurate to within 0.1 percent of mass of test sample at any point within range of use.

4.2 *Containers.*–Rust-resistant containers of a size and shape that will permit spreading of sample on bottom in a thin layer, and of sufficient depth to permit submergence of largest particle.

4.3 *Sieves.*–Sieves shall conform to ASTM E 11.

4.4 *Drying Oven.*–An oven providing free circulation of air and capable of maintaining a temperature of 230±9° F (110±5° C).

5. Samples

5.1 Aggregate for this test shall consist of material remaining after completion of testing in accordance with USBR 4117. To provide quantities designated in sections 5.3 and 5.4, it may be necessary to combine material from more than one test by USBR 4117.

5.2 The aggregate shall be dried to substantially a constant mass at 230±9 °F (110±5 °C).

5.3 Test samples of fine aggregate shall consist of particles coarser than a No. 16 (1.18-mm) sieve, and shall have a mass not less than 100 grams.

5.4 Test samples of coarse aggregate shall be separated into different sizes using the following sieves: No. 4 (4.75 mm), 3/8 inch (9.5 mm), 3/4 inch (19.0 mm), and 1-1/2 inches (37.5 mm). Test sample shall have a mass not less than that indicated in table 1.

5.5 In the case of mixtures of fine and coarse aggregates, material shall be separated into two sizes on the No. 4 (4.75-mm) sieve, and samples of fine and coarse aggregates shall be prepared in accordance with sections 5.3 and 5.4.

Table 1. – Size of test sample for determining clay lumps and friable particles.

Size of particles in test sample	Minimum mass of test sample, lbm	(grams)
No. 4 to 3/8 inch (4.75 to 9.5 mm)	2.20	(1000)
3/8 to 3/4 inch (9.5 to 19.0 mm)	4.41	(2000)
3/4 to 1-1/2 inches (19.0 to 37.5 mm)	6.61	(3000)
Over 1-1/2 inches (>37.5 mm)	11.02	(5000)

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

7.2 Balances or scales shall be calibrated to meet requirements of section 4.1 in accordance with USBR 1012.

7.3 Sieves shall be calibrated to meet requirements of ASTM E 11 in accordance with USBR 1025.

7.4 Drying ovens shall be calibrated to meet requirements of section 4.4 in accordance with USBR 1020.

8. Conditioning

8.1 The only conditioning required in this test procedure is soaking the sample for 24±4 hours in potable water.

9. Procedure

9.1 Determine mass of test sample to accuracy specified in 4.1, spread sample in a thin layer on bottom of container, cover with potable water, and allow to soak for 24±4 hours. Roll and squeeze particles individually between thumb and forefinger to attempt to break particle into smaller sizes. Do not use the fingernails to break up particles, and do not press particles against a hard surface or each other. Any particles that can be broken by rolling and squeezing into fines removable by wet sieving shall be classified as clay lumps or friable particles. After all discernible clay lumps and friable particles have been broken, separate the detritus from remainder of sample by wet sieving over the sieve prescribed in table 2. Perform the wet sieving by passing water over sample through sieve, while manually agitating sieve, until all undersize material has been removed.

Table 2. – Size of sieve for wet sieving aggregates for determination of clay lumps and friable particles in each size fraction.

Size of particles in test sample	Size of sieve for removing residue of clay lumps and friable particles
Fine aggregate [retained on No. 16 (1.18-mm) sieve]	No. 30 (600μm)
No. 4 to 3/8 inch (4.75 to 9.5 mm)	No. 8 (2.36 mm)
3/8 to 3/4 inch (9.5 to 19.0 mm)	No. 4 (4.75 mm)
3/4 to 1-1/2 inches (19.0 to 37.5 mm)	No. 4 (4.75 mm)
Over 1-1/2 inches (>37.5 mm)	No. 4 (4.75 mm)

9.2 Remove retained particles carefully from sieve, dry to substantially a constant mass at 230±9°F (110±5°C), allow to cool, and determine mass to nearest 0.1 percent of mass of test sample as defined in section 5.3 or 5.4.

10. Calculation

10.1 Calculate percent of clay lumps and friable particles in fine aggregate, or individual sizes of coarse aggregate as follows:

$$P_1 = \frac{M_1 - M_2}{M_1} (100) \qquad (1)$$

$$P_2 = P_1 \times \% \text{ original grading} \times 100 \qquad (2)$$

where:

P_1 = percent of clay lumps and friable particles,

M_1 = mass of test sample (for fine aggregate, this is mass of portion coarser than No. 16 (1.18-mm) sieve as described in section 5.3),

M_2 = mass of particles retained on designated sieve (sec. 9.2), and

P_2 = weighted percentage of clay luumps and friable particles of the coarse aggregate based on the original percentage retained on each sieve fraction (sec. 10.2).

NOTE 1.–If a No. 200 (75-μm) sieve is nested beneath sieve prescribed for washing sample after testing, the approximate percentage of friable material, as opposed to clay- or silt-size fines, may be obtained by determining mass of material passing designated washing sieve and retained on No. 200 sieve.

10.2 For coarse aggregates, the percent of clay lumps and friable particles shall be an average based on percent of clay lumps and friable particles in each sieve size fraction weighted in accordance with grading of original sample before separation or, preferably, the average grading of the supply represented by sample. Should aggregate contain less than 5 percent of any of the sizes specified in section 9.1, that size shall not be tested but, for purpose of calculating weighted average, shall be considered to contain same percent of clay lumps and friable particles as next larger or next smaller size, whichever is present.

10.3 Figure 2 of USBR 4075 shows a suggested worksheet for calculations.

11. Report

11.1 Figure 3 of USBR 4075 serves as a typical reporting form for this procedure.

12. Precision and Bias

12.1 The precision for this test procedure has not yet been determined, but is being investigated. A precision statement will be included when proper data have been obtained and analyzed.

12.2 There is no known bias for this procedure.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4143-92

PROCEDURE FOR

SLUMP OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4143; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 143-78.

1. Scope

1.1 This designation covers the procedure for determination of slump of concrete, both in the laboratory and in the field.

NOTE 1.-This procedure is considered applicable to plastic concrete having coarse aggregate up to 1-1/2 inches (37.5 mm) in size. If coarse aggregate is larger than 1-1/2 inches, the procedure is applicable when applied on the fraction of concrete passing a 1-1/2-inch sieve with the larger aggregate being removed in accordance with section 4 of USBR 4172. This procedure is not considered applicable to nonplastic and noncohesive concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4172 Sampling Freshly Mixed Concrete
2.2 *ASTM Standard*:
C 143 Standard Test Method For Slump of Portland Cement Concrete[1]

3. Apparatus

3.1 *Mold.*-The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than No. 16 gauge (Bwg) and, if formed by the spinning process, there shall be no point on the mold where the thickness is less than 0.045 inch (1.14 mm). Mold shall be in the form of the lateral surface of the frustrum of a cone. When made using inch-pound units, the base shall be 8 inches in diameter, the top 4 inches in diameter, and the height 12 inches. All of these values shall be within ±1/8 inch of the prescribed dimension. When using SI-metric units, the base shall be 203 mm in diameter, the top 102 mm in diameter, and the height 305 mm; with all values being within ±3.2 mm of prescribed dimension. The base and the top shall be open, parallel to each other, and at right angles to axis of cone. The mold shall be provided with foot pieces and handles similar to those shown on figure 1. The mold may be constructed either with or without a seam. Interior of mold shall be relatively smooth and free from projections, such as protruding rivets or weld material. The mold shall be circular and free from dents. A mold which clamps to a nonabsorbent baseplate is acceptable provided the clamping arrangement is such that it can be fully released without movement of mold. Care must be used while disengaging the clamp because any vibration would increase the slump of the concrete.

3.2 *Tamping Rod.*-The tamping rod shall be a round, straight, steel rod 5/8 inch (16 mm) in diameter and about 24 inches (610 mm) in length, with tamping end rounded to a 5/8-inch-diameter hemispherical tip.

4. Precautions

4.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Sample

5.1 The sample of concrete from which test specimens are made shall be representative of entire batch, and shall be obtained in accordance with USBR 4172.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

7. Conditioning

7.1 Dampen the mold and place it on a flat, moist, nonabsorbent, rigid surface.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

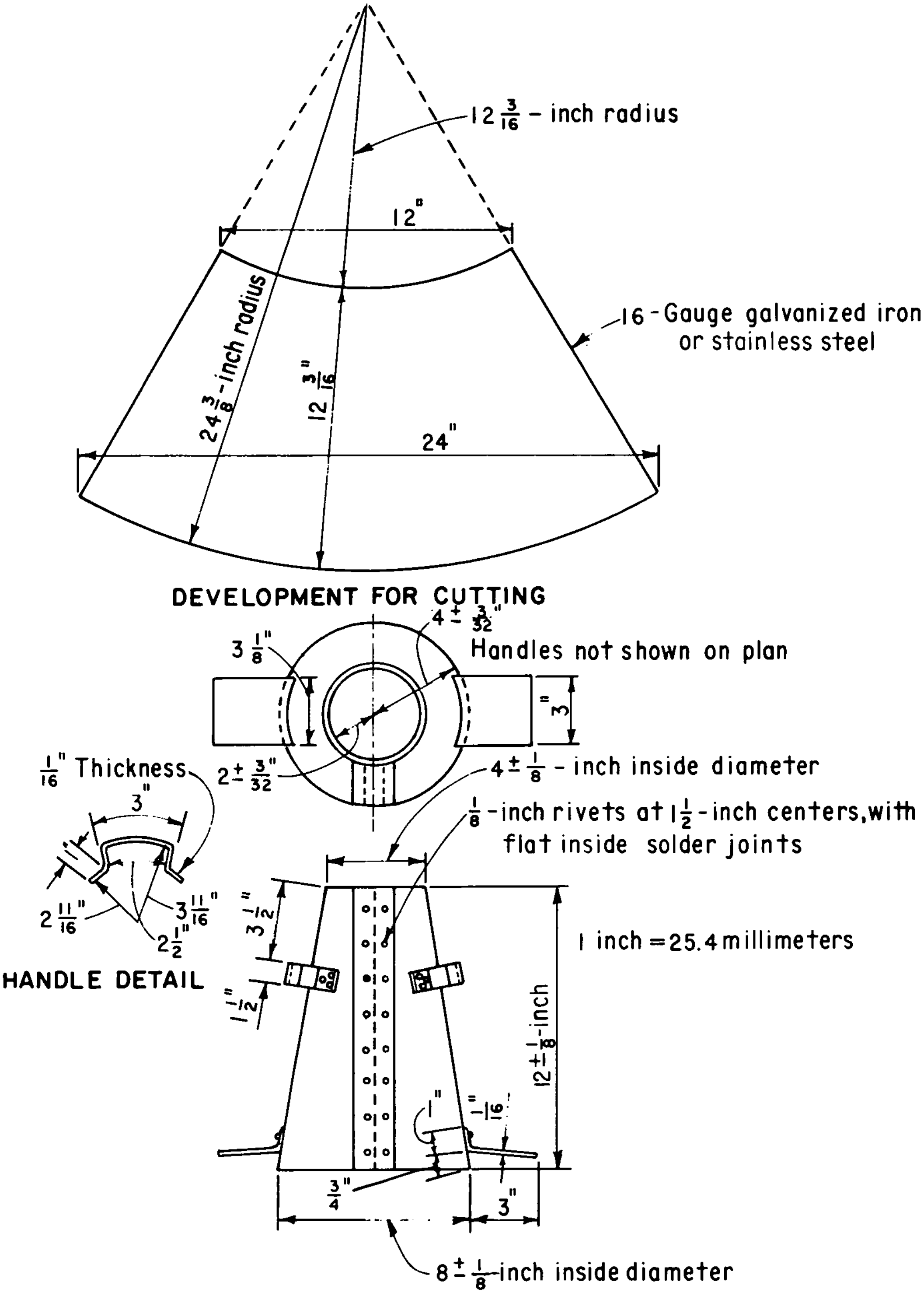


Figure 1. - Mold for slump test.

8. Procedure

8.1 The mold shall be held firmly in place during filling by the operator while standing on the two foot pieces. From sample of concrete obtained in accordance with section 5, immediately fill mold in three layers, each approximately one-third the volume of mold.

NOTE 2.-One-third of volume of the slump mold fills the mold to a depth of 2-5/8 inches (67 mm); two-thirds the volume fills the mold to a depth of 6-1/8 inches (156 mm).

8.2 Rod each layer with 25 strokes of tamping rod, uniformly distributing strokes over cross section of each layer. For bottom layer, this will necessitate inclining rod slightly and making about half the strokes near the perimeter, then progressing with vertical strokes spirally toward center. Rod bottom layer throughout its depth. Rod second layer and top layer each throughout its depth so that strokes just penetrate into underlying layer.

8.3 In filling and rodding top layer, heap concrete above mold before rodding is started. If rodding operation results in subsidence of concrete below top edge of mold, add additional concrete to keep an excess above top of mold at all times. After top layer has been rodded, strike off surface of concrete by means of a screeding and rolling motion of tamping rod. Remove mold immediately from concrete by raising it carefully in a vertical direction. Raise mold 12 inches (305 mm) in 5±2 seconds using a steady upward lift with no lateral or torsional motion. Complete entire test from start of filling through removal of mold without interruption within 2-1/2 minutes.

8.4 Immediately measure slump by determining vertical difference between top of mold and displaced original center of top surface of specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs (note 3), disregard test and make a new test on another portion of sample.

NOTE 3.-If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, concrete probably lacks necessary plasticity and cohesiveness for slump test to be applicable.

8.5 After slump measurement is completed, the side of the concrete frustum should be tapped gently with tamping rod. The behavior of the concrete under this treatment is a valuable indication of its cohesiveness, workability, and placeability, see figure 2. A well-proportioned, workable mix will slump gradually to lower elevations while retaining its original identity; however, a poor mix will crumble, segregate, and fall apart. Operations involved in making the slump test are illustrated on figure 2.

9. Calculations

9.1 No calculations are involved in this procedure.

10. Report

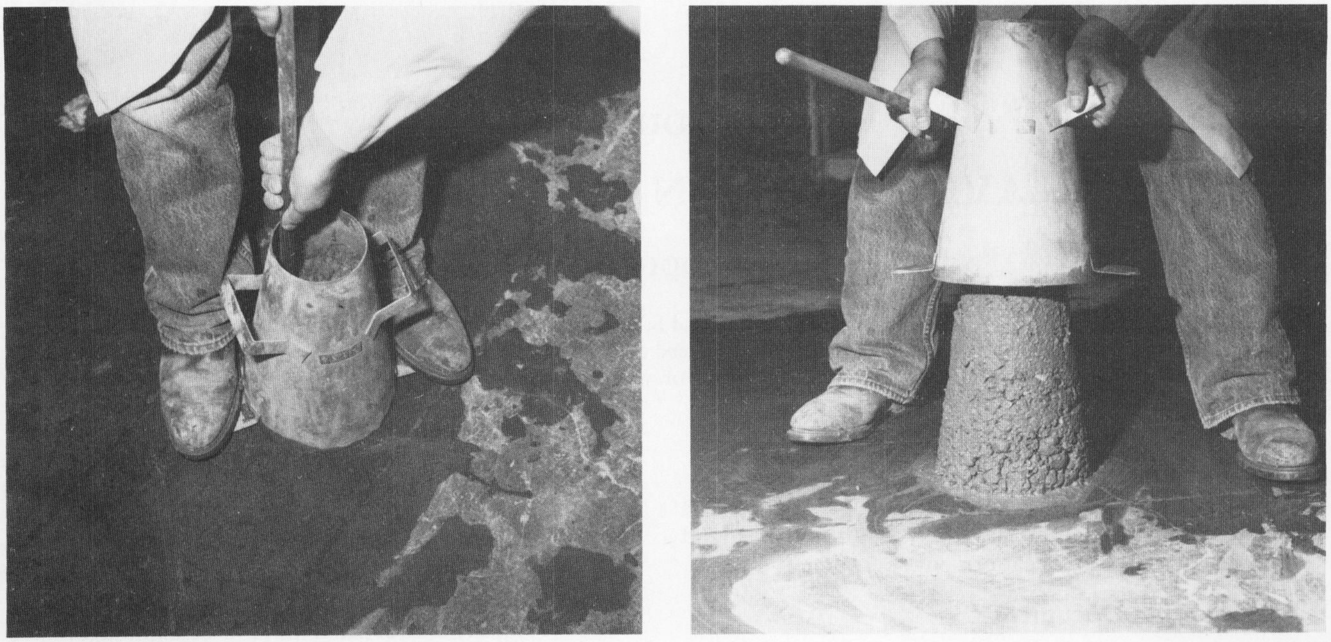
10.1 Record the slump in inches (millimeters) to nearest 1/4 inch (6 mm) of subsidence of specimen during test.

10.2 No specific reporting form is required for results of this test, but may be reported in conjunction with results of other test procedures, such as figure 3 in USBR 4138.

11. Precision and Bias

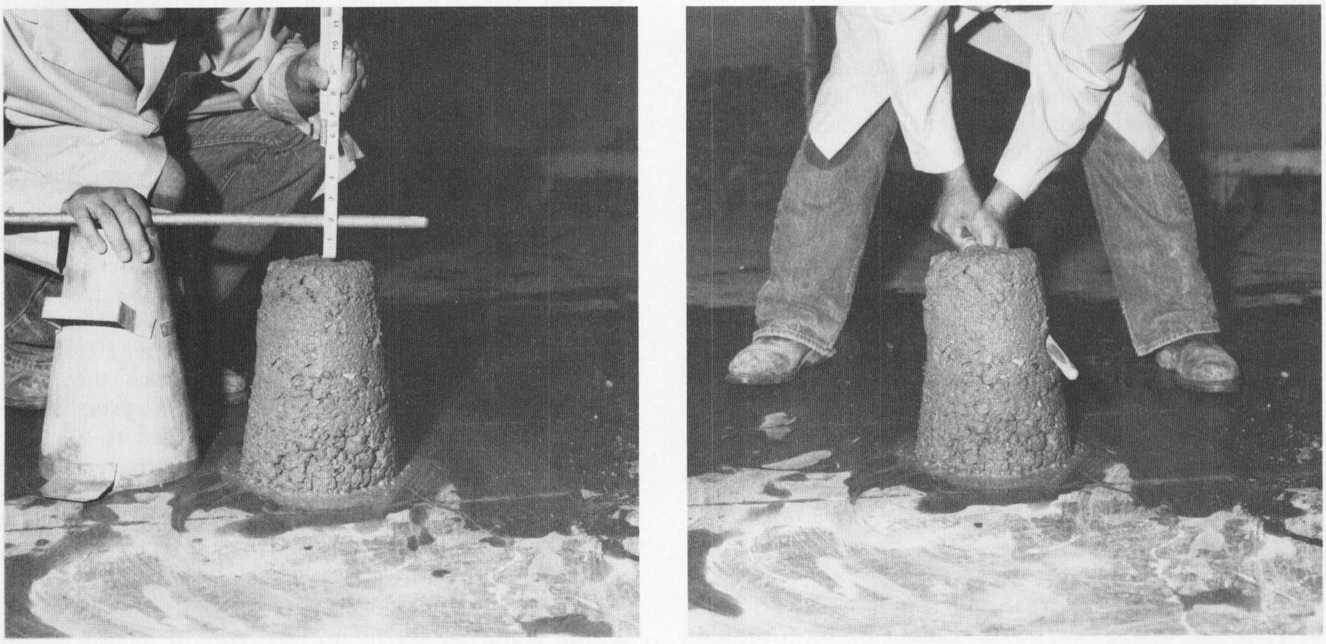
11.1 Data are being compiled and developed that will be suitable for use in developing precision statements for this procedure.

11.2 The bias for this procedure has not been established.



(a) Rodding and filling cone using three separate layers of concrete.

(b) Slow, steady, vertical removal of mold.



(c) Measuring the slump after subsidence.

(d) Tapping the concrete to observe the plasticity.

Figure 2. - Making a slump test. A good indication of the concete workability may be obtained by tapping the test specimen with a tamping rod.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4151-92

PROCEDURE FOR

AUTOCLAVE EXPANSION OF PORTLAND CEMENT

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4151; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 151-84.

1. Scope

1.1 This designation covers the procedure for determination of the autoclave expansion of portland cement using a test on a neat cement specimen.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1007 Calibrating Dial Indicators
1012 Calibrating Balances or Scales
1040 Calibrating Pressure Gauges
4183 Sampling and Acceptance of Hydraulic Cement
4187 Normal Consistency of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:

C 151 Test Method for Autoclave Expansion of Portland Cement[1]
C 490 Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,2]
C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1,2]
E 177 Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[1,3]

3. Significance

3.1 The autoclave expansion test provides an index of potential delayed expansion caused by the hydration of CaO (calcium oxide) and/or MgO (magnesium oxide).

4. Apparatus

4.1 *Scales and Standard Masses*.-For determining the mass of the materials conforming to the requirements of ASTM C 490.

4.2 *Glass Graduates*.-Graduates should have either a 200- or 250-mL capacity, conforming to the requirements of ASTM C 490.

4.3 *Molds*.-Molds shall have a 1- by 1-inch (25- by 25-mm) cross section, conforming to the requirements of ASTM C 490. Typical molds are shown on figure 1.

4.4 *Trowel*.-Trowel shall have a straightedged steel blade 4 to 6 inches (102 to 152 mm) in length.

4.5 *Autoclave*.-The autoclave shall consist of a high-pressure steam vessel with a thermometer well, and equipped with an automatic pressure control and a rupture disk with a bursting pressure of 350 lbf/in^2 (2413 kPa) ±5 percent. In locations where use of a rupture disk is not permitted, autoclave shall be equipped with a safety valve. In addition, autoclave shall be equipped with a vent valve to allow the escape of air during early part of heating period and to release any steam pressure remaining at end of cooling period. The pressure gauge shall have a dial with a nominal diameter of 4.5 inches (114 mm) and shall be graduated from 0 to 600 lbf/in^2 (0 to 4137 kPa) with scale divisions of not more than 5 lbf/in^2 (34 kPa). The error in the gauge shall not exceed ±3 lbf/in^2 (±21 kPa) at the operating pressure of 295 lbf/in^2 (2034 kPa). The capacity of heating unit shall be such that with maximum load (water plus specimens), pressure of saturated steam in autoclave may be raised to a gauge pressure of 295 lbf/in^2 in 45 to 75 minutes from the time heat is applied. The automatic pressure control shall be capable of maintaining gauge pressure at 295 ± 10 lbf/in^2 (2034 ± 69 kPa) for at least 3 hours. This pressure corresponds to a temperature of 420 ± 3 °F (215.6 ± 1.7 °C). The autoclave shall be designed to permit gauge pressure to drop from 295 lbf/in^2 to less than 10 lbf/in^2 within 1.5 hours after heat supply has been shut off. The rupture disk shall be made of a material having a tensile strength that is relatively insensitive to temperature from 68 to 420 °F (20.0 to 215.6 °C), and that is electrochemically compatible with the pipe leading to the disk and its holder. A typical autoclave is shown on figure 2.

4.6 *Length Comparator*.-The comparator used for measuring the length change of specimens shall conform to requirements of ASTM C 490. Figure 3 shows a typical length comparator.

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vol. 14.02.

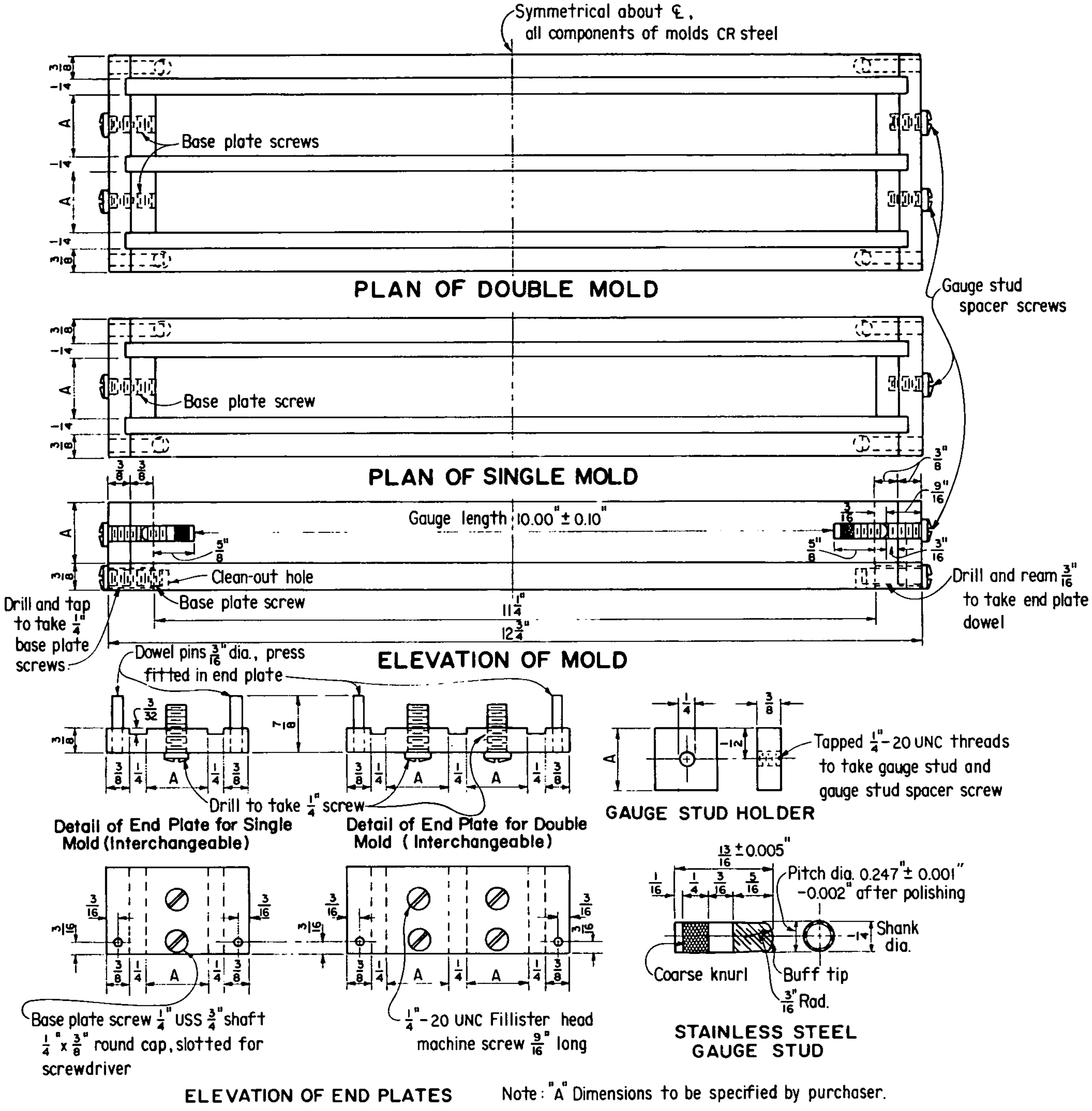


Figure 1a. - Molds (inch-pound units). From ASTM C 490.

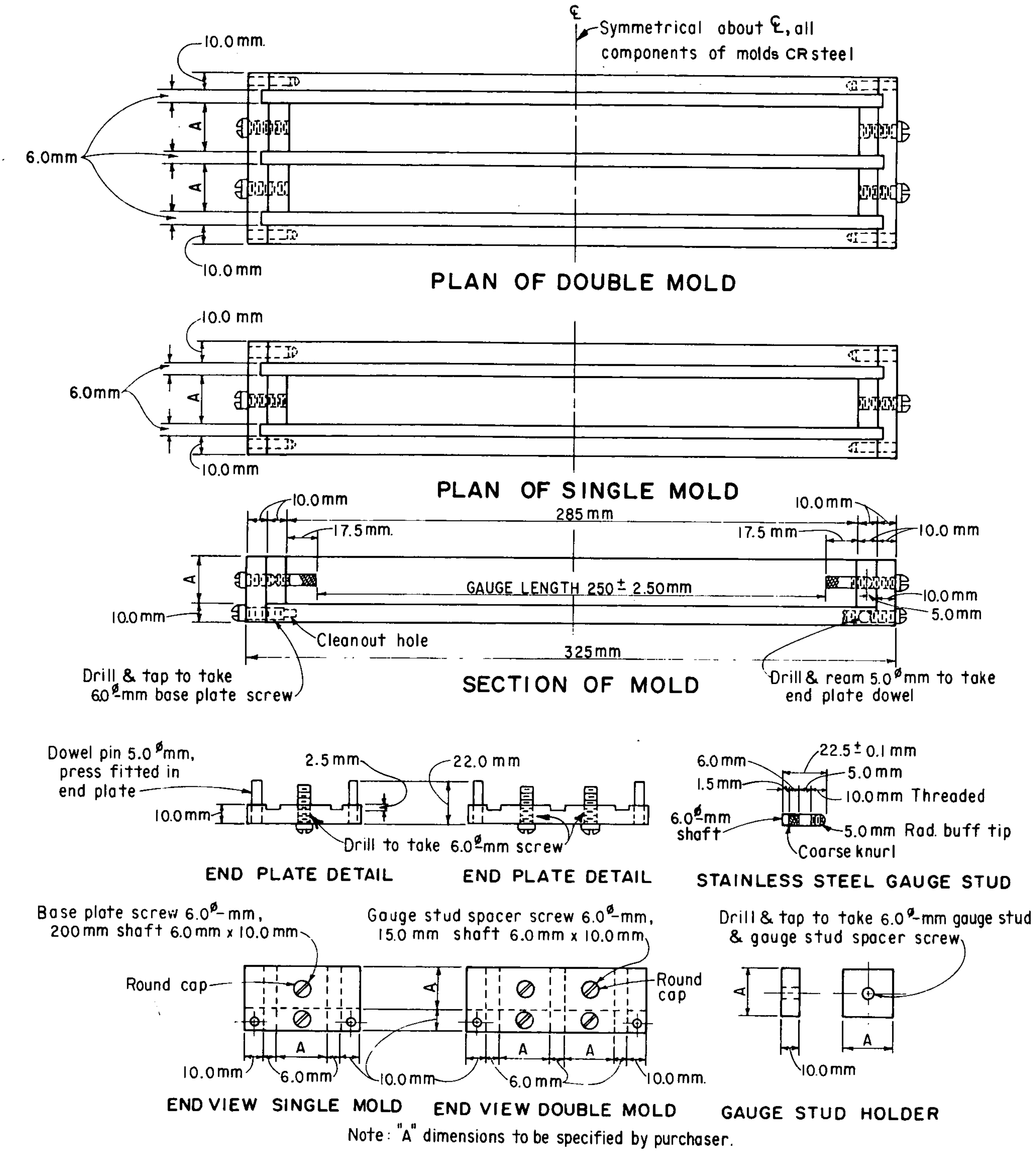
5. Temperature and Humidity

5.1 *Molding Room.*-Maintain temperature of molding room, dry materials, and mixing water; and relative humidity of molding room within the limits of ASTM C 490.

5.2 *Moist Storage Facilities.*-Maintain temperature and humidity of the moist storage facilities according to the requirements of ASTM C 511.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment; and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.



Note: "A" dimensions to be specified by purchaser.

Figure 1b. – Molds (SI-metric units). From ASTM C 490.

6.2 *Autoclave*:

6.2.1 The pressure gauge should have a maximum capacity of 600 lbf/in^2 (4137 kPa) because with a smaller capacity there is not enough arc length for the gauge hand to indicate pressures above the specified maximum working pressure. The operator must ensure that the gauge hand has not passed the maximum graduation on the scale. It is best to have the pressure gauge tested; however, a thermometer should always be used with it to provide a means of detecting any failure of the gauge to operate properly and to indicate any unusual condition.

6.2.2 Maintain the automatic control in proper working order at all times.

Figure 2. - Cement autoclave.

6.2.3 Set safety valve to relieve pressure at about 6 to 10 percent above the maximum pressure of 305 lbf/in^2 (2103 kPa), which would be at about 330 lbf/in^2 (2275 kPa). Unless the manufacturer has given specific instructions as to the maintenance of the safety valve, the valve should be tested twice a year. The valve can be tested with a gauge testing device, or by adjusting the automatic controls to allow the autoclave to reach a pressure of about 330 lbf/in^2, at which point the safety valve should either open or should be adjusted to open. Direct safety valve discharge away from operator.

NOTE 1.-Unexpected combinations of conditions may occur. In one case, for example, the automatic control had failed, the safety valve had become stuck, and the gauge hand, which at first glance appeared to be at about zero, had passed the maximum graduation on the scale and stopped on wrong side of pin. This condition of the gauge was finally detected and the pressure, then of unknown magnitude, was released before failure could occur in apparatus.

6.2.4 Wear heavy leather gloves to prevent burning of hands when removing top of autoclave at end of test. Direct vent valve away from operator. When removing autoclave lid, tilt it so that any steam escaping from beneath lid may be discharged away from operator. Care should be taken to avoid scalding by any liquid that may have been used in autoclave well.

6.2.5 **Caution**: For many autoclave pressure gauges, the return of the gauge hand to the initial rest or starting point does not necessarily indicate zero pressure within the autoclave; there may still remain appreciable pressure.

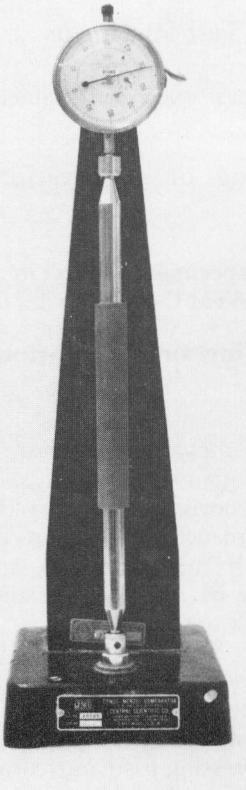


Figure 3. - Type of suitable apparatus for measurement of length changes. From ASTM C 490.

7. Calibration and Standardization

7.1 The calibration and standardization of the miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

7.2 Scales and standard masses shall be calibrated to comply with requirements of ASTM C 490 in accordance with USBR 1012.

7.3 Molds shall be calibrated to comply with requirements of ASTM C 490 by utilizing linear measurement devices calibrated in accordance with USBR 1000.

7.4 The autoclave temperature and pressure shall be checked to comply with section 4.5 by certified thermometers and pressure gauges calibrated in accordance with USBR 1040.

7.5 The comparator shall be calibrated to meet requirements of ASTM C 490 with a standardized reference bar, and dial indicators shall be calibrated in accordance with USBR 1007.

7.6 Temperature control of materials, molding room, and moist storage room; and humidity control of molding and moist storage rooms shall meet requirements of ASTM

C 490 and C 511 by checking with certified thermometers and relative humidity testers.

8. Number of Test Specimens

8.1 Make at least one test specimen for each sample tested.

9. Conditioning or Preparation of Specimen Molds

9.1 Prepare specimen molds in accordance with requirements of ASTM C 490.

10. Conditioning or Preparation of Test Specimens

10.1 *Mixing Cement Paste*.–Prepare the standard batch consisting of 650 grams of cement and sufficient water to give a paste of normal consistency (USBR 4187). Mix this batch in accordance with the procedure described in USBR 4305. Both the time-of-set specimens and an autoclave bar may be made from same batch. Figure 4 shows a typical mix record.

10.2 *Molding Specimens*.–Immediately following preparation of the time-of-set specimens or completion of mixing, mold test specimen into two approximately equal layers. Each layer should then be compacted with thumbs or forefingers by pressing paste into corners, around gauge studs, and along surface of mold until a homogeneous specimen is obtained. After compacting top layer, cut off paste flush with top of mold with thin-edged trowel, and smooth surface with a few strokes of trowel. During mixing and molding, protect hands with rubber gloves.

10.3 *Storage of Test Specimens*.–After filling mold, place it in moist closet or moist storage room. Store specimens in molds uncovered in moist enclosure for at least 20 hours; if removed from molds before 24 hours, specimens shall be kept in moist closet or moist storage room until time of test.

11. Procedure

11.1 Remove specimens from the moist atmosphere 24±0.5 hours after molding, and immediately measure for length. Then, place specimens in autoclave at room temperature in a rack so that all sides of each specimen will be exposed to the saturated steam. The autoclave shall contain enough water, at an initial temperature of 68 to 82 °F (20.0 to 27.8 °C), to maintain an atmosphere of saturated steam vapor during entire test. Ordinarily, 7 to 10 percent of autoclave volume should be occupied by water.

11.2 To permit air to escape from autoclave during early portion of heating period, leave vent valve open until steam begins to escape. Then, close valve and raise temperature of autoclave at a rate that will bring gauge pressure of steam to 295 lbf/in^2 (2034 kPa) within 45 to 75 minutes from time heat is turned on. Maintain pressure at 295±10 lbf/in^2 (2034±69 kPa) for 3 hours. At end of 3-hour period, shut off heat supply and cool autoclave at such a rate that pressure will be less than 10 lbf/in^2 after 1.5 hours. At end of 1.5-hour period, slowly release any remaining pressure by partially opening vent valve until atmospheric pressure is attained. Then, open autoclave and place test specimens in water at a temperature above 194 °F (90 °C). Cool water surrounding bars at a uniform rate by adding cold water so that water temperature will be lowered to 74 °F (23.3 °C) in 15 minutes. Maintain water temperature surrounding specimens at 74 °F for an additional 15 minutes; then, surface-dry specimens and measure their lengths again.

NOTE 2.–If it is preferred to make all measurements at 80 °F (26.7 °C), it is recommended that specimens, after removal from moist enclosure, be placed in water maintained at 80 °F for at least 15 minutes, removed and measured for length, and then placed in autoclave. Upon removal from autoclave, cool specimens and water to 80 °F in 15 minutes, keep specimens in 80 °F water for an additional 15 minutes, and then repeat length measurements.

12. Calculation

12.1 Calculate difference in length of test specimen before and after autoclaving as the percent of effective gauge length and record to nearest 0.01 percent. Record percentage of increase in length as autoclave expansion; indicate a decrease in length by a minus sign prefixed to percent value. Figure 5 shows a typical calculation form.

13. Report

13.1 A suggested reporting form is shown on figure 5 of USBR 4183.

14. Precision and Bias

14.1 For a 0.11- to 0.94-percent length expansion, the single, laboratory-operator, multibatch-day precision has been found to be 7.46 (R1S percent); and the single-operator, multilaboratory-batch-day precision has been found to be 15.31 (R1S percent), as defined in ASTM E 177. Therefore, 95 percent of the time, two test results (each the average of duplicate determinations of properly conducted tests) obtained by same operator on different days should not differ by more than 21 percent of their mean, and test results (each the average of duplicate determinations of properly conducted tests) obtained by two laboratories should not differ by more than 47 percent of their mean.

14.2 The bias for this procedure is not known.

15. Reference

15.1 For additional useful information on details of cement test methods, see "Manual of Cement Testing," *Annual Book of ASTM Standards*, vol. 04.01.

Spec. or Solic. No. DC-7612	Structure DAM	Tested by J. OWENS Date 12-2-81
Project PECOS RIVER – SW REGION	Item CEMENT RESEARCH Location DENVER LAB	Computed by J. OWENS Date 12-2-81
Feature BRANTLEY DAM & RESERVOIR	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 12-2-81

AUTOCLAVE EXPANSION OF PORTLAND CEMENT

Cement Sample No.	Brand Name	Plant ID	Type	Pozzolan Sample No.	Brand Name	Plant ID	Class	Cement Mass, grams	Pozzolan Mass, grams	Water, mL	Consistency Penetration, mm
M-7120	LAB STD.	DEVIL'S SLIDE, UTAH	II LA	M-7430	PANHANDLE FLY ASH	CARLSBAD, NM	F	320	80	95	11

Remarks:

Figure 4. - Mix proportions of hydraulic cement mortars for autoclave expansion.

Spec. or Solic. No. DC-7612	Structure DAM	Tested by J. OWENS Date 12-2-81
Project PECOS RIVER-SW REGION	Item CEMENT RESEARCH Location DENVER LAB	Computed by J. OWENS Date 12-2-81
Feature BRANTLEY DAM & RESERVOIR	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 12-2-81

AUTOCLAVE EXPANSION OF PORTLAND CEMENT

Comparator No. 2 Reference Bar Reading = 0.2650 L (Specimen Length) = 10 inches ~~(mm)~~

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Dial Reading		D Difference	Expansion $\frac{D}{L}$ (100), percent	Heating Period			Cooling Period	
				Initial	Final			Time at Start	Time at Starting Pressure	Time at 3 hours	Time at 1.5 hours	Time at Finish
M-7430	PANHANDLE FLY ASH	CARLSBAD, NM	F	0.1504	0.1566	0.0062	0.062	9:55	10:45	1:45	3:15	3:45

Remarks:

Figure 5. - Expansion of hydraulic cement mortars in autoclave exposure.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4172-92

PROCEDURE FOR

SAMPLING FRESHLY MIXED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4172; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 172-82.

1. Scope

1.1 This designation covers the procedures for obtaining representative samples of fresh concrete, as delivered to project site, on which tests are to be performed to determine compliance with quality requirements of the specifications under which the concrete is furnished (note 1). The procedure includes sampling from stationary, paving, and truck mixers; and from agitating and nonagitating equipment used to transport central-mixed concrete.

NOTE 1.-Composite samples are required by this procedure unless specifically excepted by requirements governing the tests to be performed, such as tests to determine uniformity of consistency and mixer efficiency. Methods used to select the specific test batches are not described in this procedure, but it is recommended that random sampling be used to determine overall specifications compliance.

1.2 This procedure also covers methods to be used for preparing a sample of concrete for further testing where it is desirable or necessary to remove aggregate larger than a designated size. This removal of larger aggregate particles is preferably accomplished by wet sieving.

2. Applicable Documents

2.1 *USBR Procedures*:

4094 Specifications for Ready-Mixed Concrete

2.2 *ASTM Standards*:

C 172 Standard Method of Sampling Freshly Mixed Concrete[1]

E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]

E 323 Standard Specification for Perforated-Plate Sieves for Testing Purposes[3]

3. Terminolgy

3.1 *Wet Sieving Concrete*.-The process of removing aggregate larger than a designated size from fresh concrete by sieving it on a sieve of designated size.

4. Apparatus

4.1 *Sieves*.-Designated sieves shall conform to ASTM E 11.

4.2 *Wet Sieving Equipment*.-Equipment for wet sieving concrete shall be a sieve of designated size and conveniently arranged and supported so that it can be shaken rapidly by either manual or mechanical means. Generally, a horizontal back and forth motion is preferred. The equipment shall be capable of rapidly and effectively removing the designated size of aggregate. The screening equipment shown on figures 1 and 2, although primarily designed for screening concrete aggregate or soils, can be used to remove aggregate larger than 1-1/2 inches (37.5 mm) from a concrete sample. A simpler apparatus for screening fresh concrete is shown on figures 3 and 4.

4.3 *Hand Tools*.-Shovels, hand scoops, plastering trowels, and rubber gloves as required.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling

6.1 The elapsed time between obtaining the first and final portions of the composite sample shall be as short as possible, but in no instance shall it exceed 15 minutes.

6.1.1 Transport the individual samples to the location where the fresh concrete tests are to be performed or where test specimens are to be molded. Samples shall be combined and remixed with a shovel the minimum amount necessary to ensure uniformity and compliance with minimum time limits specified in 6.1.2.

6.1.2 Start tests for slump and/or air content within 5 minutes after obtaining final portion of composite sample. Complete these tests as expeditiously as possible. Start molding specimens for strength tests within 15 minutes after obtaining composite sample. Keep the elapsed time

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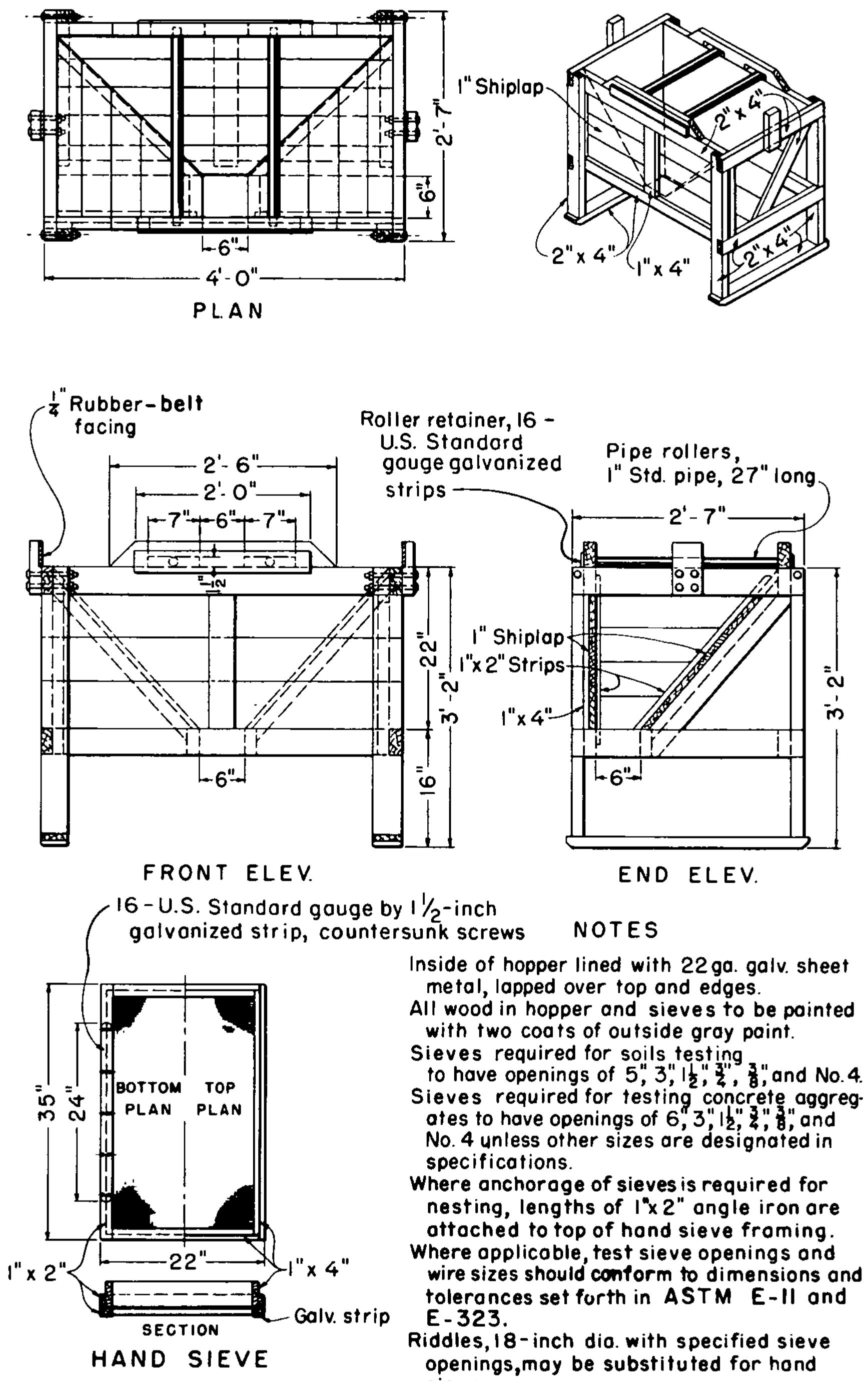
[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

[3] *Annual Book of ASTM Standards*, vols. 05.05, 14.02.



NOTES

Inside of hopper lined with 22ga. galv. sheet metal, lapped over top and edges.

All wood in hopper and sieves to be painted with two coats of outside gray paint.

Sieves required for soils testing to have openings of 5", 3", 1½", ¾", ⅜", and No. 4.

Sieves required for testing concrete aggregates to have openings of 6", 3", 1½", ¾", ⅜", and No. 4 unless other sizes are designated in specifications.

Where anchorage of sieves is required for nesting, lengths of 1"x 2" angle iron are attached to top of hand sieve framing.

Where applicable, test sieve openings and wire sizes should conform to dimensions and tolerances set forth in ASTM E-11 and E-323.

Riddles, 18-inch dia. with specified sieve openings, may be substituted for hand sieves.

1 inch = 25.4 millimeters

Figure 1. – Sieving hopper and hand sieves for gradation tests of coarse aggregate and soil materials.

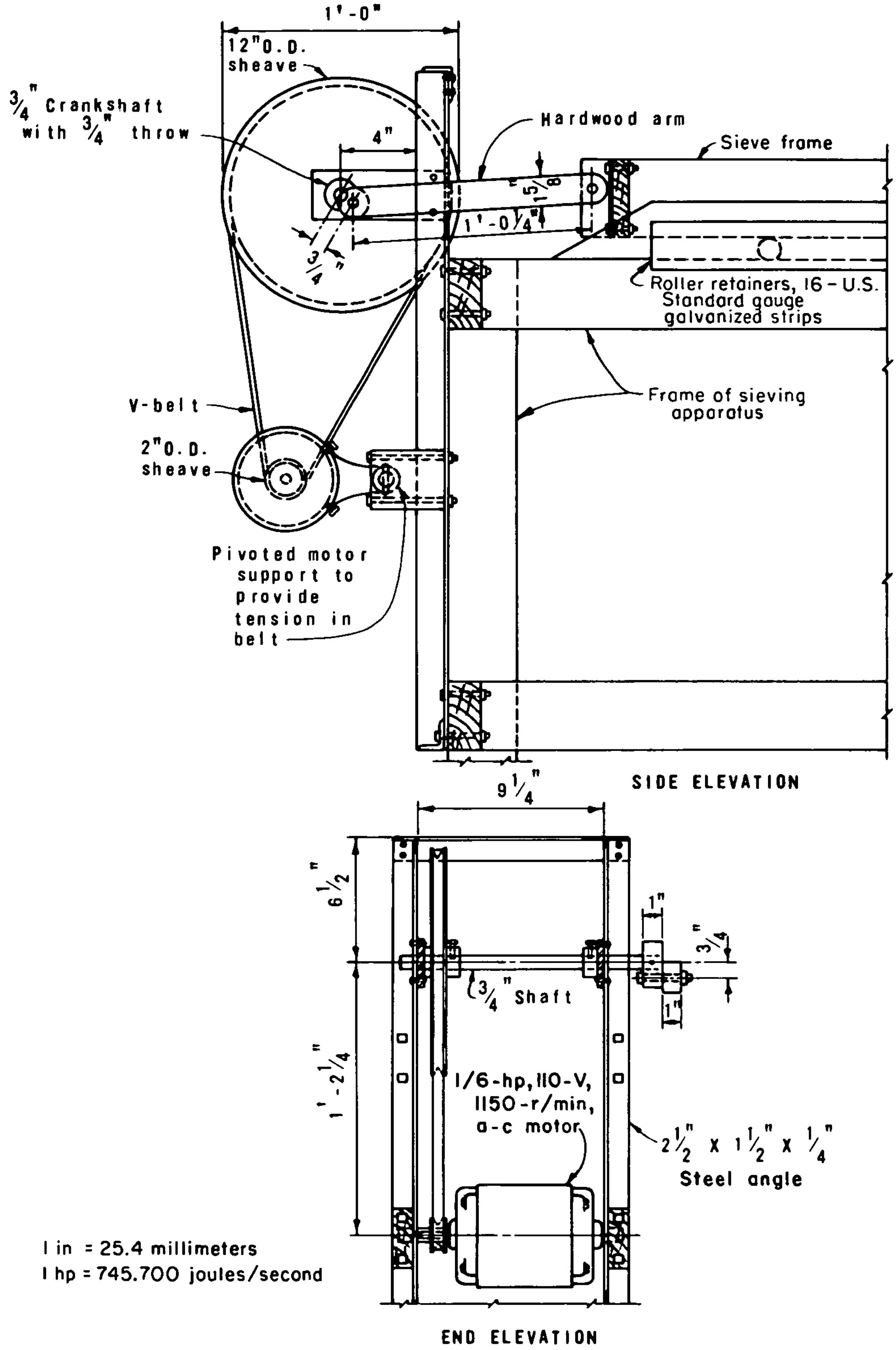


Figure 2. - Power drive for sieving apparatus shown on figure 1. This power drive is usually used in field laboratories, and will increase output considerably.

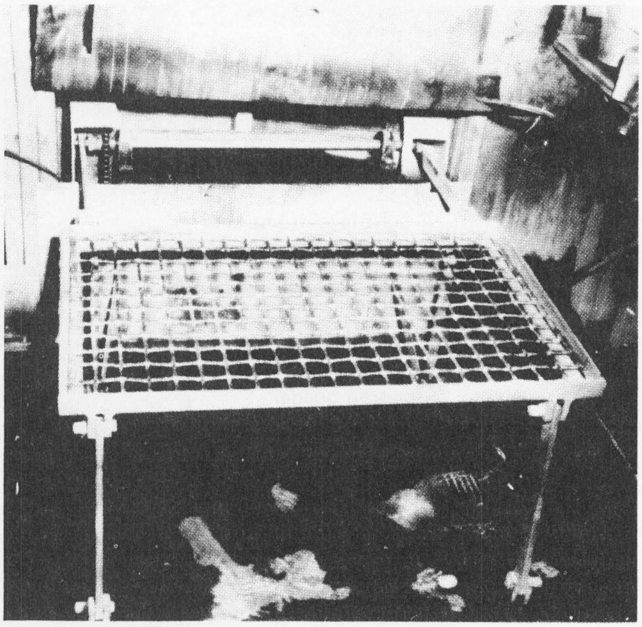


Figure 3. - Drive mechanisim and wet sieve used to remove the plus 1-1/2-inch (+37.5-mm) aggregate from fresh concrete. P382-706-10407.

between obtaining and using the sample as short as possible; and protect sample from sun, wind, and other sources of rapid evaporation, and from contamination.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

8. Conditioning

8.1 No specific conditioning is required for this procedure other than that required under the referenced applicable documents.

9. Procedure

9.1 *Size of Sample.*–The size of the composite sample for strength tests shall be a minimum of 1 ft^3 (0.03 m^3). Smaller samples may be permitted for routine air content and slump tests, and the sample size shall be dictated by the maximum aggregate size.

9.2 The methods used in sampling shall include the use of every precaution that will assist in obtaining samples that are truly representative of the nature and condition of the concrete sampled.

NOTE 2.–Sampling should normally be performed as the concrete is delivered from the vehicle used to transport the concrete to the forms; however, specifications may require other points of sampling, such as the discharge of a concrete pump.

9.2.1 *Sampling from Stationary Mixers Other Than Paving Mixers.*–Sample concrete at two or more regularly spaced intervals during discharge of middle portion of batch. Do not obtain samples from first or last portions of batch discharge. Perform sampling by passing a receptacle completely through discharge stream, or by completely diverting discharge into a sample container. If discharge of concrete is too rapid to divert complete discharge stream, discharge concrete into a container or transportation unit sufficiently large to accommodate entire batch and then accomplish the sampling as previously described. Take care not to restrict the flow of concrete from mixer, container, or transportation unit so as to cause segregation. These requirements apply to both tilting and nontilting mixers. Composite samples, within time limit specified in section 6, into one sample for test purposes.

9.2.2 *Sampling from Paving Mixers.*–Sample concrete after contents of paving mixer have been discharged. Obtain samples from at least three different portions of the discharge, and then composite these samples into one sample for test purposes. Avoid contamination with subgrade material or prolonged contact with an absorptive subgrade. To preclude contamination or absorption by the subgrade, sample the concrete by placing three shallow containers on the subgrade and discharging the concrete across these containers (note 3). Composite these samples into one sample for test purposes. The containers shall be of a size sufficient to provide a composite sample size that is in agreement with the maximum aggregate size.

NOTE 3.–In some instances, the containers may have to be supported above the subgrade to prevent displacement during discharge.

9.2.3 *Sampling from Revolving Drum Truck Mixers or Agitators.*–Sample concrete at two or more regularly spaced intervals during discharge of middle portion of batch. Do not obtain samples until after all water has been added to mixer, and do not obtain samples from first or last portions of batch discharge. Sample by repeatedly passing a receptacle through entire discharge stream or by completely diverting discharge into a sample container. Regulate rate of discharge of batch by the rate of revolution of drum and not by size of gate opening. Composite samples, within time limit specified in section 6, into one sample for test purposes.

9.2.4 *Sampling from Open-Top Truck Mixers, Agitators, Nonagitating Equipment, or Other Types of Open-Top Containers.*–Take samples by whichever method described in 9.2.1, 9.2.2, or 9.2.3 is most applicable under the given conditions.

10. Additional Method for Large, Maximum-Size, Aggregate Concrete

10.1 When concrete contains aggregate larger than that appropriate for size of molds or equipment to be used, wet sieve the sample but make density determinations for use in yield computations on the full mix.

NOTE 4.-The effect of wet sieving on the test results should be considered. For example, wet sieving concrete causes the loss of a small amount of air due to additional handling. The air content of the wet-sieved fraction of the concrete is greater than that of the total concrete because the larger size aggregate, which has been removed, does not contain air. The apparent strength of wet-sieved concrete in smaller specimens is usually greater than that of the total concrete in larger, appropriate-size specimens. The effect of these differences may need to be considered, or determined by supplementary testing for quality control or test result evaluation purposes.

10.2 When a density determination is needed for total material, including the plus 1-1/2-inch (37.5-mm) material, and a mold or equipment of sufficient size is not available, the density can be computed. An example of these computations and information on concrete uniformity and mixer performance requirements are given in USBR 4094.

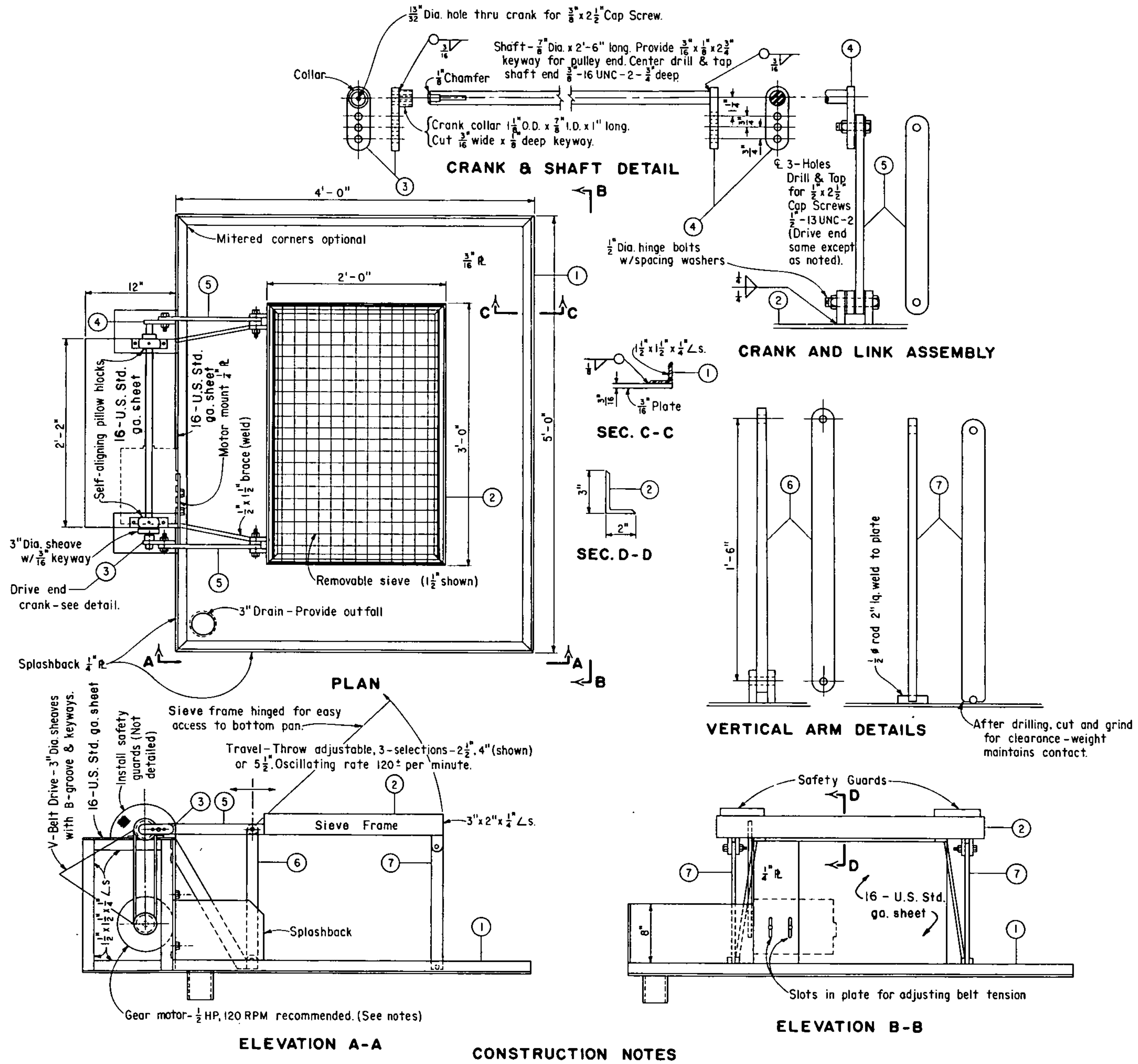
10.3 *Wet Sieving.*-After sampling concrete, pass concrete over designated sieve and remove and discard aggregate retained. This shall be done before remixing. Shake or vibrate sieve by manual or mechanical means until no undersize material remains on sieve. Mortar adhering to aggregate retained on sieve shall not be wiped from the aggregate before it is discarded. Place only enough concrete on the sieve at any one time so that after sieving, the thickness of layer of retained aggregate is not more than one particle thick. The concrete which passes the sieve shall fall into a batch pan of suitable size which has been previously dampened or onto a clean, moist, nonabsorbent surface. Scrape any mortar adhering to sides of wet-sieving equipment into the batch. After removing larger aggregate particles by wet sieving, remix batch with a shovel the minimum amount necessary to ensure uniformity and proceed with testing immediately so that time limits specified in section 6 are complied with.

11. Calculations and Report

11.1 Calculations and reporting requirements required for the specific test are covered in the procedures or standards listed under the Applicable Documents of section 2.

12. Precision and Bias

12.1 The precision and bias for this procedure have not been established.



CONSTRUCTION NOTES

Welding symbols apply to the joints of all members of similar identification.

All operating linkage made from 1/2" x 1 1/2" flat bar stock.

Motor other than that recommended could be used by changing sheave diameters. Chain drive optional.

1 inch = 25.4 millimeters

1 hp = 745.700 joules/second

Figure 4. – Design drawing of wet-sieve apparatus shown on figure 3.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4173-92

PROCEDURE FOR

AIR CONTENT OF FRESHLY MIXED CONCRETE BY VOLUMETRIC METHOD

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4173; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 173-78.

1. Scope

1.1 This designation covers the procedure for determination of air content of freshly mixed concrete containing any type of aggregate whether it be dense, cellular, or lightweight.

2. Applicable Documents

2.1 *USBR Procedures*:

4029 Density and Voids in Aggregate
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4172 Sampling Freshly Mixed Concrete
4231 Air Content of Freshly Mixed Concrete by Pressure Method

2.2 *ASTM Standard*:

C 173 Standard Test Method for Air Content of Freshly Mixed Concrete By the Volumetric Method[1]

3. Apparatus

3.1 *Airmeter*.-An airmeter (fig. 1) consisting of a bowl and top section conforming to following requirements:

3.1.1 *Bowl*.-The bowl shall be constructed of machined metal of such thickness as to be sufficiently rigid to withstand normal field use, and of such composition as not to be readily attacked by cement paste. Bowl shall have a diameter that is from 1 to 1.25 times its height, and shall have a flange at or near the top surface. Capacity of bowl shall not be less than 0.075 ft^3 (0.002 m^3).

3.1.2 *Top Section*.-The top section shall be constructed of machined metal of thickness sufficiently rigid to withstand normal field use, and of composition not readily attacked by cement paste. Capacity shall be at least 20 percent larger than the bowl, and shall be equipped with a flexible gasket and hooks or lugs to provide for attachment to bowl flange to make a watertight connection. Top section shall be equipped with a glass-lined or transparent plastic neck that is graduated in increments of no more than 0.5 percent from 0 at the top to 9 percent, or more, of the volume of the bowl. These graduations shall be accurate to ±0.1 percent by volume of bowl. Upper end of neck shall be threaded and equipped with a screwcap and gasket to make a watertight connection.

3.2 *Funnel*.-A metal funnel with spout of a size that will permit it to be inserted through neck of top section and long enough to extend to a point just above bottom of top section. Discharge end of spout shall be so constructed that when water is added to container there will be a minimum disturbance of the concrete.

3.3 *Tamping Rod*.-A round, straight, steel rod that is 5/8 inch (16 mm) in diameter and at least 12 inches (305 mm) long, with both ends rounded to a hemispherical tip of same diameter.

3.4 *Strike-Off Bar*.-A flat, straight, steel bar at least 1/8 by 3/4 by 12 inches (3 by 19 by 305 mm) long.

3.5 *Measuring Cup*.-A metal cup having a capacity equal to 1.03±0.04 percent of volume of bowl of airmeter.

NOTE 1.-Volume of measuring cup is slightly larger than 1.0 percent of volume of bowl to compensate for volume contraction that takes place when 70 percent isopropyl alcohol is mixed with water. Other alcohols or defoaming agents may be used if calculations show that their use will result in an error in indicated air content less than 0.1 percent.

3.6 *Syringe*.-A small, rubber, bulb syringe having a capacity at least that of measuring cup.

3.7 *Pouring Vessel*.-A metal or glass container of about 1 quart or 1 liter capacity.

3.8 *Trowel*.-A blunt-nosed brickmason's trowel.

3.9 *Scoop*.-A small metal scoop.

3.10 *Mallet*.-A rubber- or rawhide-head mallet with a mass of about 1.25±0.50 lbm (0.57±0.23 kg) for use with 0.5-ft^3 (0.014-m^3) measures or smaller, and a mallet with a mass of about 2.25±0.50 lbm (1.02±0.23 kg) for use with measures larger than 0.5 ft^3.

4. Reagents and Materials

4.1 *Isopropyl Alcohol*.-Use 70 percent by volume isopropyl alcohol, which is about 65 percent by mass (notes 1 and 2).

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

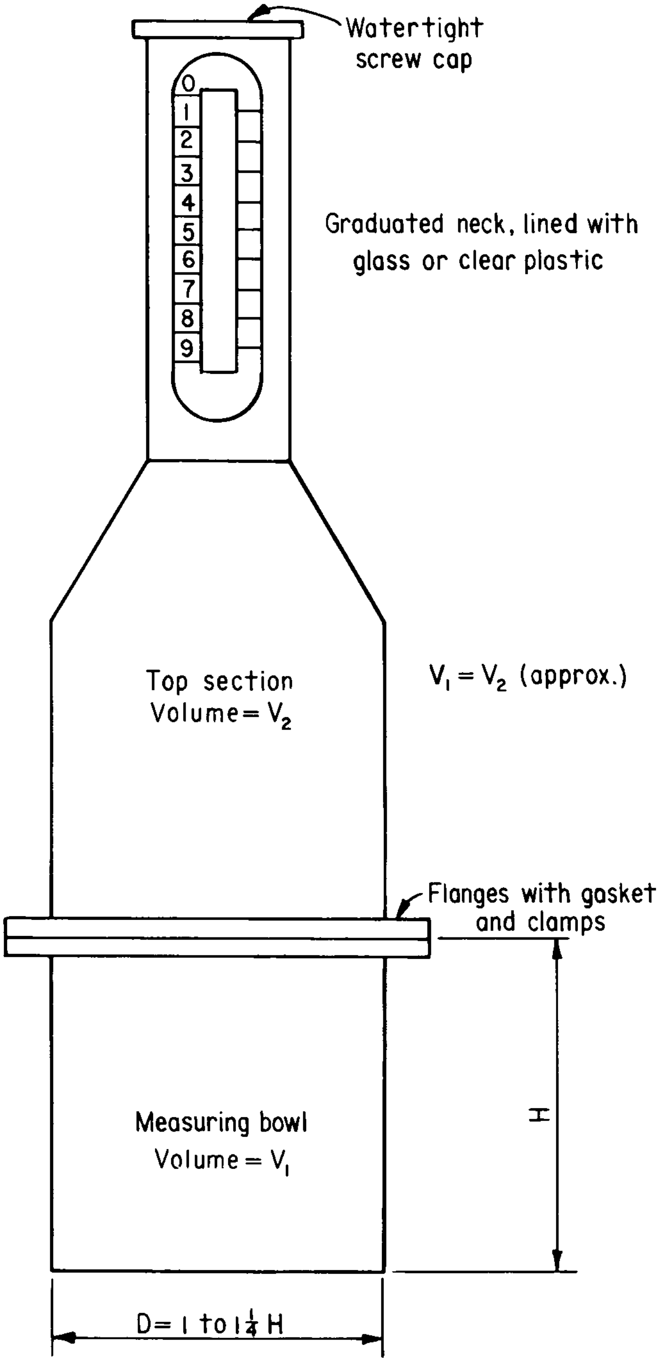

Figure 1. - Apparatus for measuring air content of fresh concrete by volumetric method.

NOTE 2.-Isopropyl alcohol (70 percent) is commonly available as rubbing alcohol. More concentrated grades can be diluted with water to required concentrations.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Calibration of Apparatus

6.1 The bowl volume of the airmeter, in cubic feet or cubic meters, shall be calibrated by accurately determining mass of water required to fill the bowl at room temperature and dividing this mass by the density of water at the same temperature. Follow the calibration procedure outlined in section 7 of USBR 4029.

6.2 Determine accuracy of graduations on neck of top section of airmeter by filling the assembled bowl and top section with water to level of mark for any air content. Then add a quantity of water at room temperature, equal to 1.0 percent of volume of bowl, to water already in the neck. The height of the water column shall increase by an amount equivalent to 1.0 percent of air.

6.3 Determine volume of measuring cup using water at 70 °F (21.1 °C) by the method outlined in section 6.1. A quick check can be made by adding 1 or more cups of water to assembled apparatus and observing increase in height of water column after filling to a given level as described in 6.2.

7. Sample

7.1 Obtain the sample of freshly mixed concrete in accordance with applicable provisions of USBR 4172. If concrete contains coarse aggregate particles that would be retained on a 1-1/2-inch (37.5-mm) sieve, wet sieve a representative sample over a 1-1/2-inch sieve to yield somewhat more than enough material to fill measuring bowl. The wet sieving procedure is described in USBR 4172. Perform the wet sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on sieve.

8. Conditioning

8.1 No specific conditioning is required for this procedure.

9. Procedure

9.1 *Rodding and Tapping.*-Using the scoop and aided by the trowel if necessary, fill bowl with freshly mixed concrete in three layers of equal depth. Rod each layer 25 times with tamping rod. When rodding second and third layers, rod should penetrate about 1/2 to 1 inch (13 to 25 mm) into layer below. After each layer is rodded, tap sides of measure 10 to 15 times smartly with mallet to close any voids left by tamping rod and to release any large bubbles of air that may have been trapped.

9.2 *Striking Off.*-After placement of third layer of concrete in accordance with 9.1, strike off excess concrete with the strike-off bar until surface is flush with top of bowl. Wipe flange of bowl clean.

9.3 *Adding Water*.–Clamp top section into position on bowl, insert funnel, and add water until it appears in neck. Remove funnel and adjust water level using rubber syringe until bottom of meniscus is level with zero mark. Attach and tighten screwcap.

9.4 *Agitating and Rolling*.–Invert and agitate the unit until concrete settles free from base and then, with neck elevated, roll and rock the unit until air appears to have been removed from concrete. Set apparatus upright, jar it lightly, and allow it to stand until air rises to top. Repeat operation until no further drop in water column is observed.

9.5 *Dispelling Bubbles*.–When all air has been removed from concrete and allowed to rise to top of apparatus, remove screwcap. In 1-cup increments using syringe, add sufficient isopropyl alcohol to dispel foamy mass on surface of water.

9.6 *Reading*.–Make a direct reading of liquid in neck, reading to bottom of meniscus, estimating to nearest 0.1 percent.

9.7 *Screening and Washing*.–If air content in mortar fraction alone is needed, screen sample across the No. 4 (4.75-mm) sieve and wash all material finer than this sieve from the fresh concrete and record a submerged mass determination.

NOTE 3.–The SSD (saturated-surface-dry) mass of the plus No. 4 to 1-1/2-inch (4.75- to 37.5-mm) material may be dried back to the SSD condition and mass determined, but it requires less time to record a submerged mass and calculate the SSD mass knowing the specific gravity as follows:

$$M_{SSD} = M_S\left(\frac{G}{G-1}\right) \qquad (1)$$

where:

M_{SSD} = saturated-surface-dry mass,
M_S = submerged mass, and
G = specific gravity of the plus No. 4 to 1-1/2-inch (4.75- to 37.5-mm) material.

10. Calculations

10.1 Calculate the air content percent of concrete in measuring bowl in percent by adding to the reading from section 9.6 the amount of alcohol used in accordance with section 9.5.

10.2 When sample tested represents that portion of the mixture obtained by wet sieving over a 1-1/2-inch (37.5-mm) sieve, calculate air content of mortar or of full mixture by using the formulas given in USBR 4231. These formulas are based on batch masses.

10.3 Figure 2 shows a typical calculation form.

11. Report

11.1 The results of this procedure shall be reported on figure 3 of USBR 4138.

12. Precision and Bias

12.1 Data are being compiled and developed that will be suitable for use in developing precision statements for this procedure.

12.2 The bias of this procedure has not been established.

Spec. or Solic. No. DC-7612 4-SI-57-00690	Structure GRAVITY SECTION	Tested by T. GAETO D. MOOTER Date 2-3-83
Project BRANTLEY, NEW MEXICO	Item MIX DESIGN Location DENVER CONCRETE LAB	Computed by T. GAETO Date 2-3-83
Feature BRANTLEY DAM	Station —— Offset —— Depth —— to ——	Checked by D. MOOTER Date 2-3-83

AIR CONTENT OF FRESHLY MIXED CONCRETE BY VOLUMETRIC METHOD

Meter No. 1 Tare Mass 5.45 lbm(~~kg~~) Volume 0.0748 ft^3(~~m^3~~)
Isopropyl Alcohol Used — cups (mL)
Specific Gravity: Plus 1.5 inch (+37.5 mm) 2.70 Plus No. 4 (+4.75 mm) 2.70

	Mass, lbm	Volume, ft^3	Mass, kg	Volume, m^3
(1) Mass of total sample	89.19		40.45	
(2) Mass of plus 1.5 inch (+37.5 mm)	14.62		6.63	
(3) Difference in mass: (1) – (2)	74.57		33.82	
*(4) Percent of plus 1.5 inch (+37.5 mm): $\frac{(2)}{(3)}$ (100)	19.6 %		19.6 %	
(5) Mass and volume of sample in air meter	10.94	0.0748	4.96	0.002118
(6) Percent air by meter	4.2 %		4.2 %	
(7) Volume of air: (6)(5 vol.)		0.00314		0.000090
(8) Mass and volume of air-free sample: (5 mass) and (5 vol.) – (7)	10.94	0.07166	4.96	0.002028
(9) Submerged mass of plus No. 4 (+ 4.75 mm)	3.642		1.652	
(10) SSD mass of plus No. 4 (+ 4.75 mm): (9) (Sp. Gr.)/(Sp. Gr. – 1)	5.78		2.62	
(11) Solid vol. of plus No. 4 (+4.75 mm) to 1.5 inch (37.5 mm): (10)/(Sp. Gr. × 62.4), ft^3 or (10)/(Sp. Gr. × 1000), m^3		0.03431		0.000970
(12) Mass and volume of mortar in sample: (5 mass) – (10), lbm (kg); (8 vol.) – (11), ft^3 (m^3)	5.16	0.03735	2.34	0.001058
(13) Mass of plus 1.5 inch (+37.5 mm) for air meter sample to represent full mix: (4) (5)	2.14		0.97	
(14) Solid volume of plus 1.5 inch (+37.5 mm) for air meter sample to represent full mix: (13)/(Sp. Gr. × 62.4), ft^3 or (13)/(Sp. Gr. × 1000), m^3		0.01270		0.000359
(15) A_t = 100 × (6) × (8 vol.)/[100 × (8 vol.) + (14) – (6) (14)], %	3.6 %		3.6 %	
(16) A_m = 100 × (6) × (8 vol.)/[100 × (12 vol.) + (6) × (8 vol. – 12 vol.)], %	7.8 %		7.8 %	

Formulas:

$$A_t = \frac{100\, A_s\, V_c}{100\, V_t - A_s\, V_a} \qquad A_m = \frac{100\, A_s\, V_c}{100\, V_m + A_s\,(V_c - V_m)}$$

where:

A_t = air content of full mixture (15), percent;
A_s = air content of sample tested (6), percent (do not use in decimal form);
V_c = absolute volume of mix passing 1.5 inch (37.5 mm) sieve, air free, (8 vol.), ft^3 (m^3);
V_t = absolute volume of total mix (8 vol.) + (14), ft^3 (m^3);
V_a = absolute volume of mix coarser than 1.5 inch (37.5 mm), (14), ft^3 (m^3);
A_m = air content of mortar fraction (16), percent; and
V_m = absolute volume of mortar fraction, air free, (12 vol.), ft^3 (m^3).

* By definition, percent retained should be based on mass of total sample. Additional steps to those shown for this example would therefore be required.

Figure 2. – Sample data and calculation form.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4183-92

PROCEDURE FOR

SAMPLING AND ACCEPTANCE OF HYDRAULIC CEMENT

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4183; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 183-83a.

1. Scope

1.1 This designation covers the procedures for sampling and evaluating hydraulic cement for acceptance.

2. Applicable Documents

2.1 *USBR Procedures*:
4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens
4114 Chemical Analysis of Hydraulic Cement
4151 Autoclave Expansion of Portland Cement
4185 Air Content of Hydraulic Cement Mortar
4186 Heat of Hydration of Hydraulic Cement
4187 Normal Consistency of Hydraulic Cement
4188 Density of Hydraulic Cementitious Materials
4191 Time-of-Setting of Hydraulic Cement by Vicat Needle
4204 Fineness of Cementitious Materials by Air Permeability Apparatus
4227 Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
4233 Testing Air-Entraining Admixtures for Concrete
4266 Time-of-Setting of Hydraulic Cement by Gillmore Needles
4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
4430 Fineness of Hydraulic Cement by No. 325 (45-μm) Sieve
4441 Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete Due to Alkali-Aggregate Reaction
4451 Early Stiffening of Portland Cement (Paste Method)

2.2 *ASTM Standards*:
C115 Standard Test Method for Fineness of Portland Cement by the Turbidimeter[1]
C 157 Standard Test Method for Length Change of Hardened Cement Mortar and Concrete[1,2]

2.3 *Army Regulation*:
ER 1110-1-2002 Cement and Pozzolan Acceptance Testing (app. A)[5]

3. Units of Measurement

3.1 A ton as used in this procedure is 2,000 lbm (907.2 kg).

4. Significance and Use

4.1 The sampling methods described in this procedure are intended for use in the procurement of samples for acceptance tests of hydraulic cement, and are not intended as sampling methods for quality control purposes in manufacturing. The acceptance procedures cover the amount of testing to be done, and provide guidance for reporting on compliance or noncompliance of cements with specifications requirements.

5. Type and Size of Samples

5.1 A cement sample secured from a conveyor, bulk storage, or from a bulk shipment in one operation shall be termed a "grab sample." A sample obtained during a 10-minute interval using an automatic sampling device that continuously samples a cement stream may also be termed a "grab sample."

5.2 Grab samples taken at prescribed intervals over a period of time may be combined to form a "composite sample" that is representative of the cement produced during that period.

5.3 Composite samples on which physical and chemical tests are to be made are called "test samples."

5.4 All samples, whether grab or composite, shall have a mass of at least 10 lbm (4.5 kg).

5.5 The Government may designate a representative to supervise the sampling, packing, and shipping of samples.

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vol. 04.03.
[4] *Annual Book of ASTM Standards*, vols. 04.06, 05.05, 14.02.

[5] *Engineering and Design*, Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314.

5.6 Samples shall be packed in moistureproof, airtight containers that are to be numbered consecutively in the order that samples were taken. Containers shall be crated, if necessary, before shipping to testing location.

NOTE 1.-Containers made of polyvinyl chloride have occasionally been found to affect the air-entraining potential of a cement sample. The same problem might be experienced with containers made from other plastics.

6. Testing Time Requirements for Compliance Verification Tests

6.1 When compliance verification tests of hydraulic cement are required to be made at a laboratory other than that of the cement manufacturer, the cement sampling schedule, sample transportation time, and sample testing schedule must be coordinated among the Government, manufacturer, and testing laboratory so that test results will be available when decision to accept or reject cement must be made.

6.2 The cement manufacturer shall make the cement available for obtaining test samples at a date prior to the date that the test results are needed for the acceptance or rejection of the cement so that at least the applicable time intervals shown in the following tabulation can be ensured. This will allow the testing laboratory to provide test results not later than the indicated number of days after sampling:

Tests[1]	Time interval, days
4109, 4114, 4151, 4185, 4191, 4204, 4266, 4451, C 115, C 265, and C 563 (1-day results)	8
4109 (3-day results)	10
4109 and 4186 (7-day results)	14
4227 and C 452 (14-day results)	21
4109 and 4186 (28-day results)	35
C 157 (34-day results)	41
4227 (56-day results)	63
4227 (91-day results)	98

[1] Numbers preceded by a C are ASTM Standard Tests; other numbers are USBR Procedures.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Sampling

8.1 The cement may be sampled by any of the applicable methods described in this section.

8.1.1 *From Conveyor Delivering to Bulk Storage.*-Take one grab sample of 10 lbm (4.5 kg) minimum at about 6-hour intervals.

8.1.2 *Transfer Sampling.*-Samples of cement in storage may be taken while the cement is being transferred from one bin to another. One grab sample shall be taken from the the transfer stream for every 400 tons (363 Mg) of cement, or fraction thereof, but no less than two samples shall be taken.

8.1.3 *Other Sampling Methods.*-When neither of the sampling methods of sections 8.1.1 and 8.1.2 is applicable, the sample may be taken, when authorized by the Government, by one of the following methods:

8.1.3.1 *From Bulk Storage at Points of Discharge.*-Withdraw cement from discharge openings in a steady stream until sampling is completed. The quantity of cement in tons to be withdrawn from one discharge opening may be estimated as 0.2 times 0.00173 d^3, where d^3 is the depth in feet of cement above the discharge opening. If a high circular silo is being sampled, all samples may be taken from one opening. If quantity of cement in bin exceeds 1,200 tons (1089 Mg) when low rectangular bins are being sampled, the number of discharge openings used in the sampling shall be such that, for no opening, shall number of samples represent more than one-half the contents of bin, or more than 2,000 tons (1814 Mg). In sampling bulk storage at points of discharge while the cement is flowing through openings, take samples at such intervals so that one sample shall be taken for every 400 tons (363 Mg) of cement in bin or silo.

8.1.3.2 *From Bulk Storage or Bulk Shipment Using a Slotted-Tube Sampler or Sampling Pipe.*-When depth of cement to be sampled does not exceed 7 feet (2.1 m), samples may be obtained by a slotted-tube sampler similar to that shown on figure 1. The sampler shall be between 5 and 6 feet (1.5 and 1.8 m) long, about 1-3/8 inches (35 mm) outside diameter, and shall consist of two polished brass telescopic tubes with registering slots which are opened or closed by rotation of the inner tube; the outer tube being provided with a sharp point to facilitate penetration. For depths of cement greater than 7 feet, a sampling pipe activated by an air jet, which is capable of removing samples from different depths, may be used where applicable. Take samples obtained with slotted-tube sampler or sampling pipe from well-distributed points and various depths of the cement so that samples taken will be representative of total quantity.

8.1.3.3 *From Packaged Cement Using Tube Sampler.*-Insert sampler (fig. 2) diagonally into valve of bag and place thumb over air hole. Then, withdraw the sampler. Take one sample from a bag for every 5 tons (4.5 Mg), or fraction thereof.

8.1.3.4 *From Bulk Shipment by Car or Truck*:

8.1.3.4.1 *Single Shipment.*-If only one car or truck is being loaded, a 10-lbm (4.5-kg) sample shall be

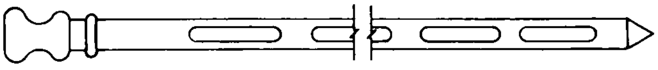

Figure 1. - Slotted tube sampler for bulk cement.

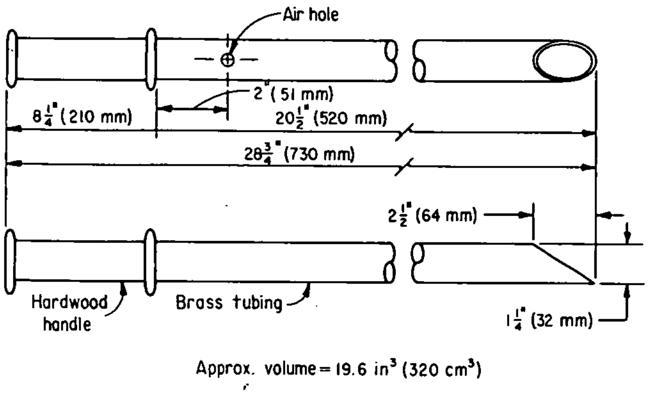

Figure 2. - Tube sampler for packaged cement.

taken if loading is continuous and all cement is from same source. If not continuous, or unknown, five or more portions from different points in the load shall be combined to form the test sample.

8.1.3.4.2 *Multiple Shipments.*-When shipment consists of several cars or trucks loaded from same source and on same day, the shipment may be sampled at a rate of one sample for every 100 tons (91 Mg) of cement, or fraction thereof, but no less than two samples shall be taken. Cement represented by such samples may be considered as a "lot" sample, and should be tested in accordance with section 11.3.

8.2 *Protection of Samples.*-As samples are taken, they shall be placed directly in moistureproof, airtight containers to avoid moisture absorption and aeration of sample. If samples are placed in cans, the cans shall be completely filled and sealed immediately. Moistureproof, multiple-wall, paper or plastic bags may be used if they are strong enough to avoid breakage; and if they can be sealed immediately after filling in such a manner as to eliminate excess air in sample and to avoid moisture absorption and aeration of sample. Samples shall be conditioned as described in section 10.

NOTE 2.-The recommended frequency for sampling and testing project samples is as follows: A minimum of one sample per project per year or when, in opinion of contracting agency, field performance of cement indicates the need for a check test. Also, the cement supplied from a qualified producing plant (App. A of Army Regulation ER 1110-1-2002) shall be sampled once at beginning of job, then once for every 1,000 tons (907 Mg) of cement thereafter. After samples are properly sealed, packaged, and contain all of the proper project identification, they should be sent to:

Department of the Army, Corps of Engineers, Waterways
Experiment Station, Attn: Structures Laboratory, Cement and
Pozzolan Test Branch, P O Box 631, Vicksburg, MS 39180.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

10. Conditioning

10.1 Before testing, pass each sample through a No. 20 (850-μm) sieve[6] or any other sieve having about 20 openings per inch (or per 25 mm) to mix the sample, break up lumps, and remove foreign materials. Discard the foreign materials and hardened lumps that do not break up during sieving or brushing. Store cement in airtight, moistureproof containers to prevent aeration or absorption of moisture prior to test.

11. Amount of Testing

11.1 *General.*-The Government shall specify the amount of testing when heat of hydration and/or false-set determinations are required. Test samples made up of composites of two consecutive samples shall be tested for autoclave soundness, normal consistency, and time-of-set. When there is an odd number of samples, the last sample shall be tested alone. All other tests shall be made on individual samples selected as shown in table 1.

Table 1. - Number of samples for testing.

Lot size, No. of samples	No. of tests at normal testing rate	No. of tests at reduced testing rate
2	2	2
3	3	2
4 to 10	4	2
11 to 20	6	2
Over 20	8	2

11.2 *Car and Truck Samples.*-All required tests shall be made on each sample, except as noted in 8.1.3.4.

11.3 *Lot Samples.*-The number of samples to be tested from each lot of samples shall be as specified in table 1, except on tests for autoclave soundness, heat of hydration, false set, normal consistency, and time-of-set.

11.4 *All Other Cases.*-For cases not otherwise specified, a test sample shall represent any quantity acceptable to the Government. For example, a test sample may represent a lot of cement stored in one bin or produced in 1 day.

NOTE 3.-Random grab samples taken at inappropriate times, such as immediately following repair or adjustment of manufacturing equipment, or from inappropriate places, such as from top surface of material in a car, will not suitably reflect the properties of a cement and therefore, should not be used as the basis for acceptance or rejection of a lot of cement.

11.5 *Normal Testing.*-The normal testing rate shall be used as follows:

- Before quality history has been established.
- When no samples from a given mill have been tested within a year.

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[6] Detailed requirements for this sieve are given in ASTM E 11.

- When quality history is based on any data more than 2 years old.
- When it is deemed necessary to recalculate critical limit because of indicated lack of control (sec. 12.2.3).

11.6 *Reduced Testing.*-After quality history has been established (sec. 12.2.1), testing may be done at the reduced testing rate (note 4). If results of these tests are within critical range, additional tests (equal to number of tests at normal testing rate) shall be made.

NOTE 4.-When quality history indicates that the results for a given requirement will probably be within critical range and that substantial delay in completion of tests would result from making additional tests (e.g., compressive strength), it may be desirable to make tests at normal rate rather than at reduced rate.

11.7 *Selection of Samples for Testing.*-The samples to be tested from each lot of samples shall be taken by some random method. The following method is suggested: A group of consecutively numbered markers equal to the number of samples are placed in a container and mixed. Then, one marker at a time is drawn from container until number of markers drawn is equal to number of samples to be tested at the normal rate. If testing is to be done at the reduced rate, the markers so drawn are again placed in a container, mixed, and two markers drawn to select the samples to be tested.

12. Acceptance

12.1 *Definitions*:

12.1.1 *Reduced Testing Rate.*-A test program that provides for testing only two samples from any given lot of samples that have been obtained and prepared for testing at normal rate as described in section 11. The program for reduced testing uses probability factors and is designed such that when results from the two tested samples fulfill requirements of test program, there is a 95-percent confidence level that less than 5 percent of the untested samples would be outside the specifications limits.

12.1.2 *Lot.*-A specific quantity of cement offered for inspection and acceptance at any one time. A lot may be one or more storage bins filled consecutively, or the contents of one or more transport units representing cement drawn from same storage bin.

12.2 The procedure for establishing a quality history and control charts shall be as follows:

12.2.1 *Quality History.*-The quality history shall represent cement from same source as cement to be tested, and shall be based on data not more than 2 years old. There shall be available test results for not less than 40 test samples representing not less than 7 lots of cement. The test samples shall conform to the applicable provisions of section 11. A pair shall be two test samples from the same lot, in numerical sequence. Several pairs from the same lot may be used when available. The number of paired samples representing a large lot may be reduced as follows: From the consecutively numbered group of tested samples representing entire lot, a subgroup is selected by some random method. The numbers identifying the subgroup are listed in numerical sequence and paired in the order of listing. The range, which is the difference between the test results of a pair, for each of these pairs of test results is then computed. These ranges are totaled and their sum divided by total number of ranges used to obtain average range ($\bar{r}$). The average range shall be computed for each included physical and chemical property limited by the specifications requirements.

12.2.2 *Critical Limit.*-Calculate the critical limit (C) for each included physical and chemical property limited by the specifications requirements. First, the average range $\bar{r}$ is multiplied by the probability factor 2.49, yielding a value which, for convenience, is called d. If the requirement has a maximum specification limit, C is obtained by subtracting d from that specification limit. If there is a minimum limit, obtain C by adding d to that limit. Quality history charts shall be maintained.

NOTE 5.-Improved estimates of $\bar{r}$ and, consequently, C will result if test results are not rounded. For example, the test result of 21.78 percent for SiO_2 is preferred to the rounded value of 21.8 percent. For fineness, the calculated value of 3243 is preferred to the rounded value of 3240.

12.2.3 *Control Chart.*-A control chart of the range shall be maintained to indicate when critical limit needs to be recomputed. The average range (sec. 12.2.1) is multiplied by the probability factor 3.267 to obtain the upper control limit for the range between each consecutive pair of test results. The horizontal scale of the chart will be successive groups of two tests, and the vertical scale will be the range. When the chart indicates lack of control (points beyond upper control limit), the critical limit may need to be recalculated. The occurrence of two consecutive points beyond upper control limit for the range or the occurrence of three points beyond upper control limit in any series of five consecutive points, shall be considered cause to recalculate critical limit. When it becomes necessary to recalculate critical limit, reduced testing shall be discontinued until a new quality history has been established.

NOTE 6.-Examples on the calculation of $\bar{r}$ and d, and quality history and control charts are shown in table 2 and on figures 3 and 4. The specifications limits used in these examples are hypothetical.

12.3 *Acceptance for Normal Testing.*-When testing is being done at normal testing rate, the cement shall be accepted if it meets specifications requirements; and shall be reported as failing to meet specifications requirements if it does not meet each requirement specified.

12.4 *Acceptance for Reduced Testing.*-When testing is being done at reduced testing rate, the cement shall be accepted if the average of the test results is further from the specified limit than it is from the critical limit. If average of results for one or more requirements are between critical limit and specification limit, additional samples shall be tested (equal to number of tests at normal rate) for that requirement. After completion of additional

Table 2. - Test data for type II, low-alkali, portland cement.

Lot No.	Sample No.	Alkalies, percent	Range, percent	7-day total load of three specimens, lbf	Range, lbf	7-day total load of three specimens, kN	Range, kN
88	1	0.58		40,200		178.8	
	13	0.61	0.03	42,700	2,500	189.9	11.1
	17	0.57		34,500		153.5	
	21	0.55	0.02	36,000	1,500	160.1	6.6
91	1	0.55		34,000		151.2	
	5	0.55	0.00	37,400	3,400	166.4	15.2
	13	0.57		38,100		169.5	
	21	0.54	0.03	39,700	1,600	176.6	7.1
98	5	0.55		37,150		165.3	
	13	0.56	0.01	37,880	730	168.5	3.2
	17	0.56		40,000		177.9	
	21	0.56	0.00	41,600	1,600	185.0	7.1
106	5	0.42		40 300		179.3	
	13	0.45	0.03	37,800	2,500	168.1	11.2
	17	0.47		36,380		161.8	
	21	0.39	0.08	35,130	1,250	156.3	5.5
107	4	0.47		37,650		167.5	
	8	0.46	0.01	38,900	1,250	173.0	5.5
	12	0.40		34,600		153.9	
	20	0.41	0.01	37,100	2,500	165.0	11.1
111	4	0.45		41,200		183.3	
	8	0.44	0.01	42,600	1,400	189.5	6.2
	16	0.41		40,350		179.5	
	20	0.40	0.01	41,350	1,000	183.9	4.4
112	3	0.45		42,400		188.6	
	7	0.48	0.03	37,900	4,500	168.6	20.0
	15	0.48		38,350		170.6	
	19	0.49	0.01	39,750	1,400	176.8	6.2
113	2	0.49		37,640		167.4	
	15	0.46	0.03	36,040	1,600	160.3	7.1
	20	0.47		38,330		170.5	
	24	0.49	0.02	37,500	830	166.8	3.7
120	1	0.46		35,000		155.7	
	6	0.46	0.00	36,170	1,170	160.9	5.2
	11	0.46		34,500		153.5	
	21	0.46	0.00	36,100	1,600	160.6	7.1
123	6	0.46		42,050		187.0	
	11	0.45	0.01	41,600	450	185.0	2.0
	21	0.44		39,800		177.0	
	26	0.44	0.00	40,750	950	181.3	4.3
Totals			0.34		33,730		149.8

Calculation of critical limit and control limit

$\bar{r}$	0.017	1,686.5	7.49
2.49 $\bar{r}$	0.04233	4,199	18.65
Critical limit	0.60-0.042 = 0.558	30,000+4,199 = 34,199	133.4+18.7=152.1
3.267 $\bar{r}$	0.0555	5,510	24.47
Control limit	0.056	5,510	24.5

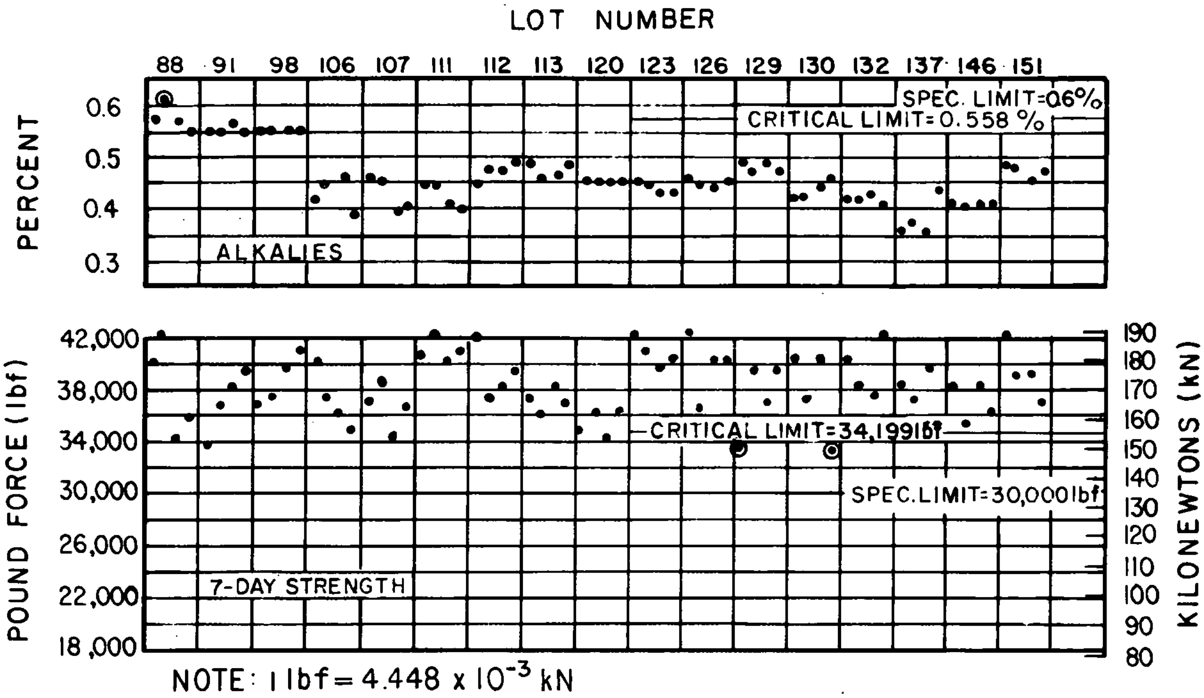

Figure 3. – Quality history chart.

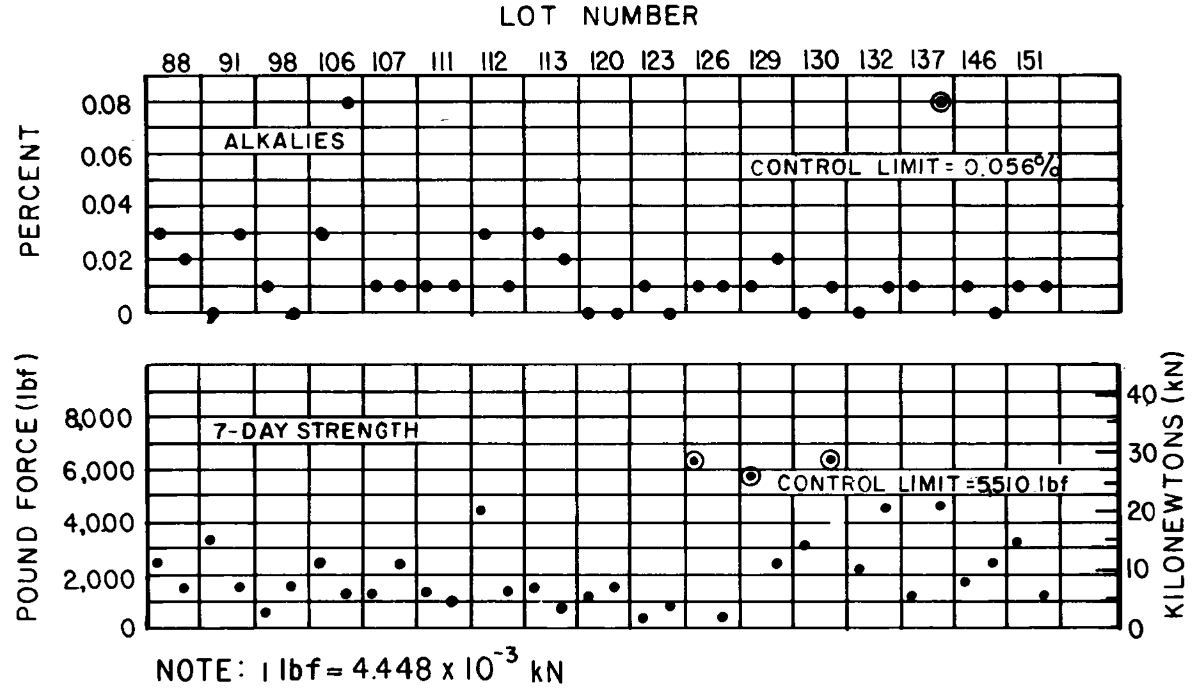

Figure 4. – Control chart for range.

tests, if all results meet specified requirements, the cement shall be accepted. The cement shall be reported as failing to meet the specifications requirements if any test result does not conform to a respective requirement.

13. Noncompliance and Retest

13.1 If any test result fails to meet a specifications requirement, the lot of cement involved shall not be rejected unless noncompliance is confirmed by a retest as described in 12.2.

13.2 A retest is considered to be an additional test of a certain property. The retest is made when results of initial test of this property would cause rejection of a cement for nonconformance with specifications requirements. A retest may consist of either a single determination or a set of replicate determinations.

13.3 Retests shall be conducted in accordance with the provisions, if given, of the applicable specifications. If no provisions are given, the following procedure shall be used:

13.3.1 Make retest on a portion of same sample used for the initial test. Use reference methods, when provided, for determination of property requiring retest. In such cases, use only the results obtained by these reference methods. Retest shall consist of same number of determinations required for initial tests or, if a within-laboratory precision statement is given which is based on a specified number of replicates (i.e., duplicate or triplicate determinations), the number of replicates used as the basis of such a precision statement. If two or more determinations are required, the value reported shall be the average of all results that are within the limits of precision of the procedure at the 95-percent confidence level, as stated in the applicable specifications or as generally recognized.

14. Calculations

14.1 Suggested worksheets for typical calculations are provided with the test procedures listed in the Applicable Documents of section 2.

15. Report

15.1 Figure 5 shows a typical reporting form for all acceptance tests of hydraulic cement.

16. Precision and Bias

16.1 Precision and bias statements are not appropriate for this procedure because numerical reports of success or failure are not required.

Project YAKIMA SOLIC. NO. 5-51-10-03220	Ownership: LEHIGH CEMENT CO.	Compiled by Date F. HELLER & K. MITCHELL 6-11-86
Feature ROZA DIVERSION DAM FISH SCREEN STR.	Location: METALINE FALLS, WA	Checked by B. HESS Date 6-11-86
Date Letter Transmitted 7-29-86	Section NA Township NA	Reviewed by T. DOLEN Date 6-12-86
Branch File No. C-12EX	Range NA Meridian NA	Submitted by J. PIERCE Date 6-13-86

QUALITY EVALUATION

☑ CEMENT ☐ POZZOLAN

State: WASHINGTON	Region: PN	Sample No. M-34EX	Date Rec'd.: 6-11-86
Material: ASTM C150 CEMENT		Type: II	Class: ~
Source Name: METALINE FALLS			Volume: ~

Physical Properties

From USBR 4188 or 4311, Density = 3.16 Mg/m^3

From USBR 4185 or 4311, Air Content = 9.0 %

From USBR 4151 or 4311, Autoclave Expansion = -0.04 %

From USBR 4311 or ASTM C157, Drying Shrinkage = ~ % Control

From USBR 4204, Fineness (Blaine Air Permeability), Specific Surface = 403 m^2/kg

From USBR 4311 or 4430, Passing No. 325 (45-µm) Sieve, 90.3 %

From USBR 4186, Heat of Hydration in [✓ kJ/kg] or cal/g: 3-day ~, 7-day 296, 28-day 351

From USBR 4187, Normal Consistency 25 %, 162 mL of H_2O, 10 mm of Penetration

Time-of-Set:
From USBR 4191, Vicat Needle, Initial 170 min, Final 280 min
From USBR 4266, Gillmore Needle, Initial 185 min, Final 320 min

False Set Penetration

USBR 4451 (Paste Method)			USBR 4359 (Mortar Method)				
Initial, mm	Final, mm	Remix, mm	Initial, mm	5-minute, mm	8-minute, mm	11-minute, mm	Remix, mm
30	13	21	50+	50	49	48	50
120 mL of H_2O 43 % Penetration Ratio							

Compressive Strength Using 2-inch or 50-mm Cubes

USBR 4109 – Standard Test USBR 4311 – Control Mix			USBR 4311 – Cement/Pozzolan Mortar Test Mix			
W/C = 48, 242 mL H_2O, 110 % Flow			W/(C+P) = ~, ~ mL H_2O, ~ % Flow			
Age, days	Comp. Str., lbf/in^2	Comp. Str., MPa	Comp. Str., lbf/in^2	Comp. Str., MPa	H_2O Req'd. Flow, % of Control	PAI of Portland Cement, % of Control
1						
3	3070	21.00	~	~	~	~
7	3540	24.40	~	~	~	~
28						
90						

USBR 4311 - PAI (Pozzolan Activity Index) With Lime

___ mL of H_2O, ___ % Flow, 7-Day Strength = ___ lbf/in^2 (MPa)

USBR 4311 or 4441 - Reactivity With Cement Alkalies

Expansion: Control Mix ~ %, Test Mix ~ %, 14-Day Reduction ~ %

From USBR 4233 or 4311, Limits on Amount of AEA in Concrete

Cement: ☐ 4233 ☐ Project; Source ________ Type ______

Aggregate: Coarse (☐ 4233 ☐ Project); Source ___, Sp.Gr. ___, MSA ___ in. (mm)

Fine (☐ 4233 ☐ Project); Source ___, Sp.Gr. ___, F.M. ___

AEA Brand ____________ Manufacturer ____________

Chemical Analysis, %

Oxide Analysis	USBR 4114	USBR 4311
SiO_2	22.00	
Al_2O_3	3.70	
Fe_2O_3	3.20	
Σ of above	28.90	
CaO	63.70	
MgO	1.90	
SO_3	2.30	
Alkalies	Total	Available
Na_2O	0.08	~
K_2O	0.68	~
Misc. Properties		
Total Alkalies *	0.53	~
CaO (Free Lime)	ND	
Insoluble Residue	0.26	
Loss on Ignition	1.50	~
Moisture Content		~
"R" Factor (C-5)/F		~
Compound Composition		
C_2S	22	
C_3A	5	
C_3S	55	
C_4AF	10	
$CaSO_4$	ND	
Minor Constituents		
TiO_2	0.19	
P_2O_5	0.07	
ZnO	ND	
Mn_2O_3	ND	
Sulfide Sulfur	ND	
Cl^-	ND	

	Control Mix	Test Mix		Control Mix	Test Mix		Control Mix	Test Mix
Cement, lbm/yd^3 (kg/m^3)			W/C or W/(C+P)			Air Content (Grav.), %		
Pozzolan, lbm/yd^3 (kg/m^3)			FA:TA Ratio			Air Content (Press.), %		
Water, lbm/yd^3 (kg/m^3)			Slump, in. (mm)					
AEA, oz/yd^3 (g/m^3)			AEA:CEM Ratio					

* Alkalies as Na_2O equivalent: $Na_2O + 0.658\ K_2O$
AEA = Air-Entraining Admixture

Figure 5. – Sample reporting form for USBR 4183.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4185-92

PROCEDURE FOR

AIR CONTENT OF HYDRAULIC CEMENT MORTAR

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4185; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 185-80.

1. Scope

1.1 This designation covers the procedure for determination of air content of hydraulic cement mortar under specified conditions.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1030 Calibrating Specific Gravity Flasks
4183 Sampling and Acceptance of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:
C 185 Standard Test Method for Air Content of Hydraulic Cement Mortar[1]
C 230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement[1,2]
C 511 Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1,2]
C 778 Standard Specification for Standard Sand[1]

3. Summary of Procedure

3.1 The mortar to be tested is prepared with standard sand and cement using a water content sufficient to give a required flow. This mortar is compacted into a measure of known volume, and then the mass is determined. The air content is then calculated from the determined mass per unit volume of the mortar, the known specific gravities of the constituents, and the mixture proportions.

4. Significance

4.1 The purpose of this procedure is to determine whether the hydraulic cement under test meets the air-entraining or non-air-entraining requirements of the applicable hydraulic cement specification for which the test is being made. The air content of concrete is influenced by many factors other than the potential of the cement for air entrainment.

5. Apparatus

5.1 *Flow Table, Flow Mold, and Caliper*.–These items shall conform to the requirements of ASTM C 230. Illustrations of these items are shown on figures 1 and 2.

5.2 *Measure*.–A cylindrical measure having an inside diameter of 3±1/16 inches (76.2±1.6 mm) and a depth of 3-15/32 inches (88 mm) is required. The depth is adjusted by standardization with water so that the measure contains 400±1 mL at 73.4±3 °F (23.0±1.7 °C) (note 1). For purposes of this test, capacity of the measure in milliliters is the amount of water content of measure, in grams, divided by 0.9976; no mass correction made for buoyant effect of air. The measure shall have a uniform wall thickness. The thickness of the wall and bottom shall not be less than 0.115 inch (2.92 mm). The total mass of empty measure shall not be more than 900 grams. The measure shall be made of a metal that will not be chemically attacked by the cement mortar.

NOTE 1.–The 400-mL measure can be calibrated readily by filling with distilled water at 73.4±3 °F (23.0±1.7 °C) to a point where meniscus extends appreciably above top of measure, placing a clean piece of plate glass on top of measure, and allowing the excess water to be squeezed out. The absence of air bubbles, as seen through the glass, ensures that measure is completely full. Care shall be taken to wipe excess water from sides of container before determining mass.

5.3 *Clearance Adjustment Bracket, Mixer, Bowl, and Paddle*.–These items shall conform to section 4 of USBR 4305. An illustration of these items is shown on figure 3.

5.4 *Straightedge*..–A steel straightedge not less than 4 inches (102 mm) long and not less than 1/16 inch (1.6 mm) nor more than 1/8 inch (3.2 mm) in thickness is required.

5.5 *Spatula*.–A spatula with a metal blade 6 inches (152 mm) in length and 0.5 inch (13 mm) in width, with straight edges and a wooden handle, is required.

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.

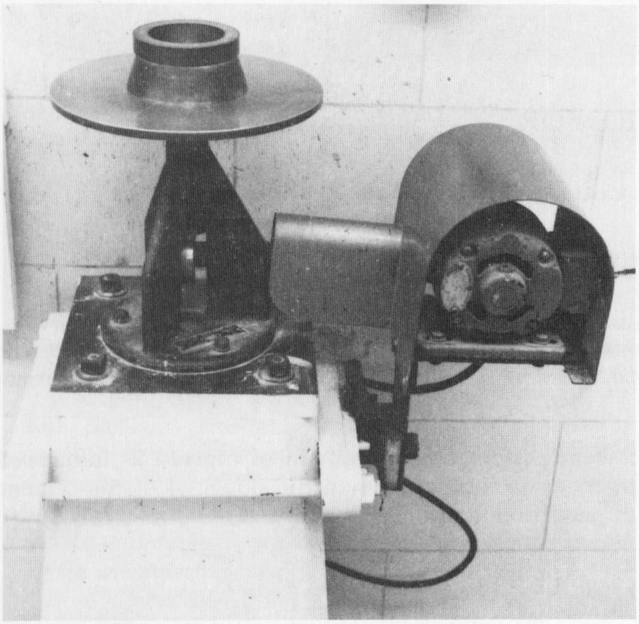

Figure 1. - A 10-inch (254-mm) flow table and flow mold.

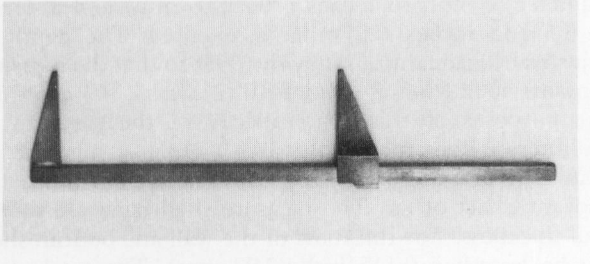

Figure 2. - A typical flow caliper.

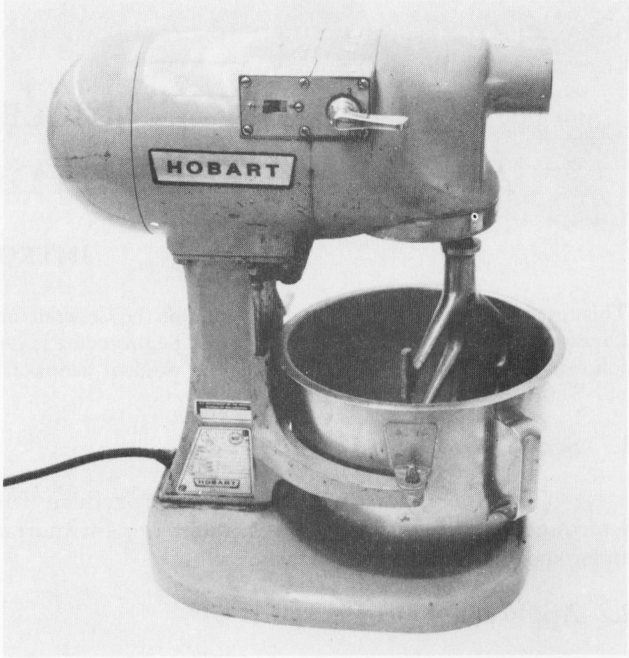

Figure 3. - A 5-quart (4.7-liter) mortar mixer.

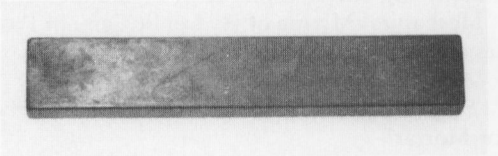

Figure 4. - A hard-rubber tamper.

5.6 *Scales*.-Scales having a capacity sufficient to measure the mass of the mortar and container, which is about 2 kg, is required. The permissible variation at 2 kg shall be ±1 g.

5.7 *Glass Graduates*.-Glass graduates of 250-mL capacity, with graduations at 2-mL intervals for measuring the mixing water, are required to deliver indicated volume at 68 °F (20 °C). The permissible variation of the volume shall be ±2 mL. The main graduation lines shall encircle the graduate and shall be numbered. The least graduations shall extend at least one-seventh the circumference of the graduate and intermediate graduations shall extend at least one-fifth the circumference. Subdivisions may be omitted for the bottom 10 mL of the graduate.

5.8 *Tamper*.-A tamper made of a nonabsorptive, nonabrasive, nonbrittle material such as a rubber compound having a Shore A durometer hardness of 80±10, or seasoned oak wood rendered nonabsorptive by immersion for 15 minutes in paraffin at about 392 °F (200 °C), and having a cross section of 0.5 by 1 inch (13 by 25 mm) and a convenient length of 5 to 6 inches (127 to 152 mm) is required. The tamping face of the tamper shall be flat and at right angles to the length of the tamper. A typical hard-rubber tamper is shown on figure 4.

5.9 *Tapping Stick*.-A tapping stick made of hard wood and having a diameter of 5/8 inch (16 mm) and a length of 6 inches (152 mm) is required.

5.10 *Spoon*.-A typical serving spoon with about a 9-inch (230-mm) long handle and 4-inch (100-mm) long bowl is required.

6. Conditioning or Preparation of Temperature and Humidity

6.1 The temperature of the room and dry materials shall be maintained between 68.0 and 81.5 °F (20.0 and 27.5 °C).

6.2 The mixing water and the measure, if it is being calibrated, shall be conditioned to the temperature required for moist cabinets or rooms, which is 73.4±3 °F (23.0± 1.7 °C), in accordance with ASTM C 511.

6.3 The relative humidity of the laboratory shall not be less than 50 percent.

7. Standard Sand

7.1 The sand used for making the standard mortar (sec. 11.1) shall be natural silica sand, conforming to the requirements for No. 20 to No. 30 (850- to 600-μm) standard sand as described in ASTM C 778.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

9. Sampling

9.1 Sample the cement in accordance with USBR 4183.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

10.2 The flow table, flow mold, and caliper shall be checked to meet the requirements of ASTM C 230 by using linear measurement devices conforming to USBR 1000.

10.3 The measure shall be checked to meet the requirements of section 5.2 by using linear measurement devices conforming to USBR 1000. Further calibration of the measure may be made in accordance with note 1, section 5.2.

10.4 The mixer, bowl, and paddle shall be checked for compliance with USBR 4305. The straightedge, spatula, tamper, tapping stick, and spoon shall be checked for compliance with section 5 by using linear measurement devices conforming to USBR 1000.

10.5 The scales shall be checked to meet the requirements of section 5.6 in accordance with USBR 1012.

10.6 Glass graduates shall comply with section 5.7 by being checked in accordance with USBR 1030.

10.7 Temperature controls of materials and molding room and the humidity in molding room shall comply with section 6 and ASTM C 511 by using certified thermometers and relative humidity testers.

11. Procedure

11.1 *Batch.*-The proportions of the standard mortar shall be 350 grams of cement to 1400 grams of No. 20 (850-μm) to No. 30 (600-μm) standard sand and sufficient water to give a flow of 87.5±7.5 percent when determined in accordance with section 11.3.

11.2 *Mixing of Mortar.*-Mix the mortar in accordance with USBR 4305.

11.3 *Flow Determination.*-Carefully wipe dry the top of the flow table and place flow mold at center. Using the spoon, place about a 1-inch (25-mm) layer of mortar in mold and tamp 20 times with tamper. The tamping pressure shall be just sufficient to ensure uniform filling of mold. Then, finish filling mold with a second layer of mortar and tamp as specified for first layer. Cut off mortar to a plane surface, flush with top of mold, by drawing straightedge across top of mold with a sawing motion. Wipe top of flow table clean and dry, being especially careful to remove any water from around edge of mold. Lift mold away from mortar 1 minute after completing mixing operation. Immediately drop table 0.5 inch (12.7 mm) 10 times in 6 seconds. The flow is the resulting increase in average diameter of mortar mass, as determined with calipers, measured on at least four diameters at about equally spaced intervals, and expressed as a percentage of original diameter. Make trial mortars with varying percentages of water until specified flow is obtained. Make each trial with fresh mortar.

11.4 *Mortar Mass.*-When the quantity of mixing water has been found that produces a flow of 87.5±7.5 percent, immediately determine the mass per 400 mL of mortar using the mortar remaining in mixing bowl after flow has been determined; *do not* use the mortar used in the flow determination. Using spoon, place mortar gently into 400-mL measure in 3 equal layers, spading each layer 20 times with spatula in one complete revolution around inner surface of measure. One complete up and down motion with the spatula held in a vertical position shall be considered one spading. When spading first layer, do not strike spatula forcibly against bottom of measure. When spading second and final layers, use only enough force to cause spatula to penetrate surface of previous layer. After measure has been filled and spaded, tap sides of measure lightly with the side of the tapping stick one time at five different points at about equal spacing around outside of measure to preclude entrapment of extraneous air (note 2). No obvious space shall be left between mortar and inner surface of measure as a result of the spading operation. Then, cut off mortar to a plane surface, flush with top of measure, by drawing straightedge across top of measure with a sawing motion. Make two passes over entire surface, with second pass being made at right angles to the first. If, in the cutting-off operations, loose sand grains cause straightedge to ride above top surface of measure, these grains shall be removed and the operation repeated. Complete entire operation of filling and cutting off measure within 1.5 minutes. Wipe off all mortar and water adhering to outside of measure. Determine mass of measure and its contents, subtract mass of container, and record mass of mortar in grams.

NOTE 2.-This operation may be facilitated by placing measure on a steady, flat-surfaced support of lesser diameter than the measure while filling and wiping.

12. Calculations

12.1 Calculate air content of mortar from equation (1), which is based on the use of the measure specified in section 5.2 and on the batch proportions given in section 11.1

(note 3). This equation also uses a specific gravity of portland cement of 3.15, and 2.65 for the No. 20 to No. 30 (850- to 600-μm) standard sand. When the hydraulic cement is other than portland, the appropriate value for its specific gravity shall be substituted for the 3.15 value and the equation rederived accordingly. Figure 5 shows a typical calculation form.

$$V = 100 - M\left(\frac{182.7 + P}{2000 + 4P}\right) \qquad (1)$$

where:

V = volume of air content of mortar in percent,
M = mass of 400 mL of mortar in grams, and
P = percentage of mixing water based on mass of cement used.

NOTE 3.-Equation (1) can be derived as follows:

$$V = 100\left(1 - \frac{M_a}{M_c}\right) \qquad (2)$$

where:

M_a = actual mass per unit of volume as determined by USBR 4185 (note 4)
= $(M/400\ \text{g})/\text{mL}$ (sec. 11.4)
M_c = theoretical mass per unit of volume calculated on an air-free basis and using values for quantities of materials and specific gravities as given in sections 11.1 and 12.1

$$= \frac{350 + 1400 + (350)(P)(0.01)}{\frac{350}{3.15} + \frac{1400}{2.65} + (350)(P)(0.01)}$$

$$= \frac{5+0.01\ P}{1.827 + 0.01P}$$

V, M, and P = as previously defined

Substituting the above values for M_a and M_c into equation (2):

$$V = 100\left[1 - \left(\frac{M}{400}\right)\left(\frac{1.827 + 0.01P}{5 + 0.01P}\right)\right]$$

$$= 100 - \left(\frac{M}{4}\right)\left(\frac{1.827 + 0.01P}{5 + 0.01P}\right)$$

$$= 100 - 2.5M\left(\frac{182.7 + P}{5000 + 10P}\right)$$

$$= 100 - M\left(\frac{182.7 + P}{2000 + 4P}\right)$$

= Equation (1)

12.2 Make only one determination of air content per batch of mortar.

NOTE 4.-Difficulty has occasionally been experienced in determining the mass per unit volume using USBR 4185 by some personnel. These difficulties usually have been with values for air content that are abnormally high and that may be greater than the specified maximums in specifications for hydraulic cement. The air-entraining potential of the sand may be reduced by washing in the laboratory with potable water and by decantation until a clear, colorless, supernatant liquid is obtained. In case of dispute, such freshly washed sand shall be used.

13. Report

13.1 A suggested reporting form is shown on figure 5 of USBR 4183.

14. Precision and Bias

14.1 The single-operator, within-laboratory, standard deviation has been found to be 0.56 percent air content throughout the range of 8 to 19 percent air. Therefore, results of two properly conducted tests by the same operator on similar batches should not differ by more than 1.6 percent air.

14.2 The multilaboratory standard deviation has been found to be 1.0 percent air content throughout the range from 8 to 19 percent air. Therefore, results of two different laboratories on similar batches should not differ from each other by more than 2.8 percent air.

14.3 There is no known bias for this test procedure.

15. Reference

15.1 For additional useful information on details of cement test methods, reference may be made to the "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.

Spec. or Solic. No. DC-7224	Structure TUNNELS	Tested by J. OWENS Date 5-25-79
Project FRY ARK	Item CEMENT RESEARCH Location DENVER LAB	Computed by J. OWENS Date 5-25-79
Feature MORMAN-CARTER TUNNELS	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 5-25-79

AIR CONTENT OF HYDRAULIC CEMENT MORTAR

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	*C* Cement, grams	*S* Sand, grams	*W* Water, mL*	Flow, percent	*P* $\frac{W}{C}$ (100) percent	Mass of Mortar Plus Container, grams	Mass of Container, grams	*M* Mass of Mortar, grams	*V* Volume of Air, percent
M-7108	IDEAL CEMENT	PORTLAND CO	II	350	1400	244	86	69.7	1703	887	816	9.3

NOTES:

* 1 mL = 1 cm^3 = 1 gram

Figure 5. - Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4186-92

PROCEDURE FOR

HEAT OF HYDRATION OF HYDRAULIC CEMENT

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4186; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 186-82.

1. Scope

1.1 This designation covers a procedure for the determination of heat of hydration of a hydraulic cement by measuring heat of solution of dry cement and heat of solution of a separate portion of the cement that has been partially hydrated for 7 and 28 days; the difference between these values being the heat of hydration for the respective hydrating period.

2. Applicable Documents

2.1 *USBR Procedures*:

1000	Standards for Linear Measurement Devices
1012	Calibrating Balances or Scales
1020	Calibrating Ovens
1025	Checking Sieves
4114	Chemical Analysis of Hydraulic Cement
4183	Sampling and Acceptance of Hydraulic Cement

2.2 *ASTM Standards*:

C 186 Standard Test Method for Heat of Hydration of Hydraulic Cement[1]

C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[2]

E 11 Standard Specifications for Wire-Cloth Sieves for Testing Purposes[3]

3. Apparatus

3.1 *Calorimetric Apparatus*:

3.1.1 *Calorimeter.*–The calorimeter (fig. 1) shall consist of a 1-pint (0.47-L), wide-mouth vacuum jar, with cork stopper, held in a suitably insulated container (sec. 3.1.2) to keep vacuum jar in position and protect jar from excessive temperature fluctuations. The vacuum jar shall be coated inside with a material resistant to hydrofluoric acid, such as a baked phenolic resin, baked vinyl-chloride acetate resin, or beeswax. The acid-resistant coating shall be intact and free of cracks at all times; it shall be examined frequently and recoated whenever necessary. An alternative method of protecting the vacuum jar is a plastic liner of suitable size. The contents of the vacuum jar shall not change by more than 0.001 °C/min per degree difference from room temperature when filled with 425 grams of the acid specified in section 6.2, stoppered, and allowed to stand unstirred for 30 minutes. The temperature for this check shall approximate the starting temperatures to be used in making the determination.

3.1.2 *Insulated Container.*–The insulated container shall have an insulating layer of cotton or similar material, which shall be at least 1 inch (25 mm) thick and encase sides and bottom of vacuum jar, but shall be so arranged as to permit easy removal of jar.

3.1.3 *Differential and Reference Thermometers.*–The adjustable differential thermometer shall be of the Beckmann type, graduated to at least 0.01 °C, and shall have a range of about 6 °C. The thermometer shall be so adjusted that upper limit of scale approximates room temperature. The portion of thermometer that rests inside calorimeter shall be protected with a coating resistant to hydrofluoric acid (sec. 3.1.1). The differential thermometer shall be equipped with a suitable reading lens. The differential thermometer zero must be determined by immersion in a liquid and by comparison with reference thermometer. An accurate reference thermometer, of appropriate range and having 0.1 °C divisions, shall be placed in the proximity of calorimetric apparatus. The reference thermometer shall be used for room temperature readings and for establishing the differential thermometer zero.

3.1.4 *Funnel.*–The funnel through which sample is introduced into calorimeter shall be glass or plastic, shall have a stem about 3 inches (76 mm) long, and an inside diameter of not less than 1/4 inch (6.4 mm).

3.1.5 *Stirring Assembly.*–The stirrer shall be a three-bladed polyethylene propeller having dimensions as shown on figure 2, and shall extend as close as possible to bottom of calorimeter (note 1). The motor shall be of the constant-speed type, at least 1/20 horsepower (37 W), and shall be equipped with a geared speed reducer so that one speed, in the range of 350 to 700 revolutions per minute, can be maintained constant.

NOTE 1.–The stirrer shown on figure 2 may be readily made from a commercially available three-bladed polyethylene propeller having a propeller diameter of 1-3/8 inches (34.9 mm), shaft

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[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

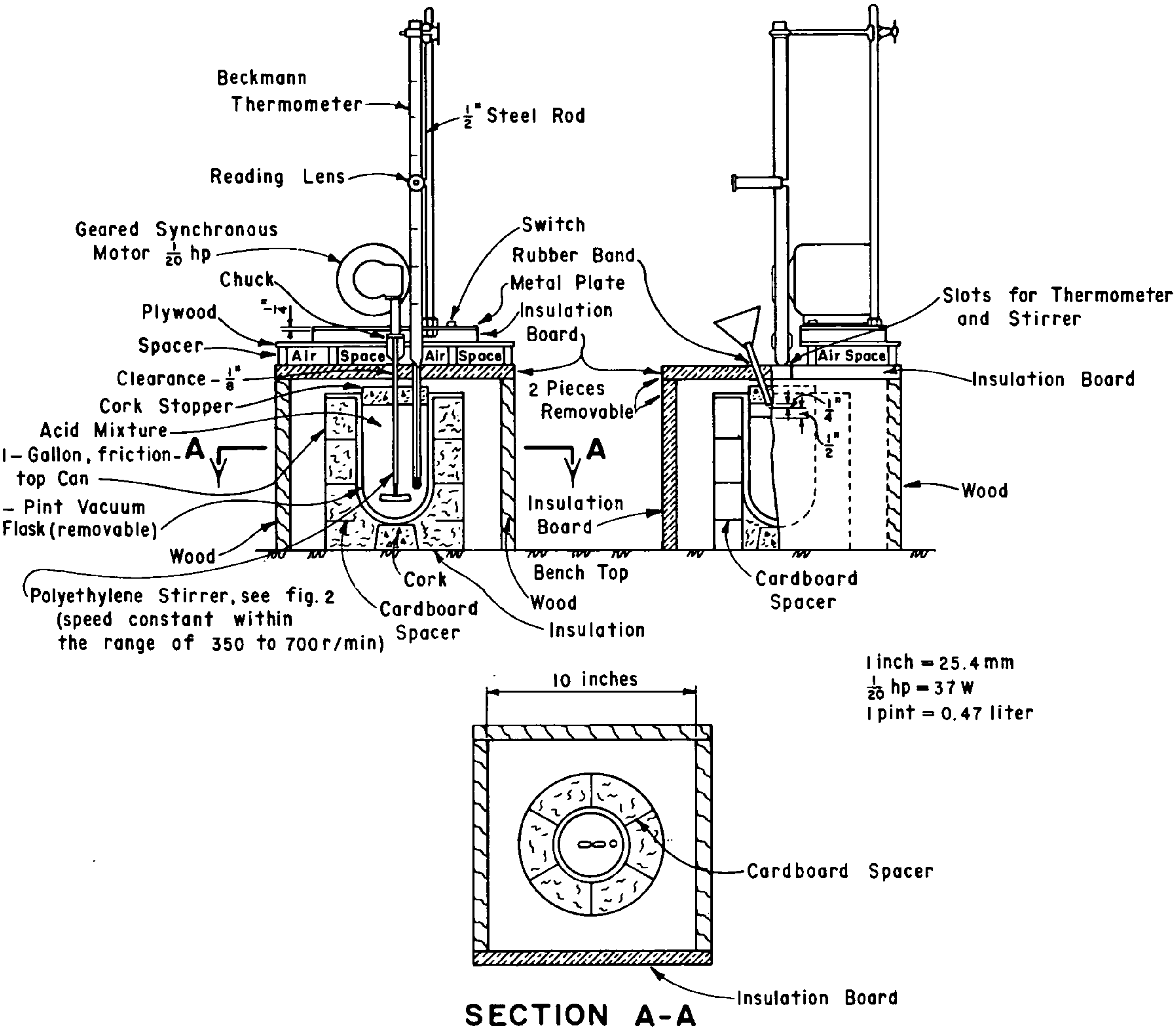

Figure 1. - Calorimeter.

diameter of 1/4 inch (6.4 mm), and a shaft length of 18 inches (457 mm). The stirrer has two functions: (1) to maintain uniform temperature throughout liquid, and (2) to supply sufficient agitation to keep the solid in suspension in acid mixture. Since a stirrer capable of keeping the solid in suspension generates considerable heat in the calorimeter, it is important that the stirrer speed, and hence the rate of heat generation, be maintained constant. Therefore, a synchronous motor and geared speed reducer are almost mandatory.

3.2 *Mixer.*-A moderate-speed mechanical mixer, such as a milk-shake mixer, capable of intimately mixing the cement and water to a uniform paste is required.

3.3 *Storage.*-Storage space shall be temperature controlled at 73.4±3 °F (23.0±1.7 °C).

3.4 *Mortar Bowl and Pestle.*-A vessel about 8 inches (200 mm) in diameter with a bowl-shaped cavity in which partially hydrated samples are ground or pounded with the pestle.

3.5 *Plastic Vials.*-The vials shall be about 3-5/32 by 1 inch (80 by 25 mm), shell type, with tight-fitting stoppers or caps.

3.6 *Drying Oven.*-Drying oven shall be maintained at 212 to 230 °F (100 to 110 °C).

3.7 *Mass Determination Bottles.*-These bottles shall be about 1.6 inches (40 mm) in height and 1 inch (25 mm) wide, with matching stoppers.

3.8 *Stop Watch or Clock Timer.*-Required for timing.

3.9 *Sieves.*-No. 100 (150 μm) and No. 20 (850 μm), conforming to ASTM E 11.

3.10 *Crucibles.*-Platinum, 30-mL capacity, with covers, for loss-on-ignition determination.

3.11 *Muffle Furnace.*-A muffle furnace, or suitable burners capable of maintaining a temperature of 1652 to 1742 °F (900 to 950 °C).

3.12 *Analytical Balance and Analytical Weights.*-These items shall conform to the requirements prescribed in

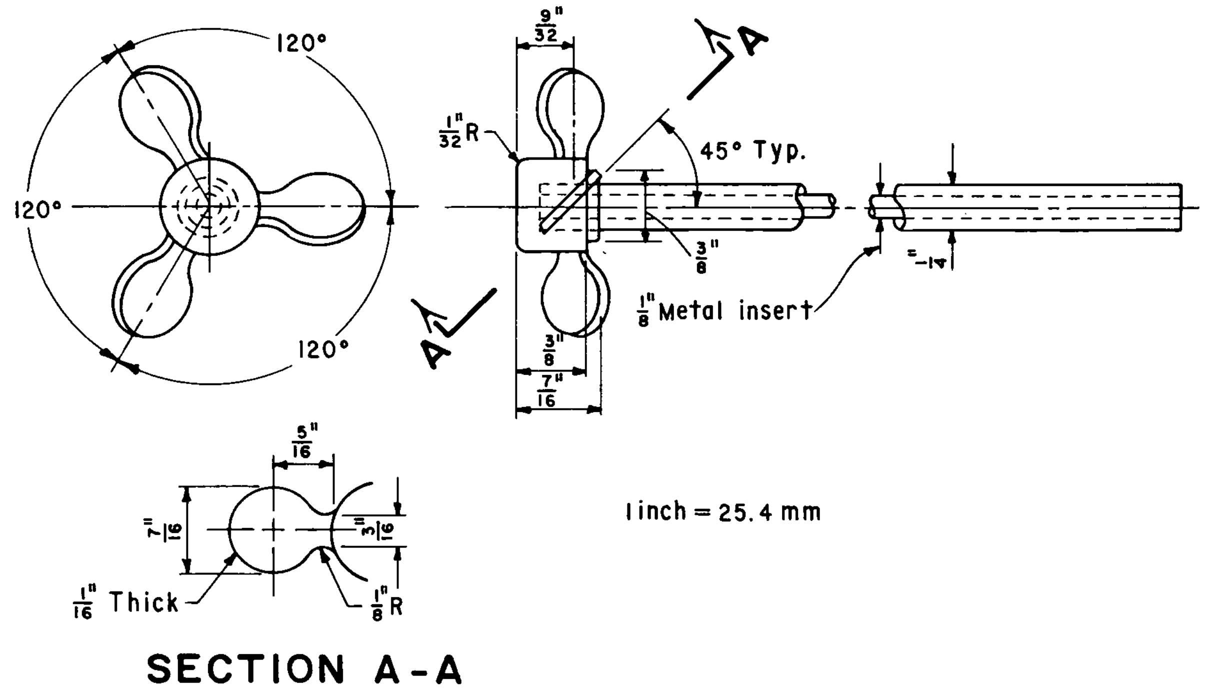

Figure 2. – Stirring assembly.

USBR 4114 for determining mass of calorimetric samples and loss-on-ignition samples.

3.13 *Balance.*–Balance shall have a capacity of 1 kilogram, and be capable of measuring mass of acid charge to nearest 0.05 gram.

4. Significance and Use

4.1 The purpose of this procedure is to determine if the hydraulic cement under test meets the heat of hydration requirement of applicable hydraulic cement specification.

5. Reagents

5.1 *Purity of Reagents.*–Reagent grade chemicals shall be used in all tests [1][4]. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. For suggestions on the testing of reagents not listed in reference [1], see references [2,3]. Other grades of chemicals may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Hydrofluoric Acid.*–Concentrated HF (hydrofluoric acid) with a specific gravity of 1.15.

5.3 *Nitric Acid.*–The 2.00 *N* (normal) HNO_3 (nitric acid), for use in the calorimeter, shall be prepared and standardized in large quantities. Optionally, the dilute HNO_3 may be made with 127 mL of concentrated HNO_3 (sp. gr. 1.42) per liter of solution, provided that heat capacity determinations are made with each batch of diluted HNO_3 so prepared.

5.4 *Wax.*–Paraffin wax, or other suitable wax, for sealing vials.

5.5 *Zinc Oxide.*–The ZnO (zinc oxide) shall be heated at 1652 to 1742 °F (900 to 950 °C) for 1 hour, cooled in a desiccator, ground to pass a No. 100 (150-µm) sieve, and stored. Immediately prior to a heat capacity determination, 7 grams of the ZnO so prepared shall be heated for not more than 5 minutes at 1652 to 1742 °F, cooled to room temperature in a desiccator, and the mass determined accurately for introduction into calorimeter.

NOTE 2.–The rate of solution of the ZnO varies with the preliminary treatment. The procedure describes results in a product which dissolves at about same rate as dry cement.

6. Procedure for Determining Heat Capacity of Apparatus

6.1 To determine the heat capacity of the system, that is, the number of calories or joules required to raise temperature of calorimeter and contents 1 °C, measure corrected temperature rise obtained by dissolving 7 grams of ignited ZnO in the specified acid mixture (sec. 6.2 to 6.6).

6.2 Transfer about 400 grams of the 2.00 *N* HNO_3, which has been cooled to temperature indicated by lower range of differential thermometer, ordinarily about 4 to 5 °C below room temperature, into the vacuum jar, add 8.0 mL of HF (sp. gr. 1.15), determine mass, and add sufficient additional 2.00 *N* HNO_3 to bring total mass

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[4] Numbers in brackets refer to entries in References, section 15.

of solution to 425 grams. Then, assemble calorimeter and start stirring motor. Ensure that stirrer blades or shaft do not touch thermometer, sides or bottom of jar, or cork stopper. The lower end of funnel stem shall extend about 1/4 inch (6 mm) below lower surface of stopper and at least 1/2 inch (13 mm) above level of liquid. The upper end of differential thermometer bulb shall be at least 1-1/2 inches (38 mm) below surface of liquid. Place upper end of bulb at same depth in all determinations. After an initial stirring period of at least 20 minutes to allow temperature of system to become uniform, record temperature of room to nearest 0.1 °C, record temperature of acid to nearest 0.001 °C, record time, and then immediately introduce prepared ZnO through funnel at a uniform rate (note 3). Complete introduction of ZnO in not less than 1 nor more than 2 minutes. Brush any ZnO clinging to funnel stem into acid mixture using a small "camel's-hair" brush.

NOTE 3.-Temperature of sample shall be identical with that of room when sample is introduced into calorimeter.

6.3 Read temperature to the nearest 0.001 °C, at 20 and 40 minutes after beginning introduction of sample. The first 20-minute period is the uncorrected temperature rise, which covers the solution period, and the second 20-minute period is the rating period. The temperature difference between the 20- and 40-minute readings is the correction to be added to or subtracted from the uncorrected temperature rise, according to whether calorimeter temperature rises or falls during rating period.

6.4 *Calculations*:

6.4.1 Calculate corrected temperature rise as follows:

$$R_0 = \theta_{20} - \theta_0 \qquad (1)$$

$$R = R_0 - (\theta_{40} - \theta_{20}) \qquad (2)$$

where:

R_0 = observed temperature rise in °C,
θ_{20} = calorimeter temperature at end of solution period,
θ_0 = calorimeter temperature when sample was introduced,
R = corrected temperature rise in °C, and
θ_{40} = calorimeter temperature at end of rating period.

6.4.2 Calculate heat capacity of calorimeter and contents (note 4) as follows:

$$C \text{ (in cal/°C)} = \frac{M_i\,[256.1 + 0.1\,(30-t) + 0.12\,(T-t)]}{R} \qquad (3)$$

$$C \text{ (in J/°C)} = \frac{M_i\,[1072 + 0.42\,(30-t) + 0.5\,(T-t)]}{R} \qquad (4)$$

where:

C = heat capacity in cal/°C (J/°C);
M_i = mass of calorimetric sample, on ignited basis, in grams;
t = final temperature of calorimeter in °C, θ_{20} plus temperature when differential thermometer reading is zero;
T = room temperature when sample is introduced into calorimeter, in °C; and
R = corrected temperature rise in °C.

NOTE 4.-Heat of solution of the ZnO is 256.1 cal/g (1072 kJ/kg) at 30 °C. For each degree decrease in temperature below 30 °C, the heat of solution increases by 0.1 cal/g (0.42 kJ/kg). The heat capacity of ZnO is 0.12 cal/(g·°C) [0.5 kJ/(kg·°C)]. The heat required to bring the ZnO to the final temperature of the calorimeter must be included in the effective heat of solution.

6.4.3 Figures 3 and 4 show typical calculations.

6.5 If more than a trace of ZnO is found adhering to the tip of the funnel or to the stopper when the calorimeter is opened, reject the test.

6.6 Redetermine the heat capacity at the following times:

- When differential thermometer is reset.
- When a new coating is applied to thermometer, stirrer, or flask.
- When a new thermometer, stirrer, or flask is put in service.
- When a new batch of acid is used.
- At other times when, according to judgment of operator, need is indicated.

7. Precautions

7.1 This procedure involves the use of hazardous materials, operations, and equipment. Users are responsible for determining applicability of regulations and for establishing appropriate safety practices.

8. Calibration and Standardization

8.1 Calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

8.2 Calibration of calorimeter shall be checked by thermometers certified to meet requirements of section 3.1.3.

8.3 The stirring assembly shall be checked for compliance with section 3.1.5 by using linear measuring devices meeting the requirements of USBR 1000 and with certified revolution counters.

8.4 Drying oven shall meet requirements of section 3.6 by being calibrated in accordance with USBR 1020.

8.5 Sieves shall be calibrated to meet requirements of section 3.9 and ASTM E 11 in accordance with USBR 1025.

8.6 The muffle furnace shall be checked for compliance with section 3.11 using thermometers certified by manufacturer.

8.7 The analytical balance, analytical masses, and the balance shall be calibrated to meet requirements of sections 3.12 and 3.13, and the balance and masses shall also meet requirements of USBR 4114 in accordance with USBR 1012.

9. Conditioning and Standardization

9.1 *Preparation of Cement Paste.*–Store the cement and mixing water in a constant-temperature room at 73.4±3 °F (23±1.7 °C) until materials are at ambient temperature before preparation of paste. Mix 150 grams of cement and 60 mL of distilled water using a spatula, and then vigorously stir mixture with a mechanical stirrer for 5 minutes. Place approximately equal representative portions of paste in four or more plastic vials, filling vials to within about 1/2 inch (13 mm) of top. Immediately after filling vials, seal them with tight-fitting stoppers or caps. If there is any doubt regarding tightness of seal, sealed ends of vials should be dipped in molten paraffin wax. Store the vials in an upright position in a water bath at 73.4±3 °F until time of test.

9.2 *Preparation of Partially Hydrated Sample for Heat of Solution Test.*–At specified age of test, remove a vial of partially hydrated sample from storage and, during the 20-minute initial stirring period of calorimeter, break the plastic away from the sample and rapidly crush entire sample with mortar bowl and pestle so that all material will pass through a No. 20 (850-μm) sieve; then quickly place sample in a well-stoppered bottle. Take care, particularly with the 7-day partially hydrated sample, to expose sample to the air as little as possible, and thus minimize any carbon dioxide action or loss of moisture from sample.

10. Procedure for Determining Heat of Hydration

10.1 *Calorimetric Procedure, Dry Cement.*–Determine the heat of solution of the dry cement sample according to the procedure described for the heat capacity determination in section 6, but use a 3-gram sample (determined to nearest 0.001 gram) of the dry cement instead of the prepared ZnO (note 3). Exercise care in securing a uniform and representative sample. Calculate and report the results on the ignited mass basis (sec. 10.3). Make the heat of solution test on the dry cement just prior to the test on the corresponding 7-day partially hydrated sample.

10.2 *Calorimetric Procedure, Partially Hydrated Sample.*–For the heat of solution of the partially hydrated sample, follow the same procedure as for dry cement described in section 10.1, but use a 4.18±0.05-gram calorimetric sample of the partially hydrated cement, determined to nearest 0.001 gram (note 3). Calculate the results on the ignited mass basis (sec. 10.3).

10.3 *Loss on Ignition.*–Immediately before and after calorimetric sample mass has been determined, determine mass of a similar sample and place it into a platinum crucible for determination of loss on ignition. Use the average of the two determinations for the final recorded value. Ignite the dry cement at 1652 to 1742 °F (900 to 950 °C) for at least 1-1/2 hours. Immediately place crucible containing sample in a desiccator and allow to cool to room temperature; then immediately determine mass of crucible. When determining loss on ignition of hydrated cement, first dry the sample with known mass in an oven at 212 to 230 °F (100 to 110 °C) for 1 hour; then place sample in muffle furnace at 1652 to 1742 °F overnight, or over a suitable burner for not less than 5 hours. Reduce mass of cement sample that was introduced into calorimeter to ignited mass basis for use in final calculations (figs. 3 and 4) as follows:

$$M_i = \frac{A}{B}(M) \tag{5}$$

where:

A = mass of ignited sample, in grams;
B = mass of sample before ignition, in grams;
M = mass of original calorimetric sample, in grams; and
M_i = as previously defined.

11. Calculations

11.1 *Heat of Solution of Dry Cement.*–Calculate corrected temperature rise as described in sections 6.3 and 6.4. Also, correct the heat of solution value if final calorimeter temperature of the heat of solution test is different from temperature of calorimetric sample when introduced. Thus, for the dry cement, which has a specific heat of about 0.2 cal/(g·°C) [0.8 kJ/(kg·°C)], if final calorimeter temperature *exceeds* temperature of cement sample at time it was introduced, *add* a correction of 0.2 cal/(g·°C) difference in those temperatures when calculating the heat of solution. Calculate the heat of solution of the dry cement as follows:

$$H_1\ (\text{cal/g}) = \frac{RC}{M_i} - 0.2\ (T - t_d) \tag{6}$$

$$H_1\ (\text{kJ/kg}) = \frac{RC}{M_i} - 0.8\ (T - t_d) \tag{7}$$

where:

H_1 = heat of solution of dry cement, in calories per gram (kilojoules per kilogram);
t_d = final calorimeter temperature at end of determination on dry cement, in °C; and other terms as previously defined.

11.2 *Heat of Solution of Partially Hydrated Sample.*–The heat of solution of a partially hydrated sample is calculated similar to the dry cement calculations of section 11.1 with some additional corrections. Because an increase of 1 °C in temperature, at which the heat of solution test occurs, causes a decrease of about 0.3 cal/g (1.3 kJ/kg) in the heat of solution, if the temperature of the heat of solution test of the partially hydrated sample *exceeds* the temperature of the dry cement determination, a correction of 0.3 cal/(g·°C) [1.3k J/(kg·°C)] difference in temperature shall be *added* to the heat of solution value obtained for the partially hydrated sample. Also, correct the heat of solution value if final calorimeter temperature of the solution test is different from the temperature of the calorimetric sample when introduced. Thus, for the partially hydrated sample, which has a specific heat of about 0.4 cal/g (1.7 kJ/kg) of ignited cement, if the final calorimeter temperature exceeds the temperature of the sample at the time it was introduced, add a correction of 0.4 cal/(g·°C) [1.7 kJ/(kg·°C)] difference in those temperatures when calculating the heat of solution.

11.2.1 Calculate the heat of solution of the partially hydrated sample as follows:

$$H_2 \text{ (cal/g)} = \frac{RC}{M_i} - 0.4\,(T - t_h) - 0.3\,(t_d - t_h) \qquad (8)$$

$$H_2 \text{ (kJ/kg)} = \frac{RC}{M_i} - 1.7\,(T - t_h) - 1.3\,(t_d - t_h) \qquad (9)$$

where:

H_2 = heat of solution of partially hydrated sample, in calories per gram (kilojoules per kilogram);
R, C, M_i, and T = as previously defined for equations (3) and (4), but as related to partially hydrated sample;
t_d = same numerical value as in equation (6) of section 11.1, and
t_h = final calorimeter temperature at end of determination on partially hydrated sample, in °C.

11.2.2 Figures 3 and 4 show typical calculations.

11.3 *Heat of Hydration.*-A final calorimeter temperature of 25 °C shall be considered as the basis to which the heat of hydration shall be referred. Also, any variation in this temperature should be kept in mind when considering the test results. An increase in the final temperature raises the heat of hydration about 0.1 cal/(g·°C) [0.4 kJ/(kg·°C)] of ignited cement. For example, if final temperature is 27 °C, then 0.2 cal/g (0.8 kJ/kg) should be subtracted from observed heat of hydration to refer the results to 25 °C. In borderline cases, proper correction should be made for the effects of final calorimeter temperature. Calculate the heat of hydration of the cement as follows:

$$H_h \text{ (cal/g)} = H_1 - H_2 + 0.1\,(25.0 - t_h) \qquad (10)$$

$$H_h \text{ (kJ/kg)} = H_1 - H_2 + 0.4\,(25.0 - t_h) \qquad (11)$$

where:

H_h = heat of hydration of ignited cement, in calories per gram (kilojoules per kilogram);
H_1 = heat of solution of dry cement, equation (6) in section 11.1;
H_2 = heat of solution of partially hydrated sample, equation (8) in section 11.2.1; and
t_h = same numerical value as in equation (8) in section 11.2.1.

11.3.1 Figures 3 and 4 show typical calculations.

12. Retests

12.1 In case of failure to meet the 28-day requirement for heat of hydration, a reserve sample of cement paste may be tested at a later age and a correction value of 0.5 cal/g (2.1 kJ/kg) per day of excess age added to bring the retested heat of solution to the 28-day basis. The period over which this correction may be made shall be limited to 4 days. In case of failure to meet the 7-day requirement, a complete retest including mixing of the paste should be made.

13. Report

13.1 A suggested reporting form is shown on figure 5 of USBR 4183.

14. Precision and Bias

14.1 *Single-Operator Precision.*-The single-operator standard deviations (1S) have been found to be 2.91 cal/g (12.2 kJ/kg) and 3.54 cal/g (14.8 kJ/kg) for the determinations of heat of solution and heat of hydration, respectively. Therefore, results of two properly conducted tests by the same operator on samples of the same cement should not differ from each other by more than 8 cal/g (33.5 kJ/kg) in the determination of heat of solution, or 10 cal/g (41.8 kJ/kg) in the determination of heat of hydration.[5]

14.2 *Multilaboratory Precision.*-The multilaboratory standard deviations (1S) have been found to be 4.42 cal/g (18.5 kJ/kg) and 4.03 cal/g (16.9 kJ/kg) for the determination of heat of solution and heat of hydration, respectively. Therefore, results of two properly conducted tests from two different laboratories on samples of the same cement should not differ from each other by more than 13 cal/g (54.4 kJ/kg) in the determination of heat of solution, or 11 cal/g (46.0 kJ/kg) in the determination of heat of hydration.[5]

14.3 The bias for this designation has not been established.

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[5] These deviation values represent the (1S) and (D2S) limits as described in ASTM C 670.

15. References

[1] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC.

[2] Rosen, Joseph, *Reagent Chemicals and Standards*, 3rd ed., Van Nostrand Co., Inc., New York, NY, 1955.

[3] *United States Pharmacopeia and National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS	Date 3-7-77
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS	Date 3-7-77
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by B. DUFFUS	Date 3-7-77
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT	Type II LA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☐ H_1 (Heat of Solution of Dry Cement) ☑ *C* (Heat of Capacity of Apparatus)

MASSES	TRIAL 1		TRIAL 2	
Room Temperature at 0° Beckman, °C	17.6			
Mass of container and sample, grams				
Mass of container, grams				
(1) *M*, Original calorimeter sample, grams				
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams				
(3) Crucible, Trial 1 ( ), Trial 2 ( ), grams				
(4) Sample, (2)-(3), grams				
Ignition Ratio (After/Before)				
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams				
(3) Crucible, Trial 1 ( ), Trial 2 ( ), grams				
(4) Sample, (2)-(3), grams				
Ignition Ratio (After/Before)				
(5) Average Ignition Ratio				
(6) M_i, Ignited Calorimeter Sample, grams ☐ (1) (5) ☑ Measured	6.9968			
(7) Acid No.	14			
(8) *C*, Calorimeter Heat Capacity, cal/°C ☑ (6) (29)/(15) ☐ From sheet 1 of 3	412.967			
(9) *T*, Sample Temperature, °C	23.5			
TIME	°B	*t* °C	°B	°C
(10) θ_0 10:03 a.m.	0.750			
(11) θ_{20} 10:23 a.m.	5.110	22.71		
(12) θ_{40} 10:43 a.m.	5.117			
(13) R_0, $\theta_{20}-\theta_0$, (11)-(10), °C	4.360			
(14) $\theta_{40}-\theta_{20}$, (12)-(11), °C	0.007			
(15) *R*, (13)-(14), °C	4.353			
(16) RC/M_i, (15)(8)/(6), cal/g				
(17) 0.2 ($T-t_d$), 0.2[(9)-(11)], cal/g				
(18) H_1, (16)-(17), cal/g				
(19) Avg. H_1, cal/g				
(27) 0.12 ($T-t$), 0.12 [(9)-(11)], cal/g	0.0948			
(28) 0.10 ($30.0-t$), 0.10 [(30.0)-(11)], cal/g	0.729			
(29) Sum, 256.1+(27)+(28), cal/g	256.924			

Figure 3. - Sample data and calculation form (metric). Sheet 1 of 3.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS	Date 10-1-79
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS	Date 10-1-79
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL	Date 10-1-79
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT	Type II LA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☑ H_1 (Heat of Solution of Dry Cement) ☐ C (Heat of Capacity of Apparatus)

MASSES	TRIAL 1		TRIAL 2	
Room Temperature at 0° Beckman, °C	17.6			
Mass of container and sample, grams	36.0145			
Mass of container, grams	33.0145			
(1) M, Original calorimeter sample, grams	3.0000			
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.6487	19.6100		
(3) Crucible, Trial 1 (No. 3), Trial 2 ( ), grams	16.6483	16.6483		
(4) Sample, (2)-(3), grams	3.0004	2.9617		
Ignition Ratio (After/Before)	0.9871			
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	17.8595	17.8205		
(3) Crucible, Trial 1 (No. 5), Trial 2 ( ), grams	14.8597	14.8597		
(4) Sample, (2)-(3), grams	2.9998	2.9608		
Ignition Ratio (After/Before)	0.9870			
(5) Average Ignition Ratio	0.987			
(6) M_i, Ignited Calorimeter Sample, grams ☑ (1) (5) ☐ Measured	2.9613			
(7) Acid No.	16			
(8) C, Calorimeter Heat Capacity, cal/°C ☐ (6) (29)/(15) ☑ From sheet 1 of 3	412.967			
(9) T, Sample Temperature, °C	24.0			
TIME	°B	t_d °C	°B	°C
(10) θ_0 8:13 a.m.	0.660			
(11) θ_{20} 8:33 a.m.	4.970	22.57		
(12) θ_{40} 8:53 a.m.	5.002			
(13) R_0, $\theta_{20}-\theta_0$, (11)-(10), °C	4.310			
(14) $\theta_{40}-\theta_{20}$, (12)-(11), °C	0.032			
(15) R, (13)-(14), °C	4.278			
(16) RC/M_i, (15)(8)/(6), cal/g	596.587			
(17) 0.2 $(T-t_d)$, 0.2[(9)-(11)], cal/g	0.286			
(18) H_1, (16)-(17), cal/g	596.301			
(19) Avg. H_1, cal/g	596.301			
(27) 0.12 $(T-t)$, 0.12 [(9)-(11)], cal/g				
(28) 0.10 $(30.0-t)$, 0.10 [(30.0)-(11)], cal/g				
(29) Sum, 256.1+(27)+(28), cal/g				

Figure 3. - Sample data and calculation form (metric). Sheet 2 of 3.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS 10-1-79 Date 10-22-79	
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS. 10-1-79 Date 10-22-79	
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL 10-1-79 Date 10-22-79	
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT	Type II LA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☑ H_2 (Heat of Solution of Partially Hydrated Sample) ☑ $H_1 - H_2$ (Heat of Hydration)

MASSES	TRIAL 1 (7 DAYS)		TRIAL 2 (28 DAYS)	
Room Temperature at 0° Beckman, °C	17.6		17.6	
Mass of container and sample, grams	37.2006		37.1920	
Mass of container, grams	33.0200		33.0119	
(1) *M*, Original calorimeter sample, grams	4.1806		4.1801	
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.9205	18.7500	19.0422	17.8594
(3) Crucible, Trial 1 (No. 3), Trial 2 (No. 4), grams	15.7404	15.7404	14.8620	14.8620
(4) Sample, (2)–(3), grams	4.1801	3.0096	4.1802	2.9974
Ignition Ratio (After/Before)	0.7200		0.7170	
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.6074	18.4382	19.6120	18.4308
(3) Crucible, Trial 1 (No. 8), Trial 2 (No. 11), grams	15.4272	15.4272	15.4319	15.4319
(4) Sample, (2)–(3), grams	4.1802	3.0110	4.1801	2.9989
Ignition Ratio (After/Before)	0.7203		0.7174	
(5) Average Ignition Ratio	0.7202		0.7172	
(6) M_i, Ignited Calorimeter Sample, grams ☑ (1) (5) ☐ Measured	3.0109		2.9980	
(7) Acid No.	16		16	
(8) *C*, Calorimeter Heat Capacity, cal/°C ☐ (6) (29)/(15) ☑ From sheet 1 of 3	412.967		412.967	
(9) *T*, Sample Temperature, °C	22.8		21.5	
TIME	°B	t_h °C	°B	t_h °C
(10) θ_0 8:32 a.m.	0.380		0.930	
(11) θ_{20} 8:52 a.m.	4.262	21.86	4.651	22.25
(12) θ_{40} 9:12 a.m.	4.305		4.650	
(13) R_0, $\theta_{20}-\theta_0$, (11)–(10), °C	3.882		3.721	
(14) $\theta_{40}-\theta_{20}$, (12)–(11), °C	0.043		−0.001	
(15) *R*, (13)–(14), °C	3.839		3.722	
(16) RC/M_i, (15)(8)/(6), cal/g	526.547		512.696	
(20) 0.4 $(T-t_h)$, 0.4[(9)–(11)], cal/g	0.376		−0.300	
(21)* 0.3(t_d-t_h), 0.3 [t_d –(11)], cal/g	0.213		0.096	
(22) H_2, (16)–(20)–(21), cal/g	525.958		512.900	
(23)** H_1-H_2, (19)– (22), cal/g	70.3		83.4	
(24) 0.1 $(25.0-t_h)$, 0.1 [25.0–(11)], cal/g	0.3		0.3	
(25) H_h, (23)+(24), cal/g	70.6		83.7	
(26) Average H_h, ☐ 7-day, ☐ 28-day	~			

* t_d = Line (11) of figure 3 (sheet 2 of 3).

** Obtain value for line (19) from figure 4 (sheet 2 of 3).

Figure 3. – Sample data and calculation form (metric). Sheet 3 of 3.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS	Date 3-7-77
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS	Date 3-7-77
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by B. DUFFUS	Date 3-7-77
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT	Type IILA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☐ H_1 (Heat of Solution of Dry Cement) ☑ C (Heat of Capacity of Apparatus)

MASSES	TRIAL 1		TRIAL 2	
Room Temperature at 0° Beckman, °C	17.6			
Mass of container and sample, grams				
Mass of container, grams				
(1) M, Original calorimeter sample, grams				
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams				
(3) Crucible, Trial 1 ( ), Trial 2 ( ), grams				
(4) Sample, (2)-(3), grams				
Ignition Ratio (After/Before)				
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams				
(3) Crucible, Trial 1 ( ), Trial 2 ( ), grams				
(4) Sample, (2)-(3), grams				
Ignition Ratio (After/Before)				
(5) Average Ignition Ratio				
(6) M_i, Ignited Calorimeter Sample, grams ☐ (1) (5) ☑ Measured	6.9968			
(7) Acid No.	14			
(8) C, Calorimeter Heat Capacity, J/°C ☑ (6) (29)/(15) ☐ From sheet 1 of 3	1728.64			
(9) T, Sample Temperature, °C	23.5			
TIME	°B	t °C	°B	°C
(10) θ_0 10:03 a.m.	0.750			
(11) θ_{20} 10:23 a.m.	5.110	22.71		
(12) θ_{40} 10:43 a.m.	5.117			
(13) R_0, $\theta_{20}-\theta_0$, (11)-(10), °C	4.360			
(14) $\theta_{40}-\theta_{20}$, (12)-(11), °C	0.007			
(15) R, (13)-(14), °C	4.353			
(16) RC/M_i, (15)(8)/(6), J/g				
(17) 0.8 $(T-t_d)$, 0.8[(9)-(11)], J/g				
(18) H_1, (16)-(17), J/g				
(19) Avg. H_1, J/g	~			
(27) 0.5 $(T-t)$, 0.5 [(9)-(11)], J/g	0.395			
(28) 0.42 $(30.0-t)$, 0.42 [(30.0)-(11)], J/g	3.062			
(29) Sum, 1072+(27)+(28), J/g	1075.46			

Figure 4. - Sample data and calculation form (SI-metric). Sheet 1 of 3.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS Date 10-1-79
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS Date 10-1-79
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 10-1-79
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT Type II LA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☑ H_1 (Heat of Solution of Dry Cement) ☐ C (Heat of Capacity of Apparatus)

MASSES	TRIAL 1		TRIAL 2	
Room Temperature at 0° Beckman, °C	17.6			
Mass of container and sample, grams	36.0145			
Mass of container, grams	33.0145			
(1) M, Original calorimeter sample, grams	3.0000			
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.6487	19.6100		
(3) Crucible, Trial 1 (No. 3), Trial 2 ( ), grams	16.6483	16.6483		
(4) Sample, (2)-(3), grams	3.0004	2.9617		
Ignition Ratio (After/Before)	0.9871			
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	17.8595	17.8205		
(3) Crucible, Trial 1 (No. 5), Trial 2 ( ), grams	14.8597	14.8597		
(4) Sample, (2)-(3), grams	2.9998	2.9608		
Ignition Ratio (After/Before)	0.9870			
(5) Average Ignition Ratio	0.987			
(6) M_i, Ignited Calorimeter Sample, grams ☑ (1) (5) ☐ Measured	2.961			
(7) Acid No.	16			
(8) C, Calorimeter Heat Capacity, J/°C ☐ (6) (29)/(15) ☑ From sheet 1 of 3	1728.64			
(9) T, Sample Temperature, °C	24.0			
TIME	°B	t_d °C	°B	°C
(10) θ_0 8:03 a.m.	0.660			
(11) θ_{20} 8:23 a.m.	4.970	22.57		
(12) θ_{40} 8:43 a.m.	5.002			
(13) R_0, $\theta_{20}-\theta_0$, (11)-(10), °C	4.310			
(14) $\theta_{40}-\theta_{20}$, (12)-(11), °C	0.032			
(15) R, (13)-(14), °C	4.278			
(16) RC/M_i, (15)(8)/(6), J/g	2497.51			
(17) 0.8 $(T-t_d)$, 0.8[(9)-(11)], J/g	1.144			
(18) H_1, (16)-(17), J/g	2496.37			
(19) Avg. H_1, J/g	2496.37			
(27) 0.5 $(T-t)$, 0.5 [(9)-(11)], J/g				
(28) 0.42 $(30.0-t)$, 0.42 [(30.0)-(11)], J/g				
(29) Sum, 1072+(27)+(28), J/g				

Figure 4. - Sample data and calculation form (SI-metric). Sheet 2 of 3.

Spec. or Solic. No. NA	Structure NA	Tested by J. OWENS	10-1-79 Date 10-22-79
Project RESEARCH	Item CEMENT HEAT OF HYDRATION Location DENVER LAB	Computed by J. OWENS	10-1-79 Date 10-22-79
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL	10-1-79 Date 10-22-79
Sample No. M-7120 LAB STANDARD	Brand Name IDEAL CEMENT	Plant Ident. DEVIL'S SLIDE, UT	Type IILA

HEAT OF HYDRATION OF HYDRAULIC CEMENT

☑ H_2 (Heat of Solution of Partially Hydrated Sample) ☑ $H_1 - H_2$ (Heat of Hydration)

MASSES	TRIAL 1 (7 DAYS)		TRIAL 2 (28 DAYS)	
Room Temperature at 0° Beckman, °C	17.6		17.6	
Mass of container and sample, grams	37.2006		37.1920	
Mass of container, grams	33.0200		33.0119	
(1) M, Original calorimeter sample, grams	4.1806		4.1801	
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.9205	18.7500	19.0422	17.8594
(3) Crucible, Trial 1 (No. 3), Trial 2 (No. 4), grams	15.7404	15.7404	14.8620	14.8620
(4) Sample, (2)-(3), grams	4.1801	3.0096	4.1802	2.9974
Ignition Ratio (After/Before)	0.7200		0.7170	
	IGNITION		IGNITION	
	BEFORE (B)	AFTER (A)	BEFORE (B)	AFTER (A)
(2) Crucible and Sample, grams	19.6074	18.4382	19.6120	18.4308
(3) Crucible, Trial 1 (No. 8), Trial 2 (No. 11), grams	15.4272	15.4272	15.4319	15.4319
(4) Sample, (2)-(3), grams	4.1802	3.0110	4.1801	2.9989
Ignition Ratio (After/Before)	0.7203		0.7174	
(5) Average Ignition Ratio	0.7202		0.7172	
(6) M_i, Ignited Calorimeter Sample, grams ☑ (1) (5) ☐ Measured	3.0109		2.9980	
(7) Acid No.	16		16	
(8) C, Calorimeter Heat Capacity, J/°C ☐ (6) (29)/(15) ☑ From sheet 1 of 3	1728.64		1728.64	
(9) T, Sample Temperature, °C	22.8		21.5	
TIME	°B	t_h °C	°B	t_h °C
(10) θ_0 8:32 a.m.	0.380		0.930	
(11) θ_{20} 8:52 a.m.	4.262	21.6	4.651	22.25
(12) θ_{40} 9:12 a.m.	4.305		4.650	
(13) R_0, $\theta_{20}-\theta_0$, (11)-(10), °C	3.882		3.721	
(14) $\theta_{40}-\theta_{20}$, (12)-(11), °C	0.043		-0.001	
(15) R, (13)-(14), °C	3.839		3.722	
(16) RC/M_i, (15)(8)/(6), J/g	2204.07		2146.10	
(20) 1.7 $(T-t_h)$, 1.7[(9)-(11)], J/g	2.04		-1.28	
(21)* 1.3(t_d-t_h), 1.3 [t_d-(11)], J/g	1.26		0.42	
(22) H_2, (16)-(20)-(21), J/g	2200.77		2146.96	
(23)** H_1-H_2, (19)-(22), J/g	295.60		349.41	
(24) 0.4 $(25.0-t_h)$, 0.4 [25.0-(11)], J/g	1.36		1.10	
(25) H_h, (23)+(24), J/g	297		351	
(26) Average H_h, ☐ 7-day, ☐ 28-day	~			

* t_d = Line (11) of figure 3 (sheet 2 of 3).

** Obtain value for line (19) from figure 4 (sheet 2 of 3).

Figure 4. - Sample data and calculation form (SI-metric). Sheet 3 of 3.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4187-92

PROCEDURE FOR

NORMAL CONSISTENCY OF HYDRAULIC CEMENT

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4187; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 187-83.

1. Scope

1.1 This designation covers the procedure for determining the normal consistency of hydraulic cement.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1030 Calibrating Specific Gravity Flasks
4183 Sampling and Acceptance of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:
C 187 Standard Test Method for Normal Consistency of Hydraulic Cement[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,2]
E 177 Standard Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurements of a Property of a Material[1,3]

2.3 *National Institute of Standards and Technology*[4]:
Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

3. Significance and Use

3.1 This test procedure is intended to be used to determine amount of water required to prepare hydraulic cement pastes for testing.

4. Apparatus

4.1 *Scales.*–For scales currently in use, the permissible variation at a load of 1 kg shall be ±1 gram. The permissible variation on new scales shall be one-half of this value. (Refer to sec. 2.3.)

4.2 *Glass Graduates.*–Graduates shall be of either 200- or 250-mL capacity, and shall conform to the requirements of ASTM C 490.

4.3 *Vicat Apparatus.*–The Vicat apparatus (fig. 1) shall consist of a frame bearing a 300-g movable rod. The plunger end of the rod shall be 10 mm in diameter for a distance of at least 50 mm; the other end of the rod shall have a 50-mm long, 1-mm-diameter, removable needle. The rod is reversible, can be held in any desired position by a set screw, and has an adjustable indicator which moves over a scale (graduated in millimeters) attached to the frame. The rod shall be made of stainless steel having a hardness of not less than 35 HRC (note 1), and shall be straight with the plunger end, which is perpendicular to the rod axis. The cement paste is held in a rigid conical ring resting on a glass plate about 100 mm square. The ring shall be made of a noncorroding, nonabsorbent material; shall have a height of 40 mm; and an inside diameter of 70 mm at the base and 60 mm at the top. In addition, the Vicat apparatus shall conform to the requirements shown in table 1.

NOTE 1.–The requirement that the rod be made of stainless steel shall apply only to new Vicat apparatus or replacement rods and not to equipment currently in use that meets the other requirements of this procedure.

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all of the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

6.2 Scales shall be calibrated to meet requirements of section 4.1 in accordance with USBR 1012.

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[1] *Annual Book of ASTM Standards*, vol. 04.01
[2] *Annual Book of ASTM Standards*, vol. 04.02
[3] *Annual Book of ASTM Standards*, vol. 14.02
[4] Formerly National Bureau of Standards

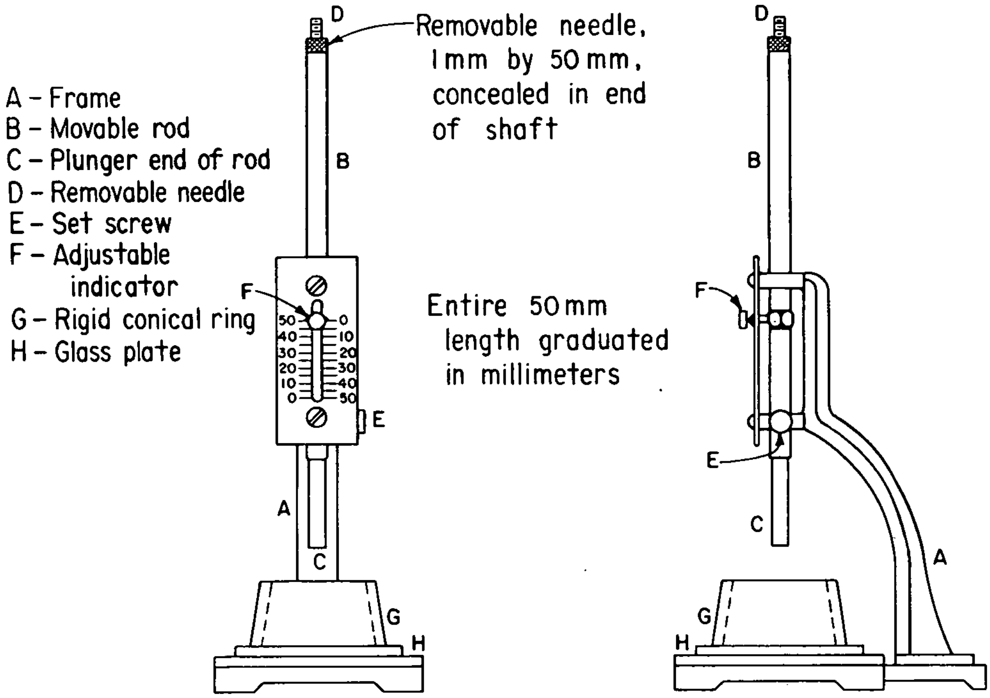


Figure 1. - Vicat aparatus.

Table 1. - Additional Vicat apparatus requirements.

Mass of movable rod	300±0.5 grams
Diameter of plunger end of rod	10±0.05 mm
Diameter of needle	1±0.05 mm
Inside diameter of ring at bottom	70±3 mm
Inside diameter of ring at top	70±3 mm
Height of ring	40±3 mm
Graduated scale[1]	

[1] The graduated scale when compared with a standard scale accurate to within 0.1 mm at all points, shall not show a deviation at any point greater than 0.25 mm.

6.3 Glass graduates shall be calibrated to meet requirements of ASTM C 490 in accordance with USBR 1030.

6.4 Compliance with section 4.3 for the Vicat apparatus shall be accomplished by using linear measurement devices complying with USBR 1000.

7. Conditioning or Preparation of Temperature and Humidity

7.1 The air temperature in vicinity of mixing slab, dry cement, molds, and base plates shall be maintained between 68 and 81.5 °F (20 and 27.5 °C). Temperature of mixing water shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

7.2 The relative humidity of the laboratory shall be not less than 50 percent.

8. Procedure

8.1 *Preparation of Cement Paste.*-Mix 650 grams of cement with a measured quantity of clean water following the procedure prescribed in section 9 of USBR 4305.

8.2 *Molding Test Specimen.*-Quickly form the cement paste (sec. 8.1) into a ball with gloved hands and toss six times through a free path of about 6 inches (150 mm) from one hand to another so as to produce a nearly spherical mass that may be easily inserted into the Vicat ring. Press ball of paste, resting in palm of one hand, into larger end of conical ring held in other hand, completely filling ring with paste. Remove excess paste at larger end by a single movement with palm of hand. Place ring on its larger end on the plane, nonabsorptive, glass plate and slice off excess paste at smaller end at top of ring by a single, oblique stroke of a sharp-edged trowel held at a slight angle with top of ring; smooth the top, if necessary, with a few light touches using pointed end of trowel. During these operations of cutting and smoothing, take care not to compress paste.

8.3 *Consistency Determination.*-Center paste, confined in ring and resting on plate, under the rod and bring plunger end of rod in contact with surface of paste; tighten setscrew. Then, set movable indicator to upper zero mark of scale, or take an initial reading, and release rod immediately. This process must not exceed 30 seconds after completion of mixing. The apparatus shall be free of all vibrations during test. The paste shall be of normal consistency when rod settles to a point 10 ±1 mm below original surface 30 seconds after being released. Make trial pastes, using fresh cement for each trial, with varying percentages of water until the normal consistency is obtained.

9. Calculation

9.1 Calculate amount of water required for normal consistency to nearest 0.1 percent and report it to nearest 0.5 percent of mass of dry cement. Figure 2 shows a typical calculation form.

10. Report

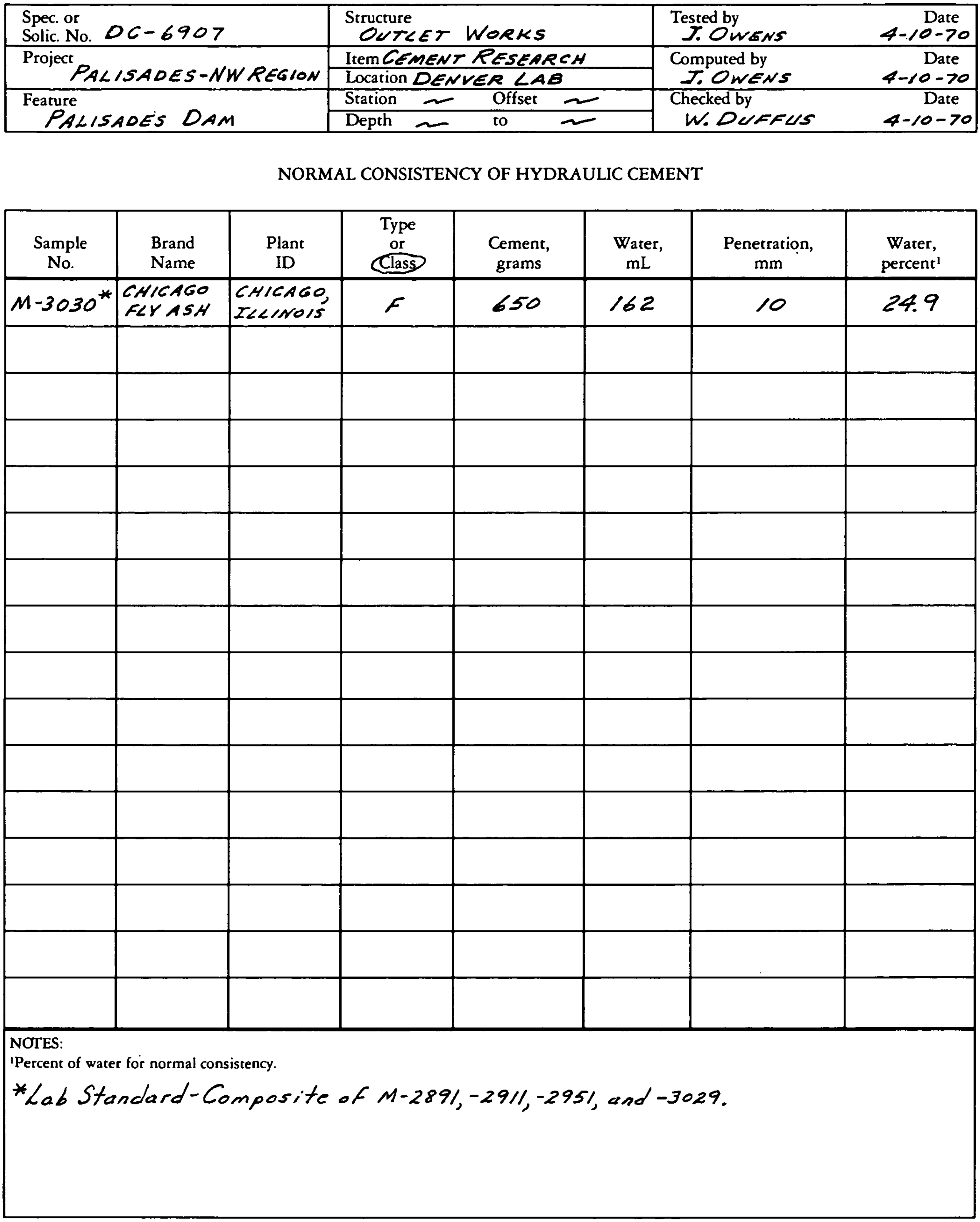
10.1 A suggested reporting form is shown on figure 5 of USBR 4183.

11. Precision

11.1 The single operator-instrument precision has been found to be 0.25 (1S), and the multilaboratory precision has been found to be 0.35 (1S), as defined in ASTM E 177. Therefore, results of two properly conducted tests by same operator in a laboratory should agree within 0.7 percent, and test results between two laboratories should agree within 1.0 percent, 95 percent of the time.

12. References

12.1 For additional useful information on details of cement test methods, reference may be made to the "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.



Spec. or Solic. No. DC-6907	Structure OUTLET WORKS	Tested by J. OWENS Date 4-10-70
Project PALISADES-NW REGION	Item CEMENT RESEARCH Location DENVER LAB	Computed by J. OWENS Date 4-10-70
Feature PALISADES DAM	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 4-10-70

NORMAL CONSISTENCY OF HYDRAULIC CEMENT

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Cement, grams	Water, mL	Penetration, mm	Water, percent[1]
M-3030*	CHICAGO FLY ASH	CHICAGO, ILLINOIS	F	650	162	10	24.9

NOTES:

[1] Percent of water for normal consistency.

*Lab Standard-Composite of M-2891, -2911, -2951, and -3029.

Figure 2. - Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4188-92

PROCEDURE FOR

DENSITY OF HYDRAULIC CEMENTITIOUS MATERIALS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4188; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C188-84.

1. Scope

1.1 This designation covers the procedure for determining the density of hydraulic cementitious materials. Its particular usefulness is in connection with the design and control of concrete mixtures.

1.2 The density of hydraulic cementitious materials is defined as the mass of a unit volume of the solids.

2. Applicable Documents

2.1 *USBR Procedures*:

1030 Calibrating Specific Gravity Flasks
4114 Chemical Analysis of Hydraulic Cement
4183 Sampling and Acceptance of Hydraulic Cement

2.2 *ASTM Standards*:

C 188 Standard Test Method For Density of Hydraulic Cement.[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials.[2]

3. Apparatus

3.1 *Le Chatelier Flask*.-This standard flask is circular in cross section with shape and dimensions conforming essentially to the design shown on figure 1 (note 1). The requirements in regard to tolerance, inscription and length, spacing, and uniformity of graduation will be rigidly observed. There shall be a space of at least 10 mm between the highest graduation mark and the lowest point of grinding for the glass stopper.

3.1.1 The material of construction shall be best quality glass, transparent, and free of striae. The glass shall be chemically resistant and shall have small thermal hysteresis. The flasks shall be thoroughly annealed before being graduated, and shall be of sufficient thickness to ensure reasonable resistance to breakage.

3.1.2 The neck shall be graduated from 0 to 1 mL and from 18 to 24 mL in 0.1-mL graduations. The error of any indicated capacity shall not be greater than 0.05 mL.

3.1.3 Each flask shall bear a permanent identification number, and the stopper, if not interchangeably ground, shall bear the same number. Interchangeable ground-glass parts shall be marked on both parts with the standard-taper symbol, followed by the size designation. The standard temperature shall be indicated, and the unit of capacity shall be shown by the letters "mL" placed above the highest graduation mark.

3.2 Kerosene, free of water, or naphtha, having a gravity not lighter than 62 API (American Petroleum Institute) shall be used in the density determination.

3.3 The use of alternative equipment or methods for determining density is permitted provided that a single operator can obtain results within ±0.03 Mg/m^3 of the results obtained using the flask method.

NOTE 1.-The design is intended to ensure complete drainage of flask when emptied, and stability of standing on a level surface, as well as accuracy and precision of reading.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all of the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

5. Calibration and Standardization

5.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

5.2 The Le Chatelier flask shall comply with requirements of section 3, and shall be calibrated in accordance with USBR 1030.

6. Conditioning

6.1 No special conditioning is required for this test procedure.

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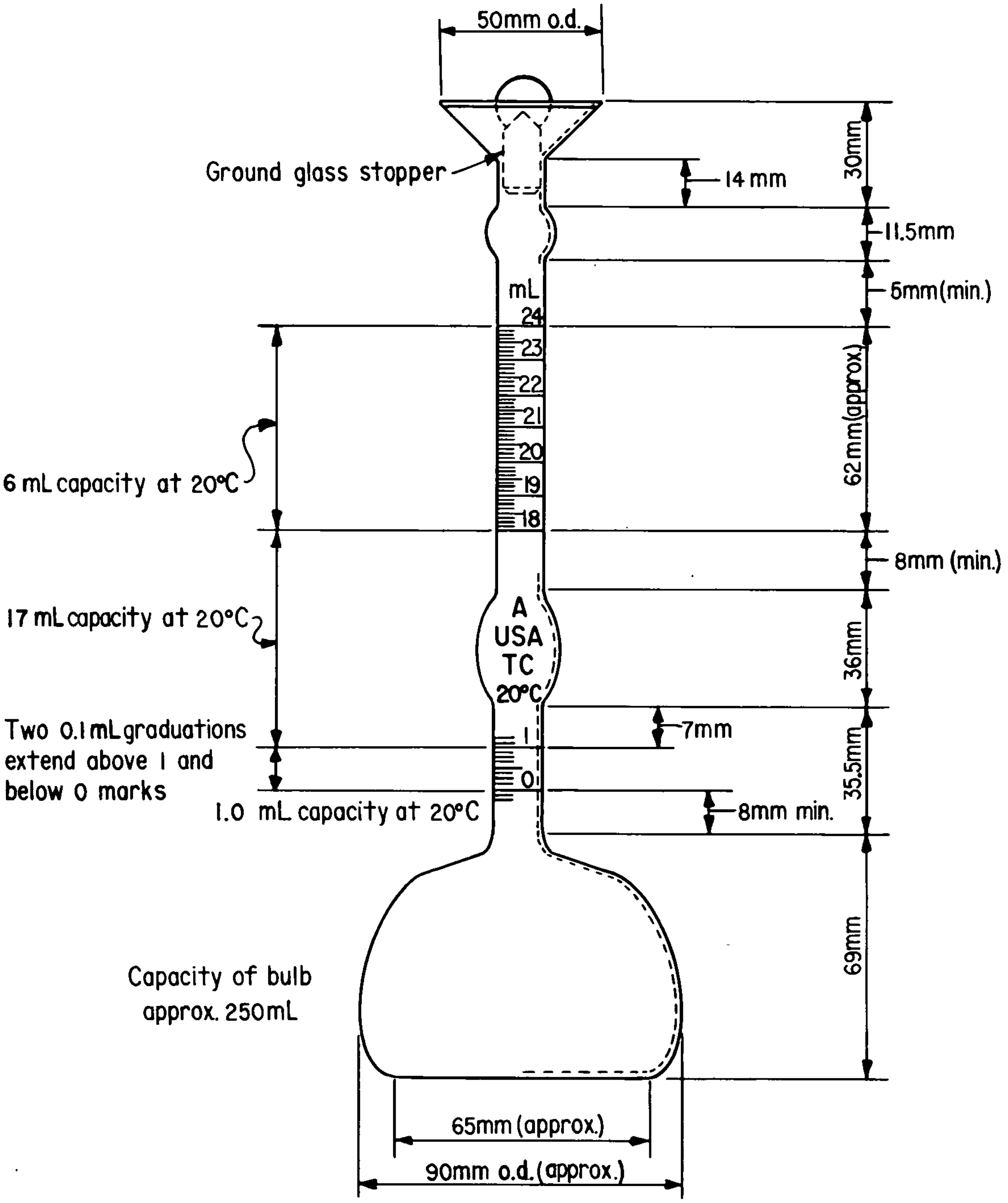
[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vol. 04.01, 04.02, 04.03, 04.08.



Note— Variations of a few millimeters in such dimensions as total height of flask, diameter of base, etc., are to be expected and will not be cause for rejection. The dimensions shown apply only to new flasks and not to flasks in use which meet other requirements of this test procedure.

Figure 1. - Le Chatelier flask.

7. Procedure

7.1 Determine the density of the cementitious materials as received, unless otherwise specified. If a density determination on a loss-free sample is required, first ignite the sample as described in the procedure for loss on ignition in section 16.1 of USBR 4114.

7.2 Fill the flask with either of the liquids specified in section 3.2 to a point on the stem between the 0 and 1-mL mark (note 2). Dry inside of flask above the level of liquid, if necessary, after pouring. Record first reading after flask has been immersed in water bath in accordance with section 7.4.

NOTE 2.–It is advisable to use a rubber pad on the table top when filling or rolling the flask.

7.3 Introduce a determined quantity of cementitious materials (about 64 grams for portland cement) in small increments at the same temperature as the liquid. Take care to avoid splashing, and ensure that the cementitious materials do not adhere to inside of flask above the liquid. A vibrating apparatus may be used to accelerate introduction of the cementitious materials into flask and to prevent them from sticking to the neck. After all the materials have been introduced, place stopper in flask and roll flask in an inclined position or gently whirl it in a horizontal circle, so as to free the materials from air until no further air bubbles rise to surface of liquid. If a proper amount of cementitious materials has been added, the level of the liquid will be in its final position at some point near the upper series of graduations. Take the final reading after flask has been immersed in water bath in accordance with section 7.4.

7.4 Immerse flask in a constant-temperature water bath for sufficient periods of time to avoid flask-temperature variations greater than 0.2 °C between initial and final readings.

NOTE 3.–Before cementitious materials have been added to flask, a loose-fitting, lead-ring weight around stem of flask will be helpful in holding flask in an upright position in water bath, or the flask may be held in water bath by a buret clamp.

8. Calculation

8.1 The difference between initial and the final readings represents volume of liquid displaced by the mass of cementitious materials used in test.

8.2 Calculate the cement density, ρ, as follows:

ρ (Mg/m^3) = ρ (g/cm^3) = mass of cementitious materials in grams per displaced volume (cm^3)

NOTE 4.–The displaced volume in millimeters is numerically equal to displaced volume in cubic centimeters. Density in megagrams per cubic meter (Mg/m^3) is numerically equal to grams per cubic centimeter (g/cm^3). Calculate the density of the cementitious materials to three decimal places and round to nearest 0.01 Mg/m^3.

NOTE 5.–In connection with proportioning and control of concrete mixtures, density may be more usefully expressed as specific gravity, the latter being a dimensionless number. Calculate specific gravity as follows:

Sp. gr. = cementitious materials density/water density at 4 °C

At 4 °C, density of water is 1 Mg/m^3(1g/cm^3).

8.3 If a constant temperature water bath is not available and the temperature variation between the initial and final temperature readings is greater than 0.2 °C, the volume change shall be corrected by 0.22 mL per °C of the variation because of expansion/contraction of the kerosene. For a decrease in temperature, add the correction to the volume difference; for an increase in temperature, subtract the correction.

8.4 Figure 2 shows a typical calculation and data form.

NOTE 6.–The results obtained from a procedure without a constant temperature water bath must check within ±0.03 Mg/m^3 of the results obtained with a constant temperature water bath.

9. Report

9.1 A suggested reporting form is shown on figure 5 of USBR 4183.

10. Precision and Bias

10.1 The single-operator standard deviation[3] for portland cements has been found to be 0.012. Therefore, the results of two properly conducted tests by the same operator on the same material should not differ by more than 0.03.

10.2 The multilaboratory standard deviation[3] for portland cements has been found to be 0.037. Therefore, the results of two properly conducted tests from two different laboratories on samples of the same cement should not differ by more than 0.10.

10.3 There is no known bias.

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[3] These deviation values represent the 1S and D2S limits as described in ASTM C 670.

Spec. or Solic. No. DC-7612	Structure DAM	Tested by K. MITCHELL Date 11-30-81
Project PECOS RIVER-SW REGION	Item CEMENT RESEARCH Location DENVER LAB	Computed by K. MITCHELL Date 11-30-81
Feature BRANTLEY DAM & RES.	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 11-30-81

DENSITY OF HYDRAULIC CEMENTITIOUS MATERIALS

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Flask No.	Sample Mass, grams	Initial Readings		Final Readings		Correction, mL	Corr. Volume Change, mL	Density, Mg/m³
						Temp., °C	Volume, mL	Temp., °C	Volume, mL			
M-7430	PANHANDLE FLY ASH INC.	CARLSBAD NM	F	187	50.00	23.0	0.40	22.8	19.25	—	18.85	2.65

NOTES:

Figure 2. – Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4191-92

PROCEDURE FOR

TIME-OF-SETTING OF HYDRAULIC CEMENT BY VICAT NEEDLE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4191: the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 191-82.

1. Scope

1.1 This designation covers the procedure for determination of the time-of-setting of hydraulic cement by means of the Vicat needle.

NOTE 1.–For the procedure for determining time-of-setting by Gillmore needles, see USBR 4266.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1030 Calibrating Specific Gravity Flasks
4183 Sampling and Acceptance of Hydraulic Cement
4187 Normal Consistency of Hydraulic Cement
4266 Time-of-Setting of Hydraulic Cement by Gillmore Needles
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:

C 191 Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete.[1,2]

2.3 *National Institute of Standards and Technology*[3]
Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

3. Apparatus

3.1 *Scales*.–The scales shall conform to the following requirements: On scales currently in use, the permissible variation at a load of 1000 grams shall be ±1 gram. The permissible variation on new scales shall be one half of this value. (Refer to sec. 2.3.)

3.2 *Glass Graduates*.–Graduates shall be of 200- or 250-mL capacity, and shall conform to requirements of ASTM C 490.

3.3 *Vicat Apparatus*.–The Vicat apparatus (see fig. 1, USBR 4187) shall consist of a frame bearing a 300-gram movable rod. The plunger end of the rod shall be 10 mm in diameter for a distance of at least 50 mm, and the other end of the rod shall have a 1-mm-diameter, 50-mm-long, removable steel needle. The rod is reversible, and can be held in any desired position by a setscrew. Mounted on the rod is an adjustable indicator which moves over a scale (graduated in millimeters) that is attached to the frame. The cement paste is held in a conical ring that rests on a glass plate that is about 100 mm square. The ring shall be made of a noncorroding, nonabsorbing material; shall have an inside diameter of 70 mm at the base and 60 mm at the top; and a height of 40 mm. In addition, apparatus shall conform to the requirements shown in table 1.

Table 1. – Vicat apparatus tolerances.

Mass of plunger	300 ± 0.5 grams
Diameter of larger end of plunger	10 ± 0.05 mm
Diameter of needle	1 ± 0.05 mm
Inside diameter of ring at bottom	70 ± 3 mm
Inside diameter of ring at top	60 ± 3 mm
Height of ring	40 ± 1 mm
Graduated scale[1]	

[1] The graduated scale, when compared with a standard scale accurate to within 0.1 mm at all points, shall not show a deviation at any point greater than 0.25 mm.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Formerly National Bureau of Standards*

to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

4.2 Further precautions for using the apparatus and the effects that the water percentage, water temperature, air temperature, humidity, and amount of kneading the paste receives will have on the final results are discussed in section 7.3.

5. Calibration and Standardization

5.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

5.2 Scales shall be calibrated to conform with section 3.1 in accordance with USBR 1012.

5.3 Glass graduates shall be calibrated to conform with ASTM C 490 in accordance with USBR 1030.

5.4 The Vicat apparatus shall be calibrated to conform with requirements of section 3.3 using scales conforming with section 5.2 and linear measurement devices in accordance with USBR 1000.

6. Conditioning and Preparation

6.1 *Temperature and Humidity*:

6.1.1 The temperature of the air in vicinity of mixing slab, dry cement, molds, and baseplates shall be maintained between 68 and 81.5 °F (20 and 27.5 °C). The temperature of mixing water and of the moist closet or moist room shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

6.1.2 The relative humidity of laboratory shall be not less than 50 percent. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 90 percent.

6.2 *Preparation of Cement Paste* [4]:

6.2.1 Mix 650 grams of cement with percentage of mixing water required for normal consistency following procedure described in USBR 4305. Distilled water is preferable and shall be used for all referee or cooperative tests.

6.2.2 The test specimen used for determination of normal consistency may be used for the additional determination of time-of-setting by Vicat needle following procedure described in section 7.2.

7. Procedure

7.1 *Molding Test Specimen*.-Quickly form cement paste, prepared as described in section 6.2, into a ball with gloved hands and toss six times from one hand to the other, keeping hands about 6 inches (150 mm) apart. Press the ball, resting in palm of one hand, into larger end of conical ring of Vicat apparatus held in other hand, completely filling ring with paste. Remove excess paste from ring by a single movement with the hand. Place ring on its larger end on the glass plate and slice off excess paste at smaller end of ring using a single oblique stroke of a sharpedged trowel held at a slight angle to top of ring. Smooth top of specimen, if necessary, with one or two light touches of pointed end of trowel. During the operation of cutting and smoothing, take care not to compress the paste. Immediately after molding, place test specimen in moist closet or moist room and allow it to remain there, except when time-of-setting determinations are being made. The specimen shall remain in conical mold and supported by glass plate throughout test period. A time-of-set specimen and an autoclave bar may be made from the same batch.

7.2 *Time-of-Setting Determination*.-Allow the time-of-setting specimen to remain in moist area for 30 minutes after molding without being disturbed. Determine the penetration of the 1-mm needle at this time and every 15 minutes thereafter (every 10 minutes for type III cements) until a penetration of 25 mm or less is obtained. For penetration test, lower the needle of the Vicat apparatus until it rests on surface of cement paste. Then, tighten the setscrew and set the indicator at upper end of scale or take an initial reading. Release the rod quickly by releasing the setscrew and allow the needle to settle for 30 seconds, then take the reading to determine penetration. If paste is obviously quite soft on initial readings, the fall of the rod may be retarded to avoid bending the needle, but the rod shall be released only by the setscrew when actual time-of-setting determinations are made. No penetration test shall be made closer than 1/4 inch (6.4 mm) from any previous penetration and no test shall be made closer than 3/8 inch (9.5 mm) from the inside of the mold. Record results of all penetration tests and, by interpolation, determine the time when a penetration of 25 mm is obtained. In accordance with the Cement and Concrete Reference Laboratory (CCRL) procedure this value shall be reported to the closest 5-minute time interval. This is the initial setting time. The final setting time is when the needle does not visibly penetrate into the paste. A typical data form is shown on figure 1.

7.3 *Precautions*.-The Vicat apparatus shall be free from vibration during the penetration test. Take care to keep the 1-mm needle straight, and also clean as the collection of cement on sides of needle may retard penetration while cement on the point may increase penetration. The time-of-setting is affected not only by the percentage and temperature of water used and the amount of kneading paste receives, but also by the temperature and humidity of the air; therefore, the results are only approximate.

8. Calculations

8.1 A suggested calculation form is shown on figure 1.

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[4] See USBR 4187.

9. Report

9.1 A suggested reporting form is shown on figure 5 of USBR 4183.

10. Precision and Bias

10.1 Statements of precision and bias will be included in a later revision of this procedure, none are available at this time.

Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 8-16-84
Project NA	Item ~ Location ~	Computed by K. MITCHELL Date 8-16-84
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 8-16-84

TIME-OF-SETTING OF HYDRAULIC CEMENT BY VICAT NEEDLE

Sample No.	Brand Name	Plant ID	Type or Class	Time, hour:minutes	Penetration, mm	Time-of-Set	
						Initial, hr:min	Final, hr:min
CCRL-74	*	*	*	8:30	START	2:50	5:20
				9:00	40+		
				9:15	40+		
				9:30	40+		
				9:45	40+		
				10:00	40		
				10:15	40		
				10:30	39		
				10:45	38		
				11:00	35		
				11:15	29		
				11:30	21		
				1:50	FINAL		

Time interpolation for initial set: $\frac{4}{8}$ (15 min) = 7.5 min, 2 hr 45 min + 5 min = 2 hr 50 min

Remarks:

*CEMENT REFERENCE
SAMPLES (NOT IDENTIFIED).

Figure 1. – Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4192–92

PROCEDURE FOR
MAKING AND CURING CONCRETE TEST SPECIMENS IN LABORATORY

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4192; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 192-81.

1. Scope

1.1 This designation covers the procedure for making and curing horizontal and vertical cylinders and beam and prism test specimens of concrete in the laboratory under accurate control of materials and test conditions. Making cylinders from no-slump concrete is not included in this procedure. For making and curing cylinders from no-slump concrete, see USBR 4906.

2. Applicable Documents

2.1 *USBR Procedures*:
1440 Calibrating the Vibratory Table for Maximum Index Unit Weight Testing
4031 Making and Curing Concrete Test Specimens in Field
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4566 Total Moisture Content of Aggregate by Drying
4617 Capping Cylindrical Concrete Specimens
4905 Consistency and Density of No-Slump Concrete With Vibratory Table
4906 Casting No-Slump Concrete in Cylinder Molds Using Vibratory Table

2.2 *ASTM Standards*:
C 192 Standard Method of Making and Curing Concrete Test Specimens in the Laboratory[1]
C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically[1]
C 511 Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1,2]
C 670 Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[1,2,3,4]

2.3 *American Concrete Institute*:
ACI 211.3 Materials and General Properties of Concrete, Standard Practice for Selecting Proportions for No-Slump Concrete[5]

2.4 *National Institute of Standards and Technology*[6]:
Handbook 44 Specifications, Tolerances and Other Technical Requirements for Commercial Weighing and Measuring Devices[7]

3. Apparatus

3.1 *Molds, General.*–Molds for specimens or fastenings thereto in contact with concrete shall be made of steel, cast iron, or other nonabsorbent material that is nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to dimensions and tolerances specified in method for which specimens are required, and shall hold their dimensions and shape under conditions of severe use. Molds shall be watertight during use as judged by their ability to hold water poured into them. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through joints. Positive means shall be provided to hold base plates firmly to molds. Molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.01.

[3] *Annual Book of ASTM Standards*, vol. 04.03.

[4] *Annual Book of ASTM Standards*, vol. 04.08.

[5] *ACI Manual of Concrete Practice*, Part 1, Available from American Concrete Institute, P O Box 19150, Redford Station, Detroit, MI 48219.

[6] Formerly National Bureau of Standards.

[7] Available from National Institute of Standards and Technology, U.S. Department of Commerce, Washington, DC 20234.

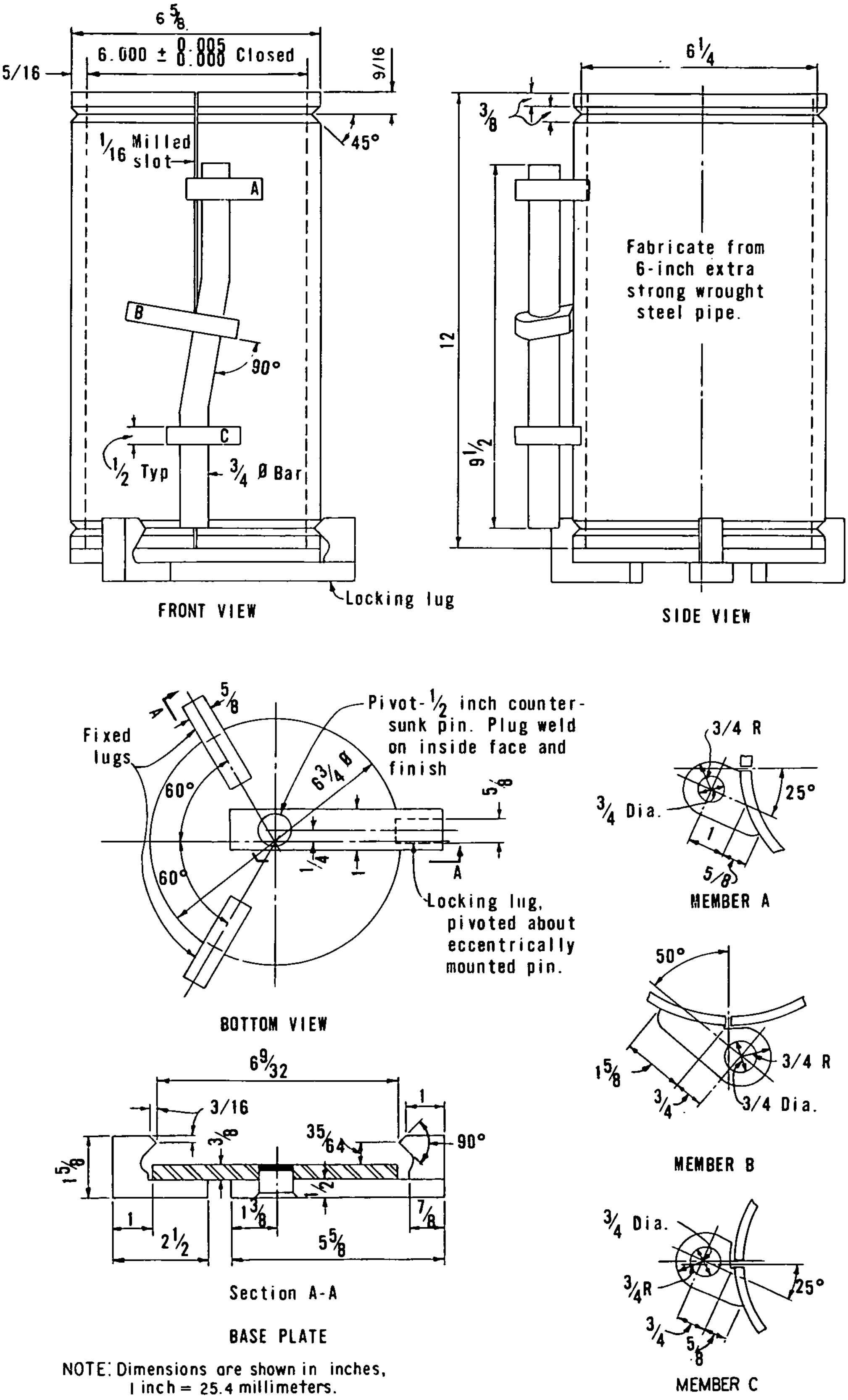


Figure 1. - Test cylinder mold. 288-D-3270

3.2 *Cylinder Molds*:

3.2.1 Molds for casting specimens vertically shall conform to requirements of section 3.1 and ASTM C 470, except that paper or cardboard molds will not be allowed and bottom of all molds shall be flush with bottom of sidewall (no inside crimp). Figure 1 shows a typical steel cylinder mold, and figure 2 shows fabrication details for plastic and tin molds.

3.2.2 Horizontal molds for creep-test cylinders (fig. 3) shall conform to requirements of section 3.1 and to requirements for symmetry and dimensional tolerance in accordance with ASTM C 470. The use of horizontal molds is intended only for creep specimens that contain axially embedded strain gauges. Molds for creep cylinders, to be filled while supported in a horizontal position, shall have a filling slot, parallel to axis of mold, which extends full length of mold to receive the concrete. The width of the slot shall be one-half the diameter of specimen. If necessary, edges of slot shall be reinforced to maintain dimensional stability. Unless specimens are to be capped or ground to produce plane ends, molds shall be provided with two machined metal end plates at least 1 inch (25 mm) thick, and working surfaces shall comply with requirements for planeness and surface roughness of section 4.2 of USBR 4617. Provision shall be made for fixing both end plates firmly to mold. The inside surface of each end plate shall be provided with at least three lugs or studs about 1 inch long and firmly fastened to plate for embedment in concrete. One base plate shall be drilled from the inside at an angle to permit lead wire from strain gauge to exit the specimen through edge of plate. Provision shall be made for accurately positioning strain gauge. All necessary holes shall be as small as possible to minimize disturbance to subsequent strain measurement, and shall be sealed to prevent leakage.

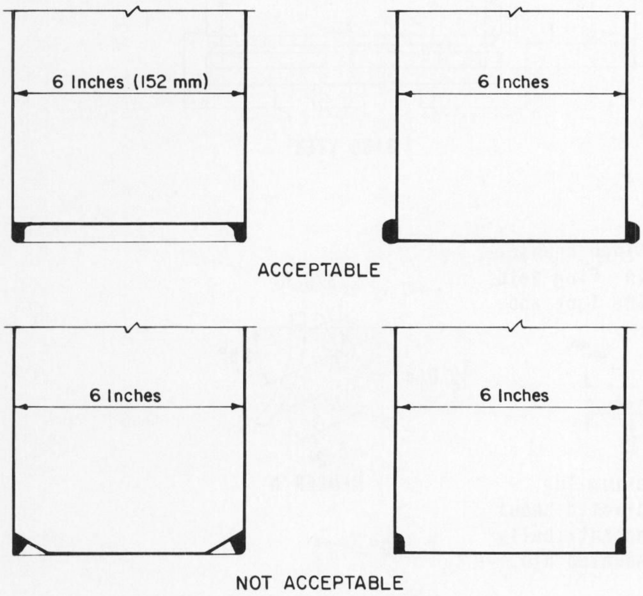


Figure 2. - Fabrication details of can bottoms (metal bands not shown). 288-D-2660.

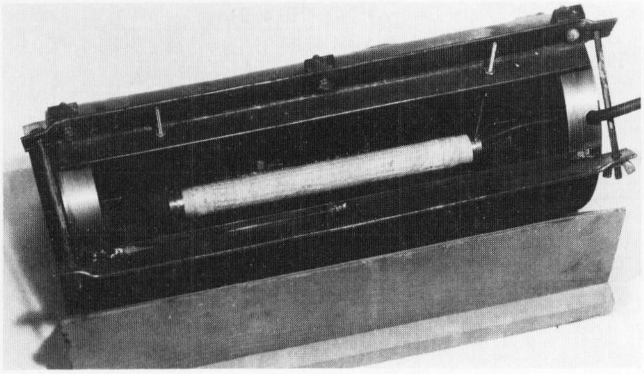


Figure 3. - Horizontal mold for creep specimens.

3.3 *Beam and Prism Molds.*-Unless otherwise specified, these molds shall be rectangular in shape and of dimensions required to produce desired specimen size. The inside surfaces of the molds shall be straight and true and free of warpage. Maximum variation from nominal cross section shall not exceed 1/8 inch (3.2 mm) for molds with depth or breadth of 6 inches (152 mm) or more, or 1/16 inch (1.6 mm) for molds of smaller depth or breadth. Except for flexure specimens, molds shall not vary from the nominal length by more than 1/16 inch. Flexure molds shall not be shorter than 1/16 inch of required length, but may exceed required length by more than 1/16 inch.

3.4 *Tamping Rods.*-Two sizes of tamping rods are required. Each rod shall be a round, straight, steel rod with at least the tamping end rounded to a hemispherical tip of same diameter as rod. If preferred, both ends may be rounded.

3.4.1 *Larger Rod.*-Shall be 5/8 inch (15.9 mm) in diameter and about 24 inches (610 mm) long.

3.4.2 *Smaller Rod.*-Shall be 3/8 inch (9.5 mm) in diameter and about 12 inches (305 mm) long.

3.5 *Mallet.*-A mallet, with a rubber or rawhide head, with a mass of 1.25±0.50 lbm (567±227 g) shall be used.

3.6 *Vibrators.*-Concrete vibrators are classified in two categories — internal and external. External vibrators are subdivided into vibrating tables and form vibrators.

3.6.1 *Internal Vibrators*:

3.6.1.1. The internal vibrator (fig. 4) shall have rigid or flexible shaft, preferably powered by an electric motor.

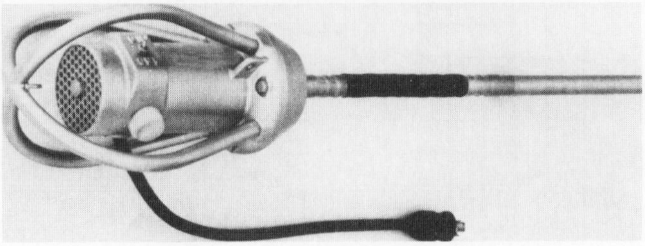


Figure 4. - Post-type vibrator for laboratory use.

3.6.1.2. The outside diameter or side dimension of the large vibrating element shall be at least 0.75 inch (19 mm) and not greater than 1.5 inches (38 mm) and the combined length of shaft and vibrating element shall exceed maximum depth of section being vibrated by at least 3 inches (76 mm).

3.6.1.3. The 3- by 6-inch (76- by 152-mm) cylinders for the freeze-thaw tests shall be vibrated internally using a specially designed 3/8-inch (10-mm) small vibrating element.

3.6.1.4. A range of frequencies, while vibrator is operating in concrete, and a calculated peak amplitude and nominal peak acceleration in air is given in table 1.

3.6.1.5. The vibrating reed tachometer (fig. 5) is a simple device for checking the frequency of the internal vibrator operating in air or in concrete. Several vibrator supply firms have prepared scales on stickers which may readily be attached to the vibrator head (fig. 6). This is a visual-effect scale (optical wedge) that provides an approximate measure of maximum amplitude and the distribution of amplitude along the head. A resonant reed tachometer (fig. 7) is a more expensive instrument that indicates more accurate values of frequency.

3.6.2 *External Vibrators.*-Low-frequency high amplitude vibration is normally preferred for stiffer mixtures. High frequency, low amplitude vibration generally results in better consolidation and better surfaces for more plastic consistencies. The dividing line between high and low frequencies for external vibration is arbitrarily taken as 6,000 vpm (100 Hz) and between high and low amplitude 0.005 inch (0.13 mm).

3.6.2.1. *Table Vibrators.*-The effectiveness of table vibration is largely a function of the acceleration imparted to the concrete by the table (fig. 8).

3.6.2.1.1. Vibratory impulses are frequently imparted to a table vibrator through electromagnetic means, or by using an eccentric mass on the shaft of an electric motor or on a separate shaft driven by a motor.

3.6.2.1.2. A range of frequencies, peak amplitude, and nominal peak acceleration is given in table 1 while vibrator is consolidating concrete.

3.6.2.1.3. A resonant reed tachometer (fig. 7) gives accurate values of frequency. A vibrograph (fig. 9) may be used to check amplitude, and it records a waveform which provides the frequency.

NOTE 1.-Comparative readings with the equipment mentioned above and a vibrating-reed tachometer indicate that most vibrating-reed tachometers give a value about 200 vpm less than actual in the 3,600 vpm range. The degree of accuracy desired or to comply with specifications will dictate the method used in determining amplitude and frequency.

3.6.2.2. *Form Vibrators.*-Form vibrators are self-cooling and can be either the rotary or reciprocating type (fig. 10).

3.6.2.2.1. Rotary-type form vibrators produce essentially simple harmonic motion. The impulses have components both perpendicular to and in the plane of the form. This type may be pneumatically, hydraulically, or electrically driven.

Table 1. - Range of characteristics, performance, and application of internal and external vibrators.

	Frequency, f		Average Amplitude, Y_p		Nominal Peak Acceleration, A_p
	Vibrations or Revolutions/min, vpm or rpm	Cycles, Hz	inch	millimeter	g* Desired
			Internal Vibrator		
	Under Load				†
Type Vibrator Outside Dia. or Side Dimension	10,000	167	0.0167	0.424	74
0.75 to 1.50 in	to	to	to		
(19 to 38 mm)	15,000	250	0.0300	0.762	300
			External Vibrators		
Table	Plastic: 3,600 to	60 to	0.0081 to 0.0136	0.206 to 0.345	3 to 5
Type	Stiff: 7,200	120	0.0041 to 0.0068	0.104 to 0.173	6 to 10
Form	Plastic: 8,000 to	133 to	0.0006 to 0.0011	0.015 to 0.028	1 to 2
Type	Stiff: 12,000	200	0.0007 to 0.0012	0.018 to 0.031	3 to 5

* $g = 32.17398$ ft/s² (9.80665 m/s²).

† A calculated acceleration with frequency and amplitude assumed in air. From ACI 309R, the frequency of internal vibrators under load is approximately 4/5 the frequency in air. With this allowance made, acceleration A_p in g's is equal to $4\pi^2 f^2 Y_p \div g$:

where:

f = $1/t$ = frequency, vibration cycles or vibrations per second (Hz),

Y_p = amplitude (deviation from point of rest, inch (mm); peak amplitude or one-half peak-to-peak amplitude or displacement,

g = 386 in/s² (9810 mm/s²), and

t = time for one complete revolution or vibration cycle, second.

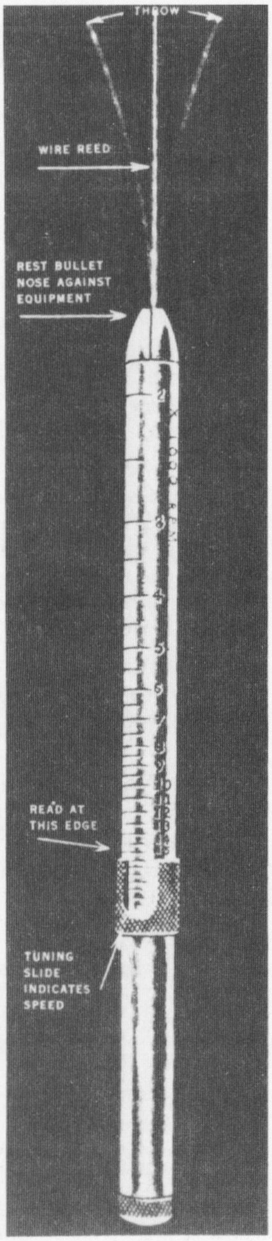


Figure 5. – Vibrating-reed tachometer.

3.6.2.2.2. Reciprocating-type form vibrators accelerate a piston in one direction, stopped (by impacting against a steel plate), and then accelerate in the opposite direction. This type is pneumatically driven. These vibrators produce impulses acting perpendicular to the form. The principles of simple harmonic motion do not apply in this case.

3.6.2.2.3. A range of frequencies, peak amplitude, and normal peak acceleration is given in table 1 while vibrator is consolidating concrete.

3.6.2.2.4. Data listed under section 3.6.2.1.3 is applicable to form vibrators as well as table vibrators.

3.7 *Small Tools.*–Miscellaneous tools and items such as shovels, pails, trowels, wood float, blunted trowels, straightedge, feeler gauge, scoops, rulers, rubber gloves, and metal mixing bowls shall be provided.

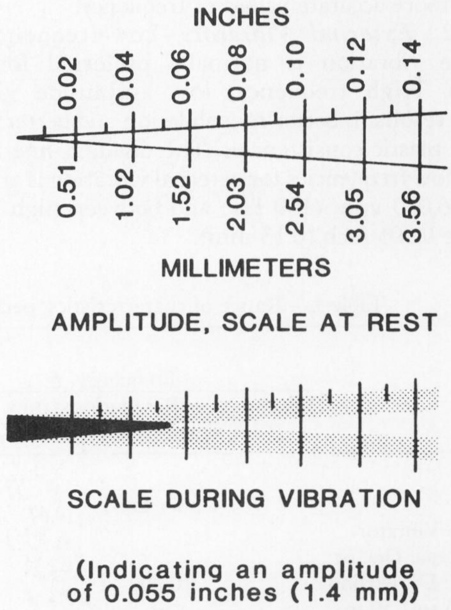
3.8 *Slump Apparatus.*–The apparatus for measurement of slump shall conform to requirements of USBR 4143.

3.9 *Sampling and Mixing Pan.*–The pan shall have a flat bottom, be of heavy-gauge metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing or remixing by shovel or trowel of entire batch or, if mixing by machine, to receive entire batch on discharge of mixer.

3.10 *Wet-Sieving Equipment.*–If wet-sieving is required, equipment shall conform to requirements of USBR 4172.

3.11 *Air-Content Apparatus.*–For low-density concrete, the apparatus for measuring air content shall conform to requirements of USBR 4173. For normal- or high-density concrete, apparatus shall conform to requirements of USBR 4173 or 4231.

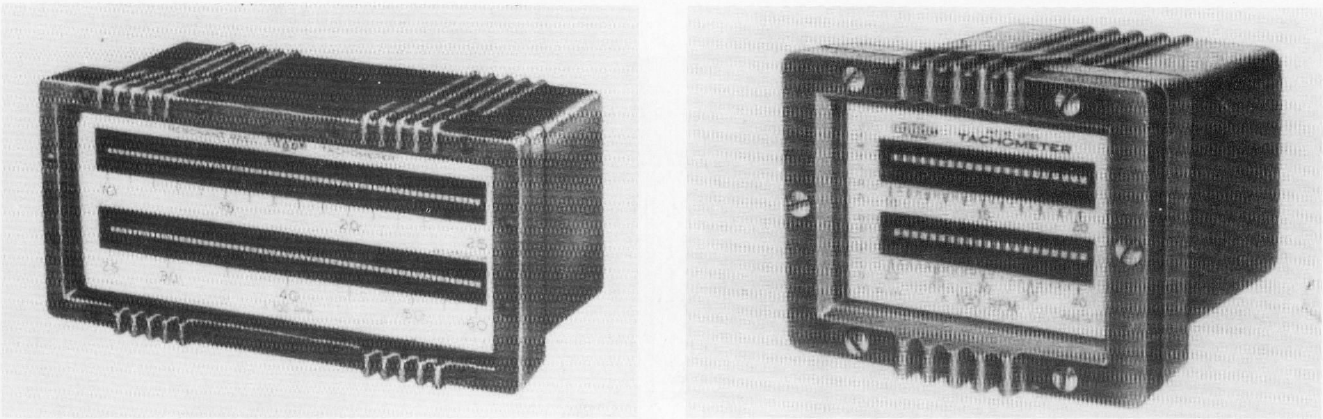
3.12 *Scales.*–Scales for determining the mass of batches of materials and concrete shall be accurate within 0.3



INSTRUCTIONS FOR USE

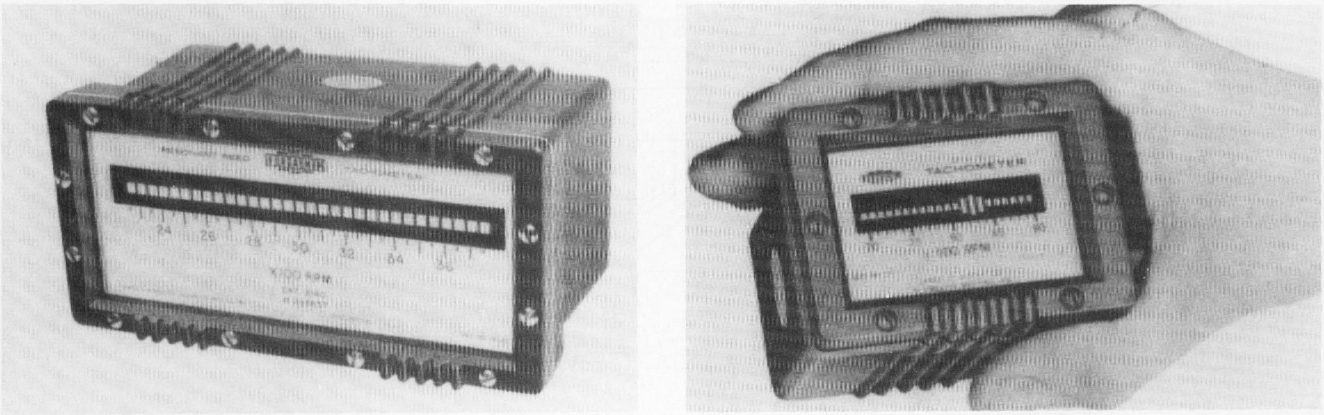
Attach scale to vibrator head at point where amplitude is desired, with centerline of "V" parallel to axis of vibrator. With head vibrating, a black triangle forms at the apex of the "V". The scale reading at tip of triangle is peak amplitude (half the peak-to-peak displacement). A hand reading glass (2 to 3X) will improve accuracy of reading. With care, this device is capable of an accuracy of about 0.005 inch(0.127 mm).

Figure 6. – Visual effect scale for measuring amplitude of vibrator operating in air.



Type T-72, 3 by 6-1/8- by 2-15/16 inches

Type T-62, 2-1/4- by 3 by 2-15/16 inches



Type T-71, 3 by 6-1/8- by 2-15/16 inches

Type T-61, 2-1/4- by 3 by 2-15/16 inches

Figure 7. – Resonant-reed tachometers.

percent of test load at any point within range of use. The scales shall also meet requirements for sensitivity and tolerances prescribed by the National Institute of Standards and Technology's *Handbook 44*. Where scales are graduated in decimal fractions of a pound mass instead of ounces, or where the metric system is used, the equivalent percentage sensitivity requirements and tolerances shall apply.

NOTE 2.–In general, small quantities of mass should not be determined on large capacity scales. In many applications, the smallest quantity to be determined on a scale should be greater than about 10 percent of maximum capacity of scale; however, this will vary with performance characteristics of scale and required accuracy of determination. Acceptable scales used for mass determination of concrete materials should preferably be accurate to about 0.1 percent of total capacity, and foregoing precaution is applicable. However, certain analytical and precision balances are exceptions to this rule, and mass can be determined accurately to 0.001 percent. Particular care must be exercised in measuring small quantities of material by determining the difference between two much larger masses.

3.13 *Concrete Mixer.*–The concrete mixer shall be a power-driven revolving-drum, tilting mixer, or suitable revolving pan or revolving-paddle mixer capable of thoroughly mixing batches of prescribed sizes at required slump.

NOTE 3.–A pan mixer is usually more suitable for mixing concrete with less than 1-inch (25-mm) slump than a revolving-drum mixer. The rate of rotation, degree of tilt, and rated capacity of tilting mixers are not always suitable for laboratory mixed concrete. It may be desirable to reduce rate of rotation, decrease angle of tilt from horizontal, or use mixer at somewhat less than manufacturer's rated capacity.

4. Test Specimens

4.1 *Cylindrical Specimens.*–Cylinders for tests such as compressive strength, Young's modulus of elasticity, creep, and splitting tensile strength may be of various sizes; however, shall be a minimum of 2 inches (51 mm) in diameter by 4 inches (102 mm) long. Where correlation or comparison with field-made cylinders (USBR 4031) is desired, the cylinders shall be 6 by 12 inches (152 by

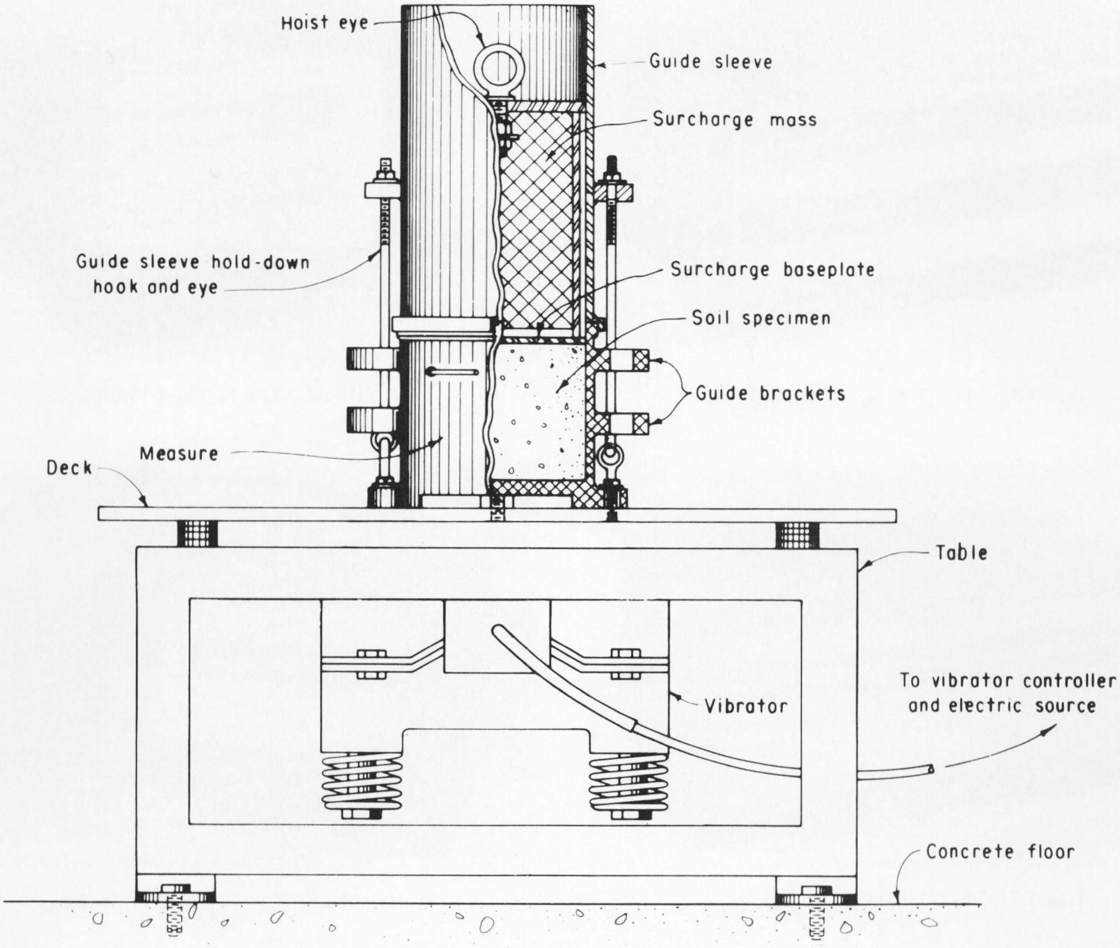


Figure 8. - Vibratory table. 101-D-592.

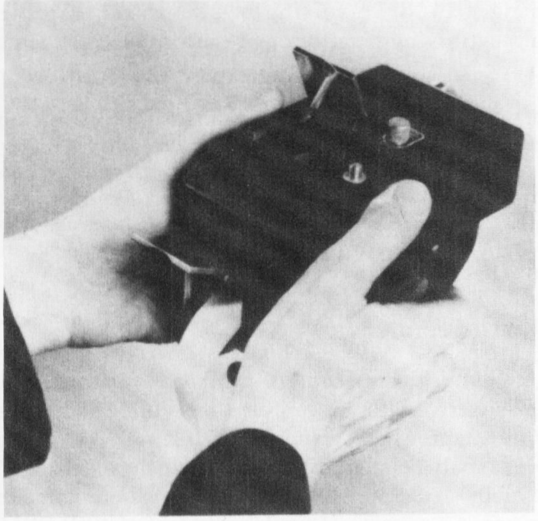


Figure 9. - Using a vibrograph to determine amplitude and frequency of a vibrating form or table.

305 mm). Otherwise, dimensions shall be governed in accordance with section 4.3 and the specific test method concerned.

4.1.1 Cylindrical specimens for tests other than creep shall be molded and allowed to harden with axis of cylinder vertical.

4.1.2 Cylindrical creep specimens may be cast with axis either vertical or horizontal and allowed to harden in position cast.

4.2 *Other Specimens.*-Other shapes and sizes of specimens for particular tests may be molded as desired, following general methods set forth in this procedure.

4.3 *Specimen Size Versus Aggregate Size.*-The diameter of a cylindrical specimen shall be at least three times the nominal maximum size of coarse aggregate in the concrete (note 4). When concrete contains aggregate larger than that appropriate for size of molds or equipment to be used, wet-sieve the sample as described in USBR 4172.

NOTE 4.-The mold diameter is determined by the nominal maximum size of aggregate. The minimum diameter mold must be at least three times the nominal maximum size aggregate.

Odd-size diameter molds could meet this requirement; however, previous research has primarily been conducted using 8-, 12-, 18-, and 36-inch (203-, 305-, 457-, and 914-mm) diameter cylinders with a length-to-diameter ratio of 2.0. For further clarification of sizing nomenclature, see table 2 and figure 11.

4.4 *Number of Specimens.*–The number of specimens and the number of test batches are dependent on established practice and nature of test program. Guidance is usually given in the test method or specification for which specimens are made. Usually, three or more specimens are molded for each test age and test condition unless otherwise specified (note 5). Specimens involving a given variable should be made from three separate batches mixed on different days. An equal number of specimens for each variable should be made on any given day. When it is impossible to make at least one specimen for each variable on a given day, mixing of entire series of specimens should be completed in as few days as possible, and one of the mixtures should be repeated each day as a standard of comparison.

NOTE 5.–Test ages frequently used are 7 and 28 days for compressive strength tests. Specimens containing type III cement are frequently tested at 1, 3, 7, and 28 days. For longer test ages, 3 months, 6 months, and 1 year are frequently used for compressive strength tests. Other test ages may be required for other types of specimens.

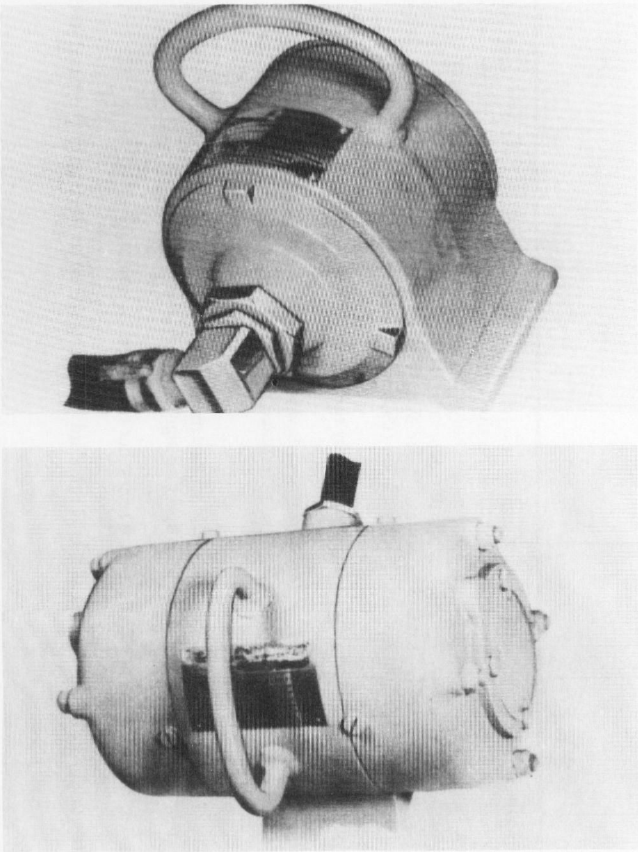


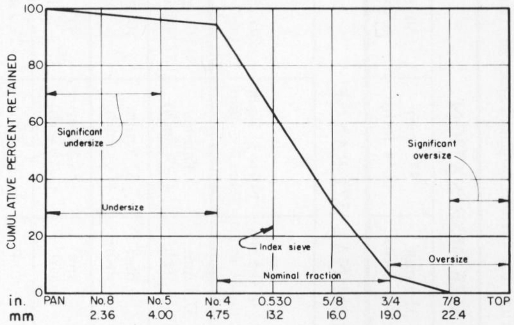
Figure 10. – Rotary form vibrators: pneumatically driven (top) and electrically driven (bottom).

5. Precautions

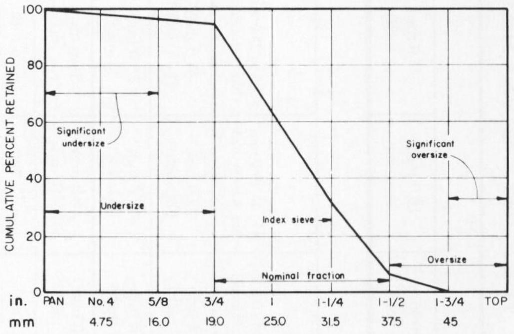
5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Calibration and Standardization

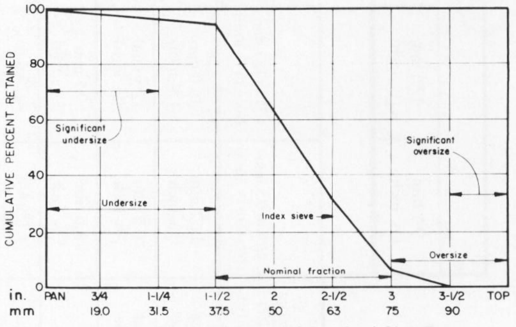
6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.



(a) No. 4 to ¾ in (4.75 to 19.0 mm) Nominal Size Range.



(b) ¾ to 1-½ in (9.0 to 37.5 mm) Nominal Size Range.



(c) 1-½ to 3 in (37.5 to 75 mm) Nominal Size Range.

Figure 11. – Sizing nomenclature for concrete aggregate.

Table 2. - Test sieves (U.S.A. Standard series) for various nominal sizes of coarse aggregate.

	SIZE DESIGNATION											
	9.5 mm (⅜ inch)	12.5 mm (½ inch)	19.0 mm (¾ inch)	19.0 mm (¾ inch)	25.0 mm (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm (2 inch)	63 mm (2-½ inch)	75 mm (3 inch)	100 mm (4 inch)	150 mm (6 inch)
	NOMINAL SIZE RANGE[1]											
SIEVE[1] DESIGNATION STANDARD (ALTERNATIVE)	4.75 to 9.5 mm (No. 4 to ⅜ inch)	4.75 to 12.5 mm (No. 4 to ½ inch)	9.5 to 19.0 mm (⅜ to ¾ inch)	4.75 to 19.0 mm[3] (No. 4 to ¾ inch)	4.75 to 25.0 mm[3] (No. 4 to 1 inch)	12.5 to 31.5 mm (½ to 1-¼ inch)	19.0 to 37.5 mm (¾ to 1-½ inch)	25.0 to 50 mm (1 to 2 inch)	31.5 to 63 mm (1-¼ to 2-½ inch)	37.5 to 75 mm (1-½ to 3 inch)	50 to 100 mm (2 to 4 inch)	75 to 150 mm (3 to 6 inch)
Significant[1,4] Oversize	11.2 mm (7/16 inch)	16.0 mm (⅝ inch)	22.4 mm (⅞ inch)	22.4 mm (⅞ inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	45 mm (1-¾ inch)	63 mm (2-½ inch)	75 mm (3 inch)	90 mm (3-½ inch)	125 mm (5 inch)	175 mm[6] (7 inch)
Nominal Oversize	9.5 mm (⅜ inch)	12.5 mm[5] (½ inch)	19.0 mm (¾ inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm[5] (2 inch)	63 mm (2-½ inch)	75 mm (3 inch)	100 mm[5] (4 inch)	150 mm[6] (6 inch)
Index[1] Sieve	8.0 mm (5/16 inch)	9.5 mm (⅜ inch)	16.0 mm (⅝ inch)	16.0 mm (0.530 inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	45 mm (1-¾ inch)	53 mm (2.12 inch)	63 mm (2-½ inch)	90 mm (3-½ inch)	125 mm (5 inch)
Nominal Undersize	4.75 mm (No. 4)	4.75 mm (No. 4)	9.5 mm) (⅜ inch)	4.75 mm (No. 4)	4.75 mm (No. 4)	12.5 mm[5] (½ inch)	19.0 mm (¾ inch)	25.0 mm[5] (1 inch)	31.5 mm (1-¼ inch)	37.5 mm (1-½ inch)	50 mm[5] (2 inch)	75 mm (3 inch)
Significant[1,4] Undersize	4.00 mm (No. 5)	4.00 mm (No. 5)	8.0 mm (5/16 inch)	4.00 mm (No. 5)	4.00 mm (No. 5)	11.2 mm (7/16 inch)	16.0 mm (⅝ inch)	22.4 mm (⅞ inch)	26.5 mm (1.06 inch)	31.5 mm (1-¼ inch)	45 mm (1-¾ inch)	63 mm (2-½ inch)
Typical[2] Minimum Percent Retained on Index Sieve	35	40	30	50	50	25	25	25	25	25	25	25

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[1] Typical nominal separation points for coarse aggregates are 4.75, 9.5, 19.0, 37.5, 75, and 150 mm (No. 4, ⅜, ¾, 1-½, 3, and 6 inch). Significant oversize and undersize sieve openings for these separation points are approximately 7/6 and 5/6, respectively, of the nominal oversize and undersize sieve openings. The Index Sieve opening is at about 2/3 of the range between maximum and minimum sieve openings of the nominal size range. For other nominal size range separation points that may be specified for shotcrete, canal lining, pumping mixtures, roller-compacted concrete, etc., the openings for significant oversize, significant undersize, and index sieves shall also have approximately the same 7/6, 5/6, and 2/3 relationships. Openings of the wire cloth of successive standard sieves in ASTM E 11, Standard Specification for Wire-Cloth Sieves for Testing Purposes, progress from a base of 1 mm in the ratio of approximately $\sqrt[4]{2}:1$ and correspond to the values recommended by the International Standards Organization (ISO) in Geneva, Switzerland.

[2] These percentages were established based on experience by the Bureau of Reclamation and are appropriate for most naturally occurring, reasonably well graded, aggregates.

[3] The workability, pumpability, and finishing properties of concrete are often affected by the amount of small-size coarse aggregate. In order to improve these characteristics, it is desirable, particularly when using crushed aggregates, to minimize the percentage of material passing the 9.5 mm (⅜ inch) sieve. This may be accomplished by maximizing the amount of material retained on the Index sieve.

[4] For any size of processed coarse aggregate, where Reclamation specifications require finish screening at the batch plant, 0 (zero) percent shall be retained on the specified significant oversize sieve and not more than 2 percent shall pass the specified significant undersize sieve.

[5] These sieves are not in the ASTM E 11 standard series, but they are in common usage.

[6] These sieves are not included in the ASTM E 11 standard series and are larger than sizes contained in that standard. They may not be commercially available from customary laboratory equipment suppliers.

6.2 The calibration of internal and external vibrators to ensure compliance with section 3.6 may be accomplished using a vibrating- or resonant-reed tachometer.

6.3 For a more positive method of verifying compliance of table vibrators with section 3.6, calibration should be performed in accordance with USBR 1440.

7. Conditioning

7.1 *Temperature.*-Bring materials to a uniform temperature, preferably in the range from 68 to 77 °F (20 to 25 °C) before mixing concrete.

7.2 *Cement.*-Store cement in a dry place in moisture-proof containers, preferably made of metal. Cement shall be thoroughly mixed to provide a uniform supply throughout the tests, and shall be passed through a No. 20 (850-μm) or finer sieve to remove all lumps, remixed on a tarp or plastic sheet, and returned to containers.

7.3 *Aggregates.*-To preclude segregation of coarse aggregate, separate into individual size fractions and, for each batch, recombine into proper proportions to produce desired grading.

NOTE 6.-Only rarely can a coarse aggregate be batched as a single size fraction. The number of size fractions will generally be between two and five for aggregate smaller than 2-1/2 inches (63 mm). When a size fraction to be batched is present in amounts in excess of 10 percent, the ratio of opening of larger to smaller sieve should not exceed 2.0. More closely sized groups are sometimes advisable.

7.3.1 Unless fine aggregate is separated into individual size fractions, maintain the aggregate in a damp condition, or restore to a damp condition, until use to prevent segregation unless material uniformly graded is subdivided into batch-size lots using a sample splitter with proper size openings. If unusual gradings are being studied, the fine aggregate may need to be dried and separated into individual sizes. In this case, if total quantity of fine aggregate required is larger than can be efficiently blended into a single unit, then mass of individual size fractions should be determined in quantity required for each individual batch. When the total quantity of fine aggregate needed for the complete investigation is such that it can be thoroughly mixed, blended, and maintained in a damp condition, then aggregate should be handled in that manner. Determine specific gravity and absorption of aggregates in accordance with USBR 4127 and 4128.

7.3.2 Before incorporating into concrete, prepare aggregate to ensure a definite and uniform condition of moisture. Determine mass of aggregate to be used in batch by one of the following procedures:

7.3.2.1 Mass of low-absorption aggregates, those with an absorption less than 1.0 percent, may be determined in room-dry condition with allowance made for amount of water that will be absorbed from unset concrete (note 7). This method is particularly useful for coarse aggregate which must be batched as individual sizes because of the possibility of segregation. This method can be used for fine aggregate only when fine aggregate is separated into individual size fractions.

NOTE 7.-When using aggregates with low absorption in a room-dry condition, the amount of water that will be absorbed by aggregates before concrete sets may be assumed to be 80 percent of the difference between the 24-hour absorption of aggregates, determined by USBR 4127 or 4128, and the amount of water in pores of aggregates in their room-dry state, as determined by USBR 4566.

7.3.2.2 The mass of the individual size fractions of aggregate may be determined separately, recombined into a tared container in amounts required for batch, and immersed for 24 hours prior to use. After immersion, excess water is decanted and combined mass of aggregate and mixing water determined. Allowance shall be made for amount of water absorbed by aggregate. The moisture content of the aggregates shall be determined in accordance with USBR 4566.

7.3.2.3 Aggregate may be brought to and maintained in a saturated condition, with surface moisture contained in sufficiently small amounts to preclude loss by draining, at least 24 hours prior to use. When this method is used, moisture content of aggregate must be determined to permit calculation of proper quantities of damp aggregate. The quantity of surface moisture present must be included as part of required amount of mixing water. Surface moisture in fine aggregate shall be determined in accordance with USBR 4566, allowing for amount of water absorbed. This method, with moisture content slightly exceeding absorption, is particularly useful for fine aggregate. This method is used less frequently for coarse aggregate because of the difficulty of accurately determining moisture content; however, if it is used, each size fraction must be handled separately to ensure that proper grading is obtained.

7.4 *Lightweight Aggregates.*-The methods for specific gravity, absorption, and preparation of aggregates described in this procedure pertain to materials with normal absorption values. Low-density aggregates, air-cooled slag, and certain highly porous or vesicular natural aggregate may be so absorptive that these methods would be difficult to use. The moisture content of low-density aggregate at time of mixing may have important effects on properties of freshly mixed and hardened concretes, such as slump loss, compressive strength, and resistance to freezing and thawing.

7.5 *Admixtures.*-Powdered admixtures that are entirely or mostly insoluble, that do not contain hygroscopic salts, and are to be added in small quantities, should be mixed with a portion of the cement before introduction into batch in mixer so as to ensure thorough distribution throughout concrete. Essentially insoluble materials that are used in amounts exceeding 10 percent by mass of cement, such as pozzolans, should be handled and added to batch in same manner as cement. Powdered admixtures that are mostly insoluble but contain hygroscopic salts, may cause balling of cement and should be mixed with sand. Water-soluble and liquid admixtures should be added to mixer in solution in the mixing water. The quantity of such solution used shall be included in calculation of water content of concrete. Admixtures that are incompatible in concentrated form, such as solutions of calcium chloride and certain air-entraining and set-retarding admixtures, should not be intermixed prior to their introduction into the concrete. The time, sequence, and method of adding some admixtures to a batch of concrete can have important effects on concrete properties, such as time-of-set and air content. The method selected must remain unchanged from batch to batch and should simulate good field practice.

NOTE 8.-The mixing apparatus and associated equipment shall be thoroughly cleaned to ensure that chemical additions or admixtures used in dissimilar batches of concrete do not affect subsequent batches.

8. Procedure

8.1 *Mixing Concrete*:

8.1.1 *General.*-Mix concrete in a suitable mixer, or by hand, in batches of such size as to have about 10 percent excess after molding test specimens. Hand-mixing methods are not applicable to air-entrained concrete or concrete with no measurable slump. Mixing methods are given in sections 8.1.2 and 8.1.3; however, other methods may be used when it is desired to simulate special conditions or practices, or when method specified is impracticable. It is important not to vary the mixing sequence and method from batch to batch unless the effect of such variation is under study.

8.1.2 *Machine Mixing.*-Prior to starting rotation of mixer, add the coarse aggregate, some of the mixing water, and the solution of admixture, when required, in accordance with section 7.5. When feasible, disperse admixture in mixing water before placing in mixer. Start mixer and then add fine aggregate, cement, and water with mixer running. If it is impractical for a particular mixer or for a particular test to add these materials while mixer is running, they may be added to a stopped mixer after permitting mixer to rotate a few revolutions following introduction of coarse aggregate and some of the water. After all ingredients are in mixer, mix for 3 minutes, stop mixing for 3 minutes, and mix again for 2 minutes. Cover open end or top of mixer to prevent evaporation during stop period. Take precautions to compensate for mortar retained by mixer so that discharged batch, as used, will be correctly proportioned (note 9). To eliminate segregation, deposit machine-mixed concrete in the clean, damp, mixing pan and remix by shovel or trowel until concrete appears to be uniform.

NOTE 9.-It is difficult to recover all of the mortar from a mixer. To compensate for this difficulty, the following method may be used to ensure correct final proportions in the batch: prior to mixing the test batch, the mixer can be "buttered" by mixing a batch proportioned to simulate the test batch. The mortar adhering to mixer after discharge will compensate for loss of mortar from actual test batch.

8.1.3 *Hand Mixing.*-Mix the batch in a watertight, clean, damp, metal pan or bowl with a bricklayer's blunted trowel. Mix the cement, powdered insoluble admixture (if used), and fine aggregate, without addition of water, until these materials are thoroughly blended. Add the coarse aggregate and mix entire batch, without addition of water, until coarse aggregate is uniformly distributed throughout batch. Then, add the water and admixture solution (if used), and mix until concrete is homogeneous in appearance and has desired consistency. If prolonged mixing is necessary because of the addition of water in increments while adjusting the consistency, discard batch and make a new batch in which mixing is not interrupted to make trial consistency tests.

8.1.4 *Mixed Concrete.*-Select portions of batch of mixed concrete to be used in tests for molding specimens so as to be representative of actual proportions and condition of concrete. When concrete is not being remixed or sampled, cover to prevent evaporation.

8.2 *Wet Sieving.*-If nominal maximum size of aggregate is in excess of 1-1/2-inches (37.5-mm), wet screen the mix across the 1-1/2-inch screen in accordance with USBR 4172 to accommodate molds or measures as required.

8.3 *Slump, Air Content, and Yield*:

8.3.1 *Slump.*-Measure the slump of each batch of concrete immediately after mixing in accordance with USBR 4143.

NOTE 10. The slump test is unsuitable for concrete that is so dry that it slumps less than 1/4 inch (6 mm). The no-slump concrete may be tested in accordance with USBR 4905. Other testing methods are described in ACI 211.3.

8.3.2 *Air Content.*-Determine the air content, when required, in accordance with either USBR 4173 or 4231; however, USBR 4231 should not be used with concretes made with low-density aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. After determining air content, discard concrete used for the determination.

8.3.3 *Yield.*-Determine the yield of each batch of concrete, if required, in accordance with USBR 4138. Concrete used for slump and density testing, provided density test is not done on same sample used for air content determination, may be returned to mixing pan and remixed into batch.

8.4 *Making Specimens*:

8.4.1 *Place of Molding.*-Mold specimens as near as practicable to location where they will be stored for initial 24 hours. If this is not possible, move specimens to place of storage immediately after being struck off. Place molds on a rigid surface that is free from vibration and other disturbances. Avoid jarring, striking, tilting, or scarring surface of specimens when moving to storage.

8.4.2 *Placing.*-Place concrete in molds using a scoop, blunted trowel, or shovel. Select each measure of concrete from mixing pan to ensure that it is representative of batch. It may be necessary to remix concrete in mixing pan with a shovel or trowel to prevent segregation during molding of specimens. Move scoop or trowel around top edge of mold as concrete is discharged to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within mold. Use a tamping rod to further distribute concrete prior to start of consolidation. Place concrete in molds by layers, as specified in table 3. When placing final layer, operator shall attempt to add an amount of concrete that will exactly fill mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

8.5 *Consolidation*:

8.5.1 *Methods of Consolidation*.-Preparation of satisfactory specimens requires different methods of consolidation. These methods are internal and external vibration, and rodding. Base selection of method on the slump, unless a specified method is stated in the specifications. Rod concretes with a slump greater than 3 inches (76 mm), rod or vibrate concretes with a slump of 1 to 3 inches (25 to 76 mm), and vibrate concretes with a slump of less than 1 inch (25 mm), see note 10 and sections 3.6.1.2, 3.6.1.3, 8.5.3.1, and 8.5.3.2.

8.5.2 *Rodding*.-Place concrete in mold, in the required number of layers of approximately equal volume. Rod each layer with rounded end of rod using the number of strokes and size of rod specified in table 4. Rod bottom layer throughout its depth. Distribute strokes uniformly over cross section of mold and, for each upper layer, allow rod to penetrate about 1/2 inch (13 mm) into underlayer when depth of layer is less than 4 inches (102 mm), and about 1 inch (25 mm) when depth is 4 inches or more. If voids are left by tamping rod, tap sides of mold lightly with mallet to close voids. Extreme care must be used when tapping sides of metal or plastic molds.

8.5.3 *Vibration*.-Maintain a standard duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration required will depend on workability of concrete and effectiveness of vibrator. For internal vibration, three insertions of 3 or 4 seconds

Table 3. - Number of layers required for specimens.

Specimen type and size, as depth	Mode of compaction	Number of layers	Approximate depth of layers
Cylinders:			
Up to 12 inches (305 mm)	Rodding	3 (equal)	4 inches (102 mm)
Over 12 inches	Rodding	As required	4 inches (102 mm)
Up to 18 inches (457 mm)	Vibration	2 (equal)	9 inches (229 mm)
Over 18 inches	Vibration	3 (or more)	8 inches (203 mm), as near as practicable
Prisms and horizontal creep cylinders:			
Up to 8 inches (203 mm)	Rodding	2 (equal)	4 inches (102 mm)
Over 8 inches	Rodding	3 (or more)	4 inches (102 mm)
Up to 8 inches	Vibration	1	8 inches (203 mm)
Over 8 inches	Vibration	2 (or more)	8 inches (203 mm), as near as practicable

Table 4. - Diameter of rod and number of roddings to be used in molding test specimens.

	Cylinders	
Diameter of cylinder	Diameter of rod	Number of strokes per layer
2 to <6 inches (51 to <152 mm)	3/8 inch (10 mm)	25
6 inches (152 mm)	5/8 inch (16 mm)	25
8 inches (203 mm)	5/8 inch (16 mm)	50
10 inches (254 mm)	5/8 inch (16 mm)	75
	Beams and Prisms	
Top surface area of specimen	Diameter of rod	Number of roddings per layer
25 in² (16 129 mm²) or less	3/8 inch (10 mm)	25
26 to 49 in² (16 774 to 31 613 mm²)	3/8 inch (10 mm)	One for every 1 in² (645 mm²) of surface area
50 in² (32 258 mm²) or more	5/8 inch (16 mm)	One for every 2 in² (1290 mm²) of surface area
	Horizontal Creep Cylinders	
Diameter of cylinder	Diameter of rod	Number of roddings per layer
6 inches (152 mm)	5/8 inch (16 mm)	50 total (25 along both sides of axis)

each are usually sufficient. Sufficient vibration has been applied when surface of concrete has become relatively smooth and exhibits a shiny, wet appearance. Continue vibration only long enough to achieve proper consolidation of concrete; overvibration may cause segregation. Fill molds and vibrate with the required number of approximately equal layers. Place all concrete for each layer in mold before starting vibration of that layer. Add the final layer so as to avoid overfilling mold by more than 1/4 inch (6 mm). Finish the surface either during vibration, when external vibration is used; or after vibration when either internal or external vibration is used. When finishing surface after vibration, add only enough concrete with a trowel to overfill mold by about 1/8 inch (3 mm), work into surface, and then strike off.

8.5.3.1 *Internal Vibration.*-For cylinders, the ratio of diameter of cylinder to diameter of vibrating element shall be 4.0 or higher. In compacting specimen, vibrator shall not be allowed to rest on or touch bottom or sides of mold or strike embedded items such as strain meters. Carefully withdraw vibrator in such a manner that no air pockets are left in specimen. After vibration of each layer, tap sides of mold to ensure removal of large entrapped air bubbles at surface of mold, using extreme care with metal or plastic molds.

8.5.3.1.1 *Cylinders.*-Use three insertions of vibrator at different points for each layer. Allow vibrator to penetrate through layer being vibrated into layer below by about 1 inch (25 mm).

8.5.3.1.2 *Beams, Prisms, and Horizontal Creep Cylinders.*-Insert vibrator at intervals not exceeding 6 inches (152 mm) along centerline of long dimension of specimen, or along both sides, but not in contact with strain gauge in creep cylinders. For specimens wider than 6 inches, use alternating insertions along two lines. Allow shaft of vibrator to penetrate into bottom layer about 1 inch (25 mm).

8.5.3.2 *External Vibration.*-When external vibration is used, ensure that mold is rigidly attached to or securely held against vibrating element or vibrating surface. No-slump concrete should be consolidated in accordance with USBR 4906.

8.6 *Finishing.*-After consolidation by any of the methods, unless finishing was done during vibration (8.5.3), strike off surface of concrete and float or trowel in accordance with method used. Perform all finishing with minimum manipulation necessary to produce a flat, even surface that is level with rim or edge of mold and which has no depressions or projections greater than 1/8 inch (3 mm). If no finish is specified, finish surface with a wood or magnesium float. If a trowel is used, it is usually better to leave surface slightly high after striking off and floating, with the intent of returning later to trowel flush. However, take care doing this because there is a tendency to overtrowel and bring too much mortar to the surface, which creates a weakened plane. Perform all finishing with minimum manipulation necessary to produce a flat, even surface that is level with rim or edge of mold and which has no depressions or projections greater than 1/8 inch.

8.6.1 *Cylinders.*-After consolidation, finish top surfaces by striking off with tamping rod or strike-off bar, where consistency of concrete permits, or with a wood float or trowel.

8.6.2 *Horizontally Cast Creep Cylinders.*-After consolidation, strike off specimen with a trowel or float, then trowel the minimum amount required to form the concrete in the opening concentrically with rest of specimen. Use a screed curved to radius of specimen to more precisely shape and finish concrete in the opening.

8.7 *Curing:*

8.7.1 *Covering After Finishing.*-To prevent evaporation of water from unhardened concrete, cover specimens immediately after finishing with a nonabsorptive, nonreactive plate or a sheet of tough, durable, impervious plastic. Wet burlap may also be used for covering, but care must be used to keep burlap wet until specimens are removed from molds. Placing a sheet of plastic over the burlap will help keep burlap wet.

8.7.2 *Removal From Molds.*-Remove specimens from molds not less than 20 nor more than 48 hours after casting.

8.7.3 *Curing Environment.*-Unless otherwise specified, all specimens shall be moist cured at 73.4±3 °F (23.0±1.7 °C) from time of molding until time of test (note 11). Storage during initial 48 hours of curing shall be in a vibration-free environment. As applied to treatment of demolded specimens, moist curing means that test specimens shall have free water maintained on entire surface area at all times. This condition may be met by immersion in saturated-lime water (note 12), or by storage in a moist room or cabinet meeting requirements of ASTM C 511. Specimens shall not be exposed to dripping or running water.

NOTE 11.-The temperature within damp sand and under wet burlap, or similar materials, will always be lower than temperature in surrounding atmosphere if evaporation takes place.

NOTE 12.-Saturated-lime (calcium hydroxide) water is defined as that point where no further lime powder will go into solution. At 73.4±3 °F (23.0±1.7 °C), 0.160 gram of lime powder per 100 mililiters of water is required to bring mixture to a saturated-lime water state. This is about 1.33 pounds of lime for every 100 gallons of water. A small cloth bag filled with high-calcium hydrated lime and placed in each tank should keep the lime water in a saturated condition. Lime water can irritate the skin and can cause rashes on the hands and arms and, consequently, personnel will need to wear gloves. Deep containers for the lime water should be avoided, or a satisfactory mechanical means should be provided to remove the specimens.

8.7.4 *Flexural Strength Test Specimens.*-Cure the flexural strength test specimens in accordance with sections 8.7.1 and 8.7.2, except that while in storage for a minimum of 20 hours immediately prior to testing, specimens shall be immersed in a saturated-lime solution at 73.4±3 °F (23.0±1.7 °C). At end of curing period, between time specimen is removed from curing until testing is completed, drying of surfaces shall be prevented.

NOTE 13. Relatively small amounts of surface drying of flexural strength specimens will induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9. Calculations

9.1 No particular calculations are involved for this test procedure.

10. Report

10.1 The report shall include:

- Specific intent of mix study in laboratory.
- Source of materials involved.
- Physical properties of materials.
- Slump.
- Air content.
- Type of specimens molded.
- Method of consolidation.
- Method of curing.
- Any special remarks concerning mix.

10.2 Because many variables may be a requirement for a specific mix design, no attempt was made to devise a typical reporting form. Each mix design submittal will probably be handled by a cover letter that will include whatever data are considered to be significant.

11. Precision and Bias

11.1 Data to establish precision statements for the various types of testing required in this procedure were obtained in the Concrete Reference Sample Program of the Cement and Concrete Reference Laboratory. Analysis of the data for the single-operator and multilaboratory precision is shown in table 5.

11.2 The single-operator standard deviations for slump, density, air content, and 7-day compressive strength of trial batches have been found to be 0.7 inch (17.8 mm), 0.9 lbm/ft^3 (14.4 kg/m^3), 0.3 percent, and 203 lbf/in^2 (1.4 MPa), respectively. Therefore, the results of properly conducted tests on two trial batches made in same laboratory should not differ by more than 2.0 inches (50.8 mm), 2.5 lbm/ft^3 (40.0 kg/m^3), 0.8 percent, and 574 lbf/in^2, (4.0 MPa), respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain the prescribed quantities of materials and having a constant water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 inches (51 mm) or more than 6 inches (152 mm), or concrete made with other than normal mass aggregate or aggregate larger than 1 inch (25.0 mm) nominal maximum size.

11.3 The multilaboratory standard deviations for slump, density, air content, and 7-day compressive strength of trial batches have been found to be 1.0 inch (25.4 mm), 1.4 lbm/ft^3 (22.4 kg/m^3), 0.4 percent, and 347 lbf/in^2 (2.4 MPa), respectively. Therefore, the results of properly conducted tests on single trial batches made in two different laboratories should not differ by more than 2.8 inches (71.1 mm), 4.0 lbm/ft^3 (64.1 kg/m^3), 1.1 percent, and 981 lbf/in^2 (6.8 MPa), respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain the prescribed quantities of materials and having a prescribed water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 inches (51 mm) or more than 6 inches (152 mm), or concrete made with other than normal mass aggregate or aggregate larger than 1 inch (25.0 mm) nominal maximum size.

11.4 *Bias.*–The bias has not been established for this test procedure.

Table 5. – Values for precision statements relating to making trial batches by USBR 4192 and testing by appropriate methods.

		Multilaboratory precision[1]		Single-laboratory precision[2]	
USBR 4192	ASTM	1S	D2S	1S	D2S
Slump, inches (mm)	C 143	1.0 (25.4)	2.8 (71.1)	0.7 (17.8)	2.0 (50.8)
Density, lbm/ft^3 (kg/m^3)	C 138	1.4 (22.4)	4.0 (64.1)	0.9 (14.4)	2.5 (40.0)
Air content[2], percent by volume	C 173	0.4	1.1	0.3	0.8
Compressive strength (7-day), lbf/in^2 (MPa)	C 39	347 (2.4)	981 (6.8)	203 (1.4)	574 (4.0)

[1] The 1S and D2S precision limits are as defined in ASTM C 670.

[2] Use the air content values with caution for air-entrained concrete.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4204-92

PROCEDURE FOR

FINENESS OF CEMENTITIOUS MATERIALS BY AIR PERMEABILITY APPARATUS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4204; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 204-84.

1. Scope

1.1 This designation covers the procedure for determination of fineness of cementitious materials using the Blaine air permeability apparatus, in terms of the specific surface expressed as total surface area of cement. Although the procedure may be, and has been, used for determination of the measures of fineness of various other materials, it should be understood that, generally, relative rather than absolute fineness values are obtained.

2. Applicable Documents

2.1 *USBR Procedures*:
4183 Sampling and Acceptance of Hydraulic Cement
2.2 *ASTM Standards*:
C 204 Standard Test Method for Fineness of Portland Cement by Air Permeability Apparatus[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2]
2.3 *Other Documents*:
UU-P-236 Federal Specification for Paper; Filtering[3]
No. 114 National Institute of Standards and Technology Standard Reference Material[4]

3. Apparatus

3.1 *Nature of Apparatus*.–The Blaine air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The number and size of pores in a prepared bed of definite porosity are a function of size of particles and determine rate of airflow through bed. The apparatus, as shown on figure 1, shall consist specifically of the parts described in sections 3.2 through 3.8.

3.2 *Permeability Cell*.–The permeability cell shall consist of a rigid cylinder 12.70±0.10 mm inside diameter, constructed of austenitic stainless steel (note 1). Interior of cell shall have a finish of 0.81 μm. The top of the cell shall be at right angles to principal axis of cell. The lower portion of the cell must be able to form an airtight fit with upper end of manometer so that there is no air leakage between contacting surfaces. A ledge 0.5 to 1 mm in width shall be an integral part of the cell or be firmly fixed in cell 55±10 mm from top of cell for support of perforated metal disk. Top of permeability cell shall be fitted with a protruding collar to facilitate removal of cell from manometer.

NOTE 1.–The AISI Type 303 stainless steel (UNS designation S30300) has been found to be suitable for construction of permeability cell and plunger.

3.3 *Disk*.–The disk shall be constructed of noncorroding metal and shall be 0.9±0.1 mm in thickness, perforated with 30 to 40 holes of 1 mm diameter equally distributed over its area. Disk shall fit snugly inside the permeability cell. The center portion on one side of the disk shall be marked or inscribed in a legible manner so as to permit operator to always place that side down when inserting it into cell. The marking or inscription shall not extend into any of the holes, touch their peripheries, or extend into that area of disk that rests on cell ledge.

3.4 *Plunger*.–The plunger shall be constructed of austenitic stainless steel and shall fit into cell with a clearance of not more than 0.1 mm. Bottom of plunger shall sharply meet lateral surfaces and shall be at right angles to principal axis. An air vent shall be provided by means of a flat that is 3.0±0.3 mm wide on one side of plunger. Top of plunger shall be provided with a collar such that when plunger is placed in cell and collar brought in contact with top of cell, the distance between bottom of plunger and top of perforated disk shall be 15±1 mm.

3.5 *Filter Paper*.–The filter paper shall be medium retentive, corresponding to Type 1, Grade B, as prescribed in Federal Specification for Paper; Filtering (UU-P-236). The filter paper disks shall be circular, with smooth edges, and shall have same diameter as inside of cell (note 2).

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[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vols. 04.02, 04.03, 04.08.

[3] Available from Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

[4] Available from National Institute of Standards and Technology (formerly National Bureau of Standards), Office of Standard Reference Materials, Chemistry Building, Washington, DC 20234.

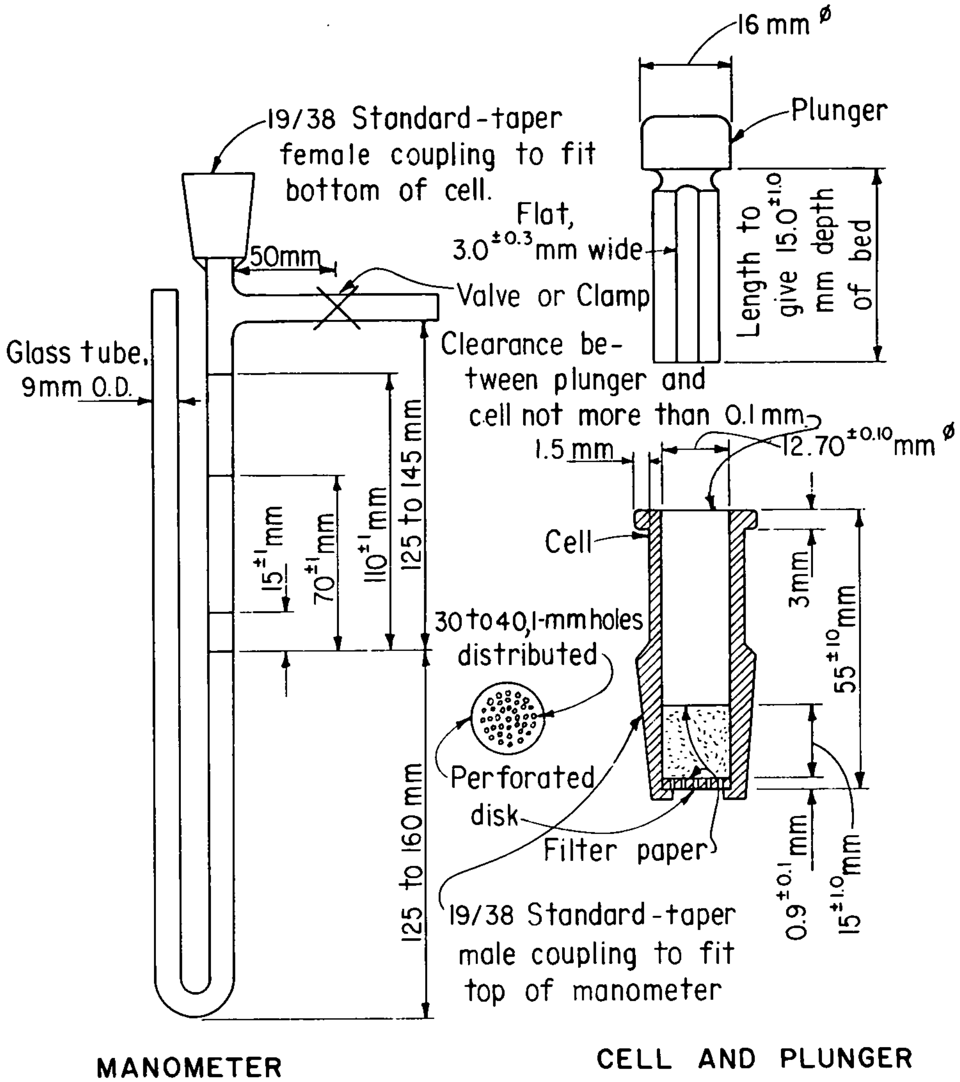

Figure 1. - Blaine air permeability apparatus.

NOTE 2.-Filter paper disks that are too small may leave part of sample adhering to inner wall of cell above top disk. When too large in diameter, disks have a tendency to buckle and cause erratic results.

3.6 *Manometer.*-The U-tube manometer shall be constructed according to the design indicated on figure 1, using nominal 9-mm-outside-diameter, standard-wall, glass tubing. The top of one arm of the manometer shall form an airtight connection with permeability cell. This arm shall have a line etched around tube 125 to 145 mm below top side outlet, and additional lines at distances of 15±1 mm, 70±1 mm, and 110±1 mm above that line (see fig. 1). A side outlet shall be provided 250 to 305 mm above bottom of manometer for use in evacuation of manometer arm connected to permeability cell. A positive airtight valve or clamp shall be provided on side outlet not more than 50 mm from manometer arm. Manometer shall be mounted firmly and in such a manner that arms are vertical.

3.7 *Manometer Liquid.*-Manometer shall be filled to midpoint with a nonvolatile, nonhygroscopic liquid of low viscosity and density, such as dibutyl phthalate (dibutyl 1,2-benzene-dicarboxylate) or a light grade mineral oil.

3.8 *Timer.*-The timer shall have a positive starting and stopping mechanism and shall be capable of being read to nearest 0.5 second or less. Timer shall be accurate to 0.5 second or less for time intervals up to 60 seconds, and accurate to 1 percent or less for time intervals of 60 to 300 seconds.

4. Reagents and Materials

4.1 *Manometer Liquid.*-Phthalate (dibutyl 1,2-benzene-dicarboxylate) or light grade of mineral oil.

4.2 *National Institute of Standards and Technolgy Standard Reference Material, No. 114.*

4.3 *Mercury.*-ACS reagent grade or better.

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5.2 Tongs are advised for handling the permeability cell as discussed in section 6.2.1.

6. Calibration of Apparatus

6.1 *Sample*.–The calibration of the air permeability apparatus shall be made using the current lot of National Institute of Standards and Technology Standard Reference Material No. 114. Sample shall be at room temperature when tested.

6.2 *Bulk Volume of Compacted Bed of Powder*.–Determine the bulk volume of compacted bed of powder by mercury displacement method as follows:

6.2.1 Place two filter paper disks in permeability cell, pressing down edges, using a rod having a diameter slightly smaller than that of cell until filter disks are flat on perforated metal disk. Fill cell with mercury, ACS reagent grade or better, removing any air bubbles adhering to wall of cell. Use tongs when handling cell. If cell is made of material that will amalgamate with mercury, interior of cell shall be protected by a very thin film of oil just prior to adding mercury. Level mercury with top of cell by lightly pressing a small glass plate against mercury surface until glass is flush with surface of mercury and rim of cell; ensure that no bubble or void exists between mercury surface and glass plate. Remove mercury from cell, and determine and record mass of mercury. Remove one of the filter disks from cell. Using a trial quantity of 2.80 grams of cement (note 3), compress cement (note 4) in accordance with section 6.5 with one filter disk above and one below sample. Into the unfilled space at top of cell, add mercury, remove entrapped air, and level off top as before. Remove mercury from cell, and again determine and record mass of mercury.

NOTE 3.–It is not necessary to use standard sample for bulk volume determination.

NOTE 4.–The prepared bed of cement shall be firm. If bed is too loose or if cement cannot be compressed to desired volume, adjust trial quantity of cement used.

6.2.2 Calculate bulk volume occupied by cement to nearest 0.005 cm³ as follows:

$$V_c = \frac{M_a - M_b}{\rho_m} \qquad (1)$$

where:

V_c = bulk volume of cement in cubic centimeters,
M_a = grams of mercury required to fill cell (no cement being in cell),
M_b = grams of mercury required to fill portion of cell not occupied by prepared bed of cement in cell, and
ρ_m = density of mercury at temperature of test in grams per cubic centimeter, see table 1.

Table 1. – Density of mercury and viscosity of air at given temperatures.

Room temperature, °F	(°C)	Density of mercury, g/cm³	Viscosity of air, η_T or η_s	$\sqrt{\eta_T}$ or $\sqrt{\eta_s}$
60.8	(16)	13.56	0.0001788	0.01337
64.4	(18)	13.55	.0001798	.01341
68.0	(20)	13.55	.0001808	.01345
71.6	(22)	13.54	.0001818	.01348
75.2	(24)	13.54	.0001828	.01352
78.8	(26)	13.53	.0001837	.01355
82.4	(28)	13.53	.0001847	.01359
86.0	(30)	13.52	.0001857	.01363
89.6	(32)	13.52	.0001867	.01366
93.2	(34)	13.51	.0001876	.01370

6.2.3 Make at least two determinations of bulk volume of cement using separate compactions for each determination. The bulk volume value used for subsequent calculations shall be the average of two values agreeing within ±0.005 cm³. Note temperature in vicinity of cell and record at beginning and end of determination.

6.2.4 Figure 2 shows a typical calculation form.

6.3 *Preparation of Sample*.–Enclose the contents of a vial of the standard cement sample in a 4-ounce jar (about 120 cm³), and shake vigorously for 2 minutes to fluff cement and break up lumps or agglomerates. Allow jar to stand unopened for an additional 2 minutes, then remove lid and stir gently to distribute throughout sample the fine fraction that has settled on surface after fluffing.

6.4 *Mass of Sample*:

6.4.1 The mass of the standard sample used for the calibration test shall be the mass required to produce a bed of cement having a porosity of 0.500±0.005, and shall be calculated as follows:

$$M_s = \rho_c V_c (1 - \epsilon_s) \qquad (2)$$

where:

M_s = grams of sample required,
ρ_c = density of cement (for portland cement, a value of 3.15 Mg/m³ or 3.15 g/cm³ shall be used.),
V_c = bulk volume of bed cement in cubic centimeters, as determined in accordance with section 6.2, and
ϵ_s = desired porosity of bed of cement, 0.500±0.005 (note 5).

NOTE 5.–Porosity is ratio of volume of voids in bed of cement to total or bulk volume of bed.

6.5 *Preparation of Bed of Cement*.–Seat perforated disk on ledge in permeability cell with the inscribed or marked face down. Place a filter paper disk on metal disk and press edges down with a rod having a diameter slightly smaller than that of cell. Determine cement mass to nearest

0.001 gram as determined in accordance with 6.4 and place in cell. Tap side of cell lightly to level bed of cement. Place a filter paper disk on top of cement and compress cement with plunger until plunger collar is in contact with top of cell. Slowly withdraw plunger a short distance, rotate about 90 degrees, repress, and then slowly withdraw. Use of fresh disks is required for each determination.

6.6 *Permeability Test*:

6.6.1 Attach permeability cell to manometer tube, ensure an airtight connection is obtained, and take care not to jar or disturb prepared bed of cement.

NOTE 6.-If a rubber stopper is used for connection, it should be moistened with water. If a standard-taper joint is used, a little stopcock grease should be applied. The efficiency of the connection can be determined by attaching cell to manometer, stoppering it, partially evacuating one arm of manometer, and then closing valve. Any continuous drop in pressure indicates a leak in system.

6.6.2 Slowly evacuate air in one arm of manometer U-tube until liquid reaches top mark; then close valve tightly. Start timer when bottom of meniscus of manometer liquid reaches second (next to top) mark, and stop timer when bottom of meniscus of liquid reaches third (next to bottom) mark. Note the time interval measured, in seconds, and record. Note the temperature of test in degrees Fahrenheit (Celsius), and record.

6.6.3 During calibration of instrument, make at least three determinations of the time of flow on each of three separately prepared beds of standard sample (note 7). Calibration shall be made by same operator making fineness determination.

NOTE 7.-Sample may be refluffed and reused for preparation of test bed, provided that it is kept dry and all tests are made within 4 hours of opening of sample.

6.6.4 Figure 3 shows a typical calculation form.

6.7 *Recalibration*.-The apparatus shall be recalibrated (note 8):

- At periodic intervals to correct for possible wear on plunger or permeability cell
- If any loss in manometer fluid occurs
- If a change is made in type or quality of filter paper used for tests

NOTE 8.-It is suggested that a secondary sample be prepared and used as a fineness standard for check determinations of instrument between regular calibrations with standard cement sample.

7. Conditioning

7.1 Conditioning or preparation of sample and bed of cement for calibration is given in sections 6.3 and 6.5.

8. Procedure

8.1 *Temperature of Cement*.-The cement sample shall be at room temperature when tested.

8.2 *Size of Test Sample*.-The mass of sample (note 9) used for test shall be same as that used in calibration test on standard sample, except that when determining fineness of Type III cements or other types of fine-ground cements whose bulk for this mass is so great that ordinary thumb pressure will not cause plunger collar to contact top of cell, sample mass shall be that required to produce a test bed having a porosity of 0.530±0.005.

NOTE 9.-When this procedure is used for materials other than portland cement, or if one of the required porosities given in 8.2 cannot be attained for a portland cement sample, the mass of sample shall be adjusted so that a firm, hard bed is produced by compacting process. In no case; however, should more than thumb pressure be used to secure proper bed, nor should such thumb pressure be used that plunger "rebounds" from cell top when pressure is removed.

8.3 *Preparation of Bed of Cement*.-Prepare test bed of cement in accordance with section 6.5.

8.4 *Permeability Tests*.-Make permeability tests in accordance with method described in 6.6, except that only one time-of-flow determination is required on each bed.

9. Calculation

9.1 Calculate specific surface values in accordance with the following equations:

$$S_T = \frac{S_s \sqrt{T_T}}{\sqrt{T_s}} \qquad (3)$$

$$S_T = \frac{S_s \sqrt{\eta_s} \sqrt{T_T}}{\sqrt{T_s} \sqrt{\eta_T}} \qquad (4)$$

$$S_T = \frac{S_s (b_s - \epsilon_s) \sqrt{\epsilon_T^3} \sqrt{T_T}}{\sqrt{\epsilon_s^3} \sqrt{T_s} (b_T - \epsilon_T)} \qquad (5)$$

$$S_T = \frac{S_s (b_s - \epsilon_s) \sqrt{\epsilon_T^3} \sqrt{\eta_s} \sqrt{T_T}}{\sqrt{\epsilon_s^3} \sqrt{T_s} \sqrt{\eta_T} (b_T - \epsilon_T)} \qquad (6)$$

$$S_T = \frac{S_s \rho_s (b_s - \epsilon_s) \sqrt{\epsilon_T^3} \sqrt{T_T}}{\rho_T (b_T - \epsilon_T) \sqrt{\epsilon_s^3} \sqrt{T_s}} \qquad (7)$$

$$S_T = \frac{S_s \rho_s (b_s - \epsilon_s) \sqrt{\eta_s} \sqrt{\epsilon_T^3} \sqrt{T_T}}{\rho_T (b_T - \epsilon_T) \sqrt{\epsilon_s^3} \sqrt{T_s} \sqrt{\eta_T}} \qquad (8)$$

where:

S_T = specific surface of test sample in square centimeters per gram,

S_s = specific surface of standard sample used in calibration of apparatus in square centimeters per gram,

T_T = measured time interval, in seconds, of manometer drop for test sample (note 10),
T_s = measured time interval, in seconds, of manometer drop for standard sample used in calibration of apparatus (note 10),
η_T = viscosity of air, in poises, at temperature of test of test sample (note 10),
η_s = viscosity of air, in poises, at temperature of test of standard sample used in calibration of apparatus (note 10),
ϵ_T = porosity of prepared bed of test sample (note 10),
ϵ_s = porosity of prepared bed of standard sample used in calibration apparatus (note 10),
ρ_T = density of test sample (for portland cement, a value of 3.15 Mg/m^3 or 3.15 g/cm^3 shall be used),
ρ_s = density of standard sample used in calibration of apparatus (assumed to be 3.15 Mg/cm^3 or 3.15 g/cm^3),
b_T = constant for other than portland cement, and
b_s = a constant (for portland cement, a value of 0.9 shall be used).

NOTE 10.–Values for $\sqrt{\eta_T}$, $\sqrt{\epsilon_T^3}$, and $\sqrt{T_T}$; or $\sqrt{\eta_s}$, $\sqrt{\epsilon_s^3}$, and $\sqrt{T_s}$ may be taken from tables 1, 2, and 3, respectively.

9.1.1 Equations (3) and (4) shall be used in calculations for the fineness of portland cements compacted to the same porosity as the standard fineness sample. Equation (3) shall be used if the room temperature (t_T) at the time of testing the test sample is within ±5.4 °F (±3 °C) of the toom temperature (t_s) at the time of testing the standard sample. Equation (4) shall be used if the temperature is not within this range.

9.1.2 Equations (5) and (6) shall be used in calculations for the fineness of portland cements compacted to some porosity other than that of the standard fineness sample. Equation (5) shall be used if the room temperature (t_T) at the time of testing the test sample is within ±5.4 °F (±3 °C) of the room temperature (t_s) at the time of testing the standard sample. Equation (6) shall be used if the temperature is not within this range.

9.1.3 Equations (7) and (8) shall be used in calculations for the fineness of materials other than portland cement. Equation (7) shall be used if the room temperature (t_T) at the time of testing the test sample is within ±5.4 °F (±3 °C) of the room temperature (t_s) at the time of testing the standard sample. Equation (8) shall be used if the temperature is not within this range.

9.1.4 It is recommended that values of b_T be determined on no less than three samples of materials in question. Test each sample at a minimum of four different porosities over a porosity range of at least 0.06. Correlation coefficients should exceed 0.9970 for the correlation of $\sqrt{\epsilon_T^3}T_T$ versus ϵ_T on each sample tested, see figure 4.

9.2 To calculate specific surface values in square meters per kilogram, multiply surface area in square centimeters per gram by the factor 0.1.

Table 2. - Values for porosity of cement bed.

Porosity of bed ϵ_T or ϵ_s	$\sqrt{\epsilon_T^3}$ or $\sqrt{\epsilon_s^3}$
0.495	0.348
.496	.349
.497	.350
.498	.351
.499	.352
.500	.354
.501	.355
.502	.356
.503	.357
.504	.358
.505	.359
.506	.360
.507	.361
.508	.362
.509	.363
.510	.364
.525	.380
.526	.381
.527	.383
.528	.384
.529	.385
.530	.386
.531	.387
.532	.388
.533	.389
.534	.390
.535	.391

9.3 Round values in square centimeters per gram to nearest 10 units, and values in square meters per kilogram to nearest unit. Example: 3447 cm^2/g is rounded to 3450 cm^2/g or 345 m^2/kg.

9.4 If it is desired to calculate specific surface values in square centimeters per cubic centimeter, multiply surface area in square centimeters per gram by the specific gravity of the sample.

9.5 Figure 5 shows a typical calculation form for specific surface of a portland cement and for a fly ash.

9.5.1 The terms in equations (5) through (8) of $(1 - \epsilon_s)$ and $(1 - \epsilon_T)$ were applicable in ASTM C 204-79a until ASTM C 204-84 changed these terms to $(b - \epsilon_s)$ and $(b - \epsilon)$, where b is equal to a constant (for portland cement, a value of 0.9 shall be used). In addition, section 9.1.4 recommends that values of b_T for materials other than portland cement be determined on no less than three samples, and each sample must be tested at a minimum of four different porosities over a porosity range of at least 0.06, see section 9.1.4 and figure 4. In this procedure, the Bureau has changed the terms $(1 - \epsilon)$ and $(b - \epsilon)$ to $(1 - \epsilon_T)$ and $(b_T - \epsilon_T)$.

Table 3. - Time of airflow.

T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$	T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$	T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$	T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$	T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$	T_T or T_s	$\sqrt{T_T}$ or $\sqrt{T_s}$
26	5.10	51	7.14	76	8.72	101	10.05	151	12.29	201	14.18
26.5	5.15	51.5	7.18	76.5	8.75	102	10.10	152	12.33	202	14.21
27	5.20	52	7.21	77	8.77	103	10.15	153	12.37	203	14.25
27.5	5.24	52.5	7.25	77.5	8.80	104	10.20	154	12.41	204	14.28
28	5.29	53	7.28	78	8.83	105	10.25	155	12.45	205	14.32
28.5	5.34	53.5	7.31	78.5	8.86	106	10.30	156	12.49	206	14.35
29	5.39	54	7.35	79	8.89	107	10.34	157	12.53	207	14.39
29.5	5.43	54.5	7.38	79.5	8.92	108	10.39	158	12.57	208	14.42
30	5.48	55	7.42	80	8.94	109	10.44	159	12.61	209	14.46
30.5	5.52	55.5	7.45	80.5	8.97	110	10.49	160	12.65	210	14.49
31	5.57	56	7.48	81	9.00	111	10.54	161	12.69	211	14.53
31.5	5.61	56.5	7.52	81.5	9.03	112	10.58	162	12.73	212	14.56
32	5.66	57	7.55	82	9.06	113	10.63	163	12.77	213	14.59
32.5	5.70	57.5	7.58	82.5	9.08	114	10.68	164	12.81	214	14.63
33	5.74	58	7.62	83	9.11	115	10.72	165	12.85	215	14.66
33.5	5.79	58.5	7.65	83.5	9.14	116	10.77	166	12.88	216	14.70
34	5.83	59	7.68	84	9.17	117	10.82	167	12.92	217	14.73
34.5	5.87	59.5	7.71	84.5	9.19	118	10.86	168	12.96	218	14.76
35	5.92	60	7.75	85	9.22	119	10.91	169	13.00	219	14.80
35.5	5.96	60.5	7.78	85.5	9.25	120	10.95	170	13.04	220	14.83
36	6.00	61	7.81	86	9.27	121	11.00	171	13.08	222	14.90
36.5	6.04	61.5	7.84	86.5	9.30	122	11.05	172	13.11	224	14.97
37	6.08	62	7.87	87	9.33	123	11.09	173	13.15	226	15.03
37.5	6.12	62.5	7.91	87.5	9.35	124	11.14	174	13.19	228	15.10
38	6.16	63	7.94	88	9.38	125	11.18	175	13.23	230	15.17
38.5	6.20	63.5	7.97	88.5	9.41	126	11.22	176	13.27	232	15.23
39	6.24	64	8.00	89	9.43	127	11.27	177	13.30	234	15.30
39.5	6.28	64.5	8.03	89.5	9.46	128	11.31	178	13.34	236	15.36
40	6.32	65	8.06	90	9.49	129	11.36	179	13.38	238	15.43
40.5	6.36	65.5	8.09	90.5	9.51	130	11.40	180	13.42	240	15.49
41	6.40	66	8.12	91	9.54	131	11.45	181	13.45	242	15.56
41.5	6.44	66.5	8.15	91.5	9.57	132	11.49	182	13.49	244	15.62
42	6.48	67	8.19	92	9.59	133	11.53	183	13.53	246	15.68
42.5	6.52	67.5	8.22	92.5	9.62	134	11.58	184	13.56	248	15.75
43	6.56	68	8.25	93	9.64	135	11.62	185	13.60	250	15.81
43.5	6.60	68.5	8.28	93.5	9.67	136	11.66	186	13.64	252	15.87
44	6.63	69	8.31	94	9.70	137	11.70	187	13.67	254	15.94
44.5	6.67	69.5	8.34	94.5	9.72	138	11.75	188	13.71	256	16.00
45	6.71	70	8.37	95	9.75	139	11.79	189	13.75	258	16.06
45.5	6.75	70.5	8.40	95.5	9.77	140	11.83	190	13.78	260	16.12
46	6.78	71	8.43	96	9.80	141	11.87	191	13.82	262	16.19
46.5	6.82	71.5	8.46	96.5	9.82	142	11.92	192	13.86	264	16.25
47	6.86	72	8.49	97	9.85	143	11.96	193	13.89	266	16.31
47.5	6.89	72.5	8.51	97.5	9.87	144	12.00	194	13.93	268	16.37
48	6.93	73	8.54	98	9.90	145	12.04	195	13.96	270	16.43
48.5	6.96	73.5	8.57	98.5	9.92	146	12.08	196	14.00	272	16.49
49	7.00	74	8.60	99	9.95	147	12.12	197	14.04	274	16.55
49.5	7.04	74.5	8.63	99.5	9.97	148	12.17	198	14.07	276	16.61
50	7.07	75	8.66	100	10.00	149	12.21	199	14.11	278	16.67
50.5	7.11	75.5	8.69	100.5	10.02	150	12.25	200	14.14	280	16.73

NOTE: T_T or T_s = Time of airflow in seconds, and $\sqrt{T_T}$ *or* $\sqrt{T_s}$ = factor for use in equations.

9.5.2 The typical example for fly ash specific surface determination (fig. 3) uses the formulas in use in 1981. No specific surface determinations on fly ash by this method have been made by the Bureau since April 1984; therefore, no typical determinations of a b_T value are included in a typical worksheet with calculations.

10. Report

10.1 For portland cements and portland cement-based materials, report results on a single determination on a single bed.

10.2 For very high fineness materials with long time intervals, report average fineness value of two permeability tests, provided that both values agree within 2 percent of each other. If they do not agree, discard the values and repeat test until two values so agreeing are obtained.

NOTE 11.–Lack of agreement indicates a need for checks on procedure and apparatus. Care shall be exercised in the preparation of test beds, and precautions shall be taken to ensure an airtight connection between permeability cell and manometer arm. For additional information, see "Manual of Cement Testing."[5]

10.3 A suggested reporting form is shown on figure 5 of USBR 4183.

11. Precision and Bias

11.1 *Single-Operator Precision.*–The single-operator coefficient of variation has been found to be 1.2 percent. Therefore, results of two properly conducted tests by same operator on same sample should not differ by more than 3.4 percent of their average (note 12).

11.2 *Multilaboratory Precision.*–The multilaboratory coefficient of variation has been found to be 2.1 percent. Therefore, results of two different laboratories on identical samples of a material should not differ from each other by more than 6.0 percent of their average (note 12).

NOTE 12.–These values represent the 1S percent and D2S percent limits as described in ASTM C 670.

11.3 There is no known bias for this test procedure.

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[5] *Annual Book of ASTM Standards*, vol. 04.01.

Spec. or Solic. No. DC-7395	Structure DAM	Tested by K. MITCHELL Date 6-20-80
Project DALLAS CREEK, COLORADO	Item ~~CEMENT~~-SPEC. VERIFICATION Location DENVER LAB	Computed by K. MITCHELL Date 6-20-80
Feature RIDGEWAY DAM-STAGE 01	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 6-20-80

FINENESS OF CEMENTITIOUS MATERIALS BY AIR PERMEABILITY APPARATUS

Apparatus No.	Standard Cement No.	Sample No.	Brand Name	Plant ID	Type ~~or Class~~	Mass of Mercury, grams		Room Temperature at Time of Test				ρ_m Density of Mercury, g/cm^3	V_c Volume of Cement, cm^3
								Initial		Final			
						M_a	M_b	°F	°C	°F	°C		
Trial No. 1 1	114M	M-7365	IDEAL CEMENT	PORT-LAND, CO	II	106.66	81.17		23.0		23.0	13.54	1.883
Trial No. 2 1	114M	M-7365	IDEAL CEMENT	PORT-LAND, CO	II	106.66	81.16		23.0		23.5	13.54	1.883
Avg.													1.883
Trial No. 1													
Trial No. 2													
Avg.													
Trial No. 1													
Trial No. 2													
Avg.													
Trial No. 1													
Trial No. 2													
Avg.													

Remarks:

Figure 2. - Calibration—bulk volume of compacted bed of powder with mercury.

Spec. or Solic. No. DC-7395	Structure DAM	Tested by K. MITCHELL — Date 6-20-80
Project DALLAS CREEK, COLORADO	Item CEMENT-SPEC. VERIFICATION Location DENVER LAB	Computed by K. MITCHELL — Date 6-20-80
Feature RIDGEWAY DAM - STAGE 01	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS — Date 6-20-80

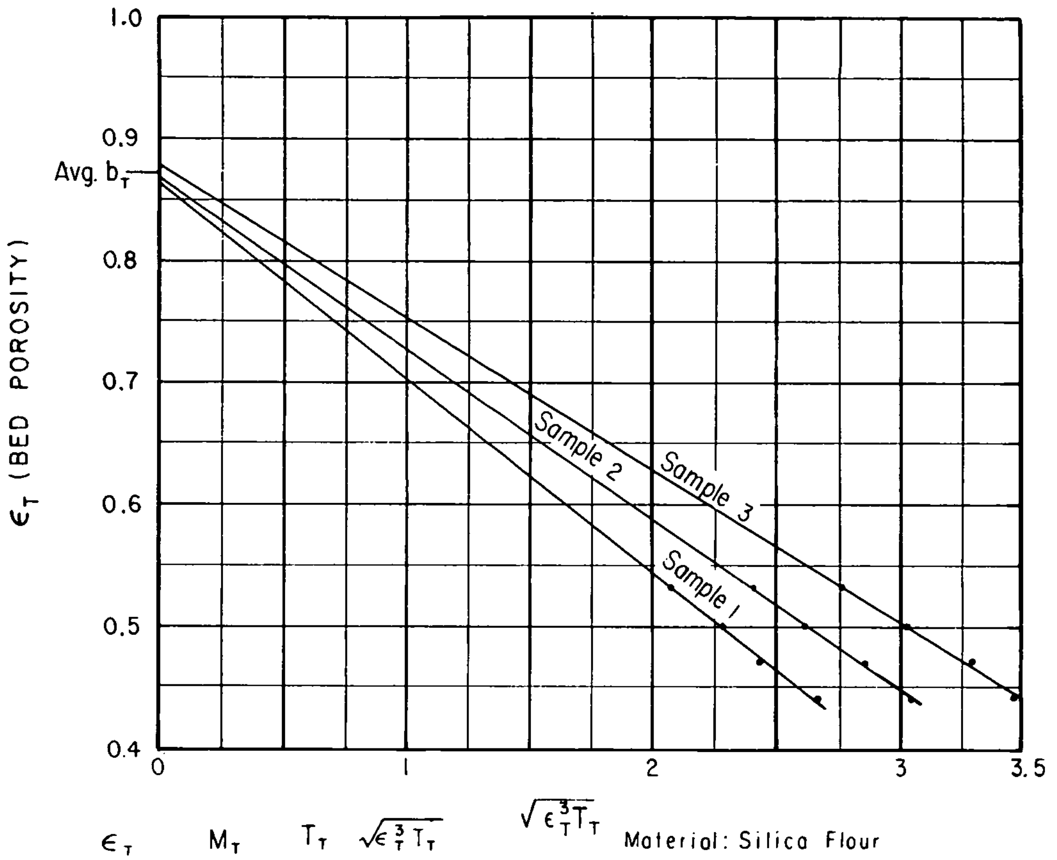
FINENESS OF CEMENTITIOUS MATERIALS BY AIR PERMEABILITY APPARATUS

Apparatus No.	Standard Cement No.	Trial No.	M_0 Mass of Sample, grams	ρ_c Density of Cement, g/cm^3	V_c Volume of Cement, cm^3	t_0 Room Temp. at Time of Testing Standard Sample		ϵ_0 Porosity Ratio	S_0 Specific Surface[1], cm^2/g	T_0 Time Interval, seconds
						°F	°C			
Bed No. 1		1	2.966	3.15	1.883		23	0.500	3930	99.5
		2					22			99.5
		3					23			99.7
Bed No. 2	114M	1					23			100.2
		2					23			99.6
		3					24			100.2
Bed No. 3		1					23			99.9
		2					23			99.9
		3	↓	↓	↓		23	↓	↓	99.8
Average										99.8
Bed No. 1		1								
		2								
		3								
Bed No. 2		1								
		2								
		3								
Bed No. 3		1								
		2								
		3								
Average										
Bed No. 1		1								
		2								
		3								
Bed No. 2		1								
		2								
		3								
Bed No. 3		1								
		2								
		3								
Average										

[1] Specific Surface of Standard Cement No. 114M = 3930 cm^2/g

Remarks:

Figure 3. - Calibration — time of flow of standard reference cement sample.



ϵ_T	M_T	T_T	$\sqrt{\epsilon_T^3 T_T}$
0.530	2.350	29.0	2.078
0.500	2.500	42.0	2.291
0.470	2.650	57.5	2.443
0.440	2.800	82.5	2.651
0.530	2.350	39.0	2.410
0.500	2.500	55.5	2.610
0.470	2.650	79.0	2.846
0.440	2.800	108.5	3.040
0.530	2.350	51.5	2.769
0.500	2.500	73.0	3.021
0.470	2.650	104.0	3.286
0.440	2.800	141.5	3.472

Material: Silica Flour
ρ_T = density of test sample = 2.65 g/cm^3
V_C = bulk volume of sample bed = 1.887 cm^3
ϵ_T = desired porosity of test
M_T = grams of sample required = $\rho_T V_C (1-\epsilon_T)$
T_T = measured test time interval in seconds
Computed values of "b_T" by linear regression:
Sample 1: b_T = 0.863 (correlation coeff. = 0.9980)
Sample 2: b_T = 0.869 (correlation coeff. = 0.9993)
Sample 3: b_T = 0.879 (correlation coeff. = 0.9973)
Average: b_T = 0.870

Figure 4. – Illustration on method for determination of b_T value for use in fineness calculations of materials other than portland cement.

Spec. or Solic. No. DC-7395	Structure DAM	Tested by K. MITCHELL Date 6-20-80
Project DALLAS CREEK, COLORADO	Item CEMENT & FLY ASH SPEC. VERIF. Location DENVER LAB	Computed by K. MITCHELL Date 6-20-80
Feature RIDGEWAY DAM - STAGE 01	Station ~ Offset ~ Depth ~ to ~	Checked by W. DUFFUS Date 6-20-80

FINENESS OF CEMENTITIOUS MATERIALS BY AIR PERMEABILITY APPARATUS

Apparatus No.	Standard Cement No.	Sample No.	Brand Name	Plant ID	Type ~~or~~ ~~Class~~	M_T Mass of Test Sample, grams	ρ_T Density of Test Sample, $\mathrm{g/cm^2}$	V_c Volume of Cement, $\mathrm{cm^3}$	t_T Room Temp. at Time of Testing Test Sample		ϵ_T Porosity Ratio	T_T Time Interval, seconds	S_T Specific Surface, $\mathrm{cm^2/g}$
									°F	°C			
1	114M	M-7365	IDEAL CEMENT	PORTLAND CO	II	2.966	3.15	1.883		23	0.500	102	3970
1	114M	M-6979	COMANCHE FLY ASH	PUEBLO, CO	C HIGH ALK.	2.750	2.57	1.883		23	0.4319	167	4400
1	114M	M-4996	FLY ASH (CHICAGO)	CHICAGO, IL	F	2.650	2.49	1.883		23	0.4351	81	3210

M-7365: EQ. (3) $S_T = \dfrac{S_s\sqrt{T_T}}{\sqrt{T_s}} = \dfrac{3930\sqrt{102}}{\sqrt{99.8}} = \dfrac{3930(10.10)}{9.990} = 3973$

M-6979 & -4996: EQ. (7) $S_T = \dfrac{S_s \rho_s (1-\epsilon_s)\sqrt{\epsilon_T^3}\sqrt{T_T}}{\rho_T(1-\epsilon_T)\sqrt{\epsilon_s^3}\sqrt{T_s}}$

M-6979: $S_T = \dfrac{(3930)\times 3.15(1.0-0.500)\sqrt{0.4319^3}\sqrt{167}}{2.57(1.0-0.4319)\sqrt{0.500^3}\sqrt{99.8}} = \dfrac{(3930)(3.15)(0.50)(0.284)(12.92)}{(2.57)(0.5681)(0.354)(9.990)} = 4398$

M-4996: $S_T = \dfrac{(3930)\times 3.15(1.0-0.500)\sqrt{0.4351^3}\sqrt{81}}{2.49(1.0-0.4649)\sqrt{0.500^3}\sqrt{99.8}} = \dfrac{(3930)(3.15)(0.50)(0.287)(9.00)}{(2.49)(0.5649)(0.354)(9.990)} = 3214$

Figure 5. - Specific surface of cementitious materials as determined by air permeability.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROCEDURE FOR

USBR 4211-92

SELECTING PROPORTIONS FOR CONCRETE MIXTURES

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4211; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ACI standard: 211.1.

1. Scope

1.1 This designation covers the procedures for selecting proportions for all normal density concrete made with aggregates of average density, as distinguished from low density and special high density aggregates, and workability suitable for normal cast-in-place construction and most precast concrete construction similar in nature to the cast-in-place concrete. Although the same basic data and procedures are used in the proportioning of mass concrete, additional information on mass concrete is also presented.

1.2 These procedures provide a first approximation of proportions intended to be checked by trial batches in laboratory or field, and adjusted to produce desired characteristics.

1.3 This designation also provides theoretical equations that predict the effects of aggregates, cements, pozzolans, air-entrainment, and chemical admixtures on concrete strength. This information is presented in appendix X1.

2. Applicable Documents

2.1 In conducting laboratory tests to provide information for selecting concrete proportions, the latest revisions of the following specifications and methods should be used.

2.1.1 *Ingredient Specifications*:

2.1.1.1 *USBR Procedures*:

4094 Specifications for Ready-Mixed Concrete

2.1.1.2 *ASTM Standards*:

C 150 Standard Specification for Portland Cement[1,2]

C 260 Standard Specification for Air-Entraining Admixtures for Concrete[1]

C 494 Standard Specification for Chemical Admixtures for Concrete[1]

C 595 Standard Specification for Blended Hydraulic Cements[1,2]

C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[1]

2.1.2 *For Tests of Ingredients*:

2.1.2.1 *USBR Procedures*:

4029 Density and Voids in Aggregate

4075 Sampling Aggregates

4127 Specific Gravity and Absorption of Coarse Aggregate

4128 Specific Gravity and Absorption of Fine Aggregate

4136 Sieve Analysis of Fine and Coarse Aggregates

4183 Sampling and Acceptance of Hydraulic Cement

4188 Density of Hydraulic Cementitious Materials

4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete

4566 Total Moisture Content of Aggregate by Drying

2.1.3 *For Tests of Concrete*:

2.1.3.1 *USBR Procedures*:

4039 Compressive Strength of Cylindrical Concrete Specimens

4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete

4143 Slump of Concrete

4172 Sampling Freshly Mixed Concrete

4192 Making and Curing Concrete Test Specimens in Laboratory

4231 Air Content of Freshly Mixed Concrete by Pressure Method

2.1.3.2 *ACI Publications*:

211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete[3]

214 Recommended Practice for Evaluation of Strength Test Results of Concrete[3]

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.01.

[3] *ACI Manual of Concrete Practice*, part 1, American Concrete Institute.

3. Significance and Use

3.1 *Introduction*:

3.1.1 Concrete is composed principally of cement, aggregates, and water; will contain some amount of entrapped air, and may also contain some purposely entrained air obtained by using an admixture or air-entraining cement. Admixtures are also frequently used for other purposes such as to accelerate or retard the time-of-set, improve workability, reduce mixing water requirement, increase strength, or alter other properties of the concrete. Certain pozzolanic materials may be used in conjunction with portland cement for economy or to provide specific properties such as reduced early heat of hydration, improved workability, or increased resistance to sulfate attack and alkali-aggregate reaction.

3.1.2 The selection of concrete proportions involves a balance between reasonable economy and requirements for placeability, strength, durability, density, and appearance. The required characteristics are governed by the actual final use for the concrete and by conditions expected to be encountered at time of placement. These factors are often, but not always, reflected in the specifications for the job.

3.1.3 The ability to tailor concrete properties to the actual job requirements reflects technological developments which have taken place, for the most part, since the early 1900's. The use of the water-cement ratio as a tool for estimating strength was recognized about 1918, and the remarkable improvement in durability resulting from the entrainment of air was recognized in the early 1940's. These two significant developments in concrete technology have been augmented by extensive research and development in many related areas, including the use of admixtures to counteract possible deficiencies, develop special properties, or achieve economy [1].[4] It is beyond the scope of this discussion to review the theories of concrete proportioning which have provided the background and sound technical basis for the relatively simple procedures of this designation. More detailed information can be obtained from references [2 through 19].

3.1.4 Proportions calculated by any method are always considered to be subject to revision on the basis of experience with trial mixes. Depending on the circumstances, trial mixes may be small batches prepared in a laboratory or full-size batches prepared in the field. The use of full-size field batches avoids the possible pitfalls of assuming that data from small batches mixed in a laboratory environment will predict the performance of concrete under field conditions.

3.2 *Basic Relationships*:

3.2.1 Concrete proportions must be selected to provide necessary placeability, strength, durability, and density for the particular application. In addition, when mass concrete is being proportioned, consideration must be given to generation of heat.

3.2.2 *Placeability*.–The placeability, including satisfactory finishing properties, encompasses traits of "workability" and "consistency." For the purpose of this discussion, workability is considered to be that property of concrete which determines its capacity to be placed and consolidated properly and to be finished without harmful segregation. The workability also includes such concepts as moldability, cohesiveness, and compactability. Workability is affected by the grading, particle shape and proportions of aggregate, amount of cement, presence of entrained air, admixtures, and consistency of mixture. Consistency is basically the wetness of the concrete mixture. The consistency is measured in terms of slump, the higher the slump the wetter the mixture; and the consistency affects the ease with which the concrete will flow during placement. Consistency is related to but not synonymous with workability. In properly proportioned concrete, the unit water content required to produce a given slump will depend on several factors. The water requirement increases as aggregates become more angular and rough textured, but this disadvantage may be offset by improvements in other characteristics such as the bond to the cement paste. Required mixing water decreases as the maximum size of clean, well-graded aggregate is increased, and also decreases with the entrainment of air. The mixing water requirement may often be significantly reduced by certain admixtures. These procedures permit all of the factors of workability and consistency to be taken into account to economically achieve satisfactory placeability.

3.2.3 *Strength*.–The strength is an important characteristic of concrete, but other characteristics such as durability, permeability, and wear resistance are often equally or more important. These characteristics may be generally related to strength but are also affected by factors not significantly associated with strength. For a given set of materials and conditions, concrete strength is determined by the net quantity of water used per unit quantity of cement. The net water content excludes water absorbed by the aggregates, but includes water adhering to the surfaces of aggregate, often termed "free moisture." Differences in strength for a given water-cement ratio may result from changes in maximum size of aggregate; grading, surface texture, shape, and strength of aggregate particles; differences in cement types and sources; air content; and the use of admixtures, which affect the cement hydration process or develop cementitious properties themselves. To the extent that these effects are predictable in the general sense, they are taken into account in this designation. Estimated values are assigned to these effects, which are outlined in appendix X1. However, in view of their number and complexity, it should be obvious that accurate predictions of strength must be based on trial batches or on experience with materials to be used.

3.2.4 *Durability*.–The concrete must be able to endure those exposures which may deprive it of its serviceability such as freezing and thawing, wetting and drying, heating and cooling, chemicals, and deicing agents. Resistance to some of these exposures may be enhanced

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[4] Numbers in brackets refer to entries in References, section 17.

by use of special ingredients such as low-alkali cement, pozzolans, or selected aggregate to prevent harmful expansion due to alkali-aggregate reaction which occurs in some areas when concrete is exposed to a moist environment. Also, sulfate resisting cement or pozzolans may be used for concrete exposed to sulfate-bearing soils and/or sulfate waters, or aggregate free of excessive soft particles where resistance to surface abrasion is required. Use of a low water-cement ratio will prolong the life of concrete by reducing the penetration of aggressive liquids. Resistance to severe weathering, particularly freezing and thawing, and to salts used for ice removal is greatly improved by incorporation of a proper distribution of entrained air. Entrained air should be used in all exposed concrete in climates where freeze-thaw cycles occur. References [20,21] provide detailed information on concrete durability.

3.2.5 *Generation of Heat.*–A major concern in proportioning mass concrete is the size and shape of the completed structure or portion thereof. Concrete placements large enough to require control measures for generation of heat and resultant volume change within the mass will also require consideration of temperature control measures, as explained in the mass concrete sections of this procedure. Generally, hydration of cement will generate a concrete temperature rise of 10 to 15 °F per 100 $\mathrm{lbm/yd^3}$ (9 to 14 °C per 100 $\mathrm{kg/m^3}$) of portland cement. If temperature rise of concrete mass is not held to a minimum and the heat allowed to dissipate at a reasonable rate, or if concrete is subjected to rapid cooling, cracking is likely to occur. Temperature control measures can include a relatively low initial placing temperature, reduced quantities of cementitious materials, and circulation of chilled water. Also, the insulation of concrete surfaces may be required to adjust for these various concrete conditions and exposures. It should be emphasized that mass concrete is not necessarily made of large aggregate concrete, and the concern about generation of an excessive amount of heat in concrete is not confined to massive dam or large foundation structures. Many large structural elements may be massive enough that heat generation should be considered, particularly when minimum cross-sectional dimensions of a solid concrete member approach or exceed 2 to 3 feet (0.6 to 0.9 m) or when cement contents above 600 $\mathrm{lbm/yd^3}$ (356 $\mathrm{kg/m^3}$) are being considered.

3.3 *Background Data.*–To the extent possible, selection of concrete proportions should be based on test data or experience with materials to be used. Where such background information is limited or not available, estimates provided in this designation may be used (note 1). The following information for available materials will be useful:

- Sieve analyses of fine and coarse aggregates.
- Optimum combination of coarse aggregates to obtain maximum density.
- Dry-rodded or dry-jigged density of coarse aggregate.
- Bulk specific gravities and absorptions of aggregates.
- Bulk specific gravity of each cementitious material.
- Mixing water requirements of concrete developed from experience with available aggregates.
- Relationships between strength and the W/(C+P) (water-cement plus pozzolan ratio) for the available combinations of cementitious materials and aggregate.

NOTE 1.–Estimates from tables 1 and 2, respectively, may be used when the last two items of information are not available.

4. Apparatus

4.1 The apparatus required for proportioning concrete mixes are covered under the individual test procedures listed under the Applicable Documents of section 2.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling, Test Specimens, and Test Units

6.1 Procedures for sampling, and a description and suggested quantities of test specimens and test units are given under the individual test procedures listed under the Applicable Documents of section 2.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

8. Conditioning

8.1 Conditioning of materials for all tests required prior to proportioning of concrete mixes are covered under the individual test procedures listed under the Applicable Documents of section 2.

9. Procedure

9.1 The procedure for selection of mix proportions discussed in this section is applicable to all normal density concrete. Although the same basic data and procedures are used in proportioning mass concrete, additional information required for mass concrete design is given in the mass concrete portion of this designation.

9.2 Estimating the required batch masses for the concrete involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the availa-

Table 1. – Approximate air and water contents per volume of concrete; and proportions of fine and coarse aggregate.[1]

Max. size of coarse aggregate, inches	Max. size of coarse aggregate, (mm)	Recommended total air content, ± 1 percent	Sand, percent of total aggregate by solid volume	Percent of dry-rodded or dry-jigged density of coarse aggregate per unit volume of concrete	Air-entrained concrete, average water content, lbm/yd^3	Air-entrained concrete, average water content, (kg/m^3)
3/8	(9.5)	7.0	60	41	320	(190)
1/2	(12.5)	6.5	50	52	305	(180)
3/4	(19.0)	6.0	42	62	280	(165)
1	(25.0)	5.5	37	67	265	(155)
1-1/2	(37.5)	5.0	34	73	245	(145)
2	(50)	4.5	30	76	230	(135)
3	(75)	4.0	28	81	200	(120)
4	(100)	4.0	26	84	185	(110)
6	(150)	3.5	24	87	165	(100)

ADJUSTMENT OF VALUES FOR OTHER CONDITIONS[2]

Changes in materials or proportions	Water content, percent	Percentage of sand	Percentage of dry-rodded or dry-jigged coarse aggregate
When WRA[3] is used	–5	+ 2	–
When HRWRA[4] is used	–12	+ 5	–
Each 0.2 increase or decrease in fineness modulus of sand	–	± 1	∓ 2
Each 1-inch (25-mm) increase or decrease in slump	± 3	–	–
Each 10 °F (5.6 °C) increase or decrease in concrete temperature	± 2	–	–
Each 1 percent increase or decrease in air content	∓ 3	∓ 1	–
Each 0.05 increase or decrease in W/(C+P)	–	± 1	–
Each 1 percent increase or decrease in sand content	± 1	–	∓ 2
Each 10 percent increase or decrease in fly ash	∓ 3	∓ 1	± 2
When manufactured sand is used	+ 5	+ 2	–
When flat, elongated or angular coarse aggregate is used	+ 8	+ 4	–

[1] For 70 °F (21 °C), concrete containing natural sand with a fineness modulus of 2.75, average coarse aggregate, and a slump of 3 to 4 inches (76 to 102 mm) at the mixer.

[2] If aggregates are proportioned by the percentage of sand method, use first and second columns; if by the dry-rodded or dry-jigged density method, use first and third columns.

[3] WRA = water reducing admixture (Type A or D, ASTM C 494).

[4] HRWRA = high-range water reducing admixture (Type F or G admixtures, ASTM C 494).

ble materials for a mixture suitable for the work. The question of suitability is frequently not decided by the individual selecting the proportions because the job specifications may dictate some or all of the following:

- Maximum W/(C+P).
- Minimum cementitious materials content.
- Air content.
- Slump.
- Maximum size of aggregate.
- Strength.
- Other requirements relating to such factors as strength overdesign, admixtures, type of cement, and type of aggregate sources.

9.3 Regardless of whether the concrete characteristics are prescribed by the specifications or are left to the individual selecting the proportions, establishment of batch masses per cubic yard or cubic meter of concrete can best be accomplished using the following sequence:

9.3.1 *Step 1, Choice of Slump*.–If a slump is not specified, a value appropriate for the work can be selected from table 3. The slump ranges shown apply when vibration is used to consolidate concrete containing

Table 2. – Approximate strength of concrete (containing good aggregate) for various water-cement ratios.[1]

Water-cement ratio by mass	Compressive strength at 28 days: Air-entrained concrete lbf/in²	Air-entrained concrete (MPa)	Air-entrained concrete with WRA lbf/in²	Air-entrained concrete with WRA (MPa)
0.40	5,700	(39.3)	6,500	(44.8)
0.45	4,900	(33.8)	5,600	(38.6)
0.50	4,200	(29.0)	4,800	(33.1)
0.55	3,600	(24.8)	4,200	(29.0)
0.60	3,100	(21.4)	3,600	(24.8)
0.65	2,600	(17.9)	3,100	(21.4)
0.70	2,200	(15.2)	2,700	(18.6)

[1] For information on mix design parameters for concrete containing chemical admixtures, see reference [29].

Table 3. – Recommended slumps for various types of construction.[1]

Type of construction	Slump, inches (mm) maximum	Slump, inches (mm) minimum
Footings, caissons, and substructures	3 (76)	1 (25)
Beams and reinforced walls	4 (102)	1 (25)
Sidewalls and arch in tunnel linings	4 (102)	1 (25)
Tops of walls, piers, parapets, and curbs	2 (51)	1 (25)
Pavements, slabs, and tunnel inverts[2]	2 (51)	1 (25)
Canal linings[3]	3 (76)	1 (25)
Mass concrete, mass construction	2 (51)	1 (25)
Building columns	4 (102)	1 (25)
Other structures	3 (76)	1 (25)

[1] The maximum slumps are for concrete after placement and before consolidation, and for mixes having air contents given in table 1. For certain applications, the use of a HRWRA (high-range water reducing admixture) is allowed. If mix is properly designed to prevent segregation, a HRWRA can be used to produce flowing concrete with a maximum slump of 9 inches (229 mm); however, each use or application must be allowed in the specifications or approved by contracting officer.

[2] The slump of tunnel inverts placed monolithically with sidewalls and arch may be increased to a maximum of 4 inches (102 mm).

[3] On machine-placed canal lining less than 3 inches (76 mm) thick, the slump may be increased to a maximum of 4 inches (102 mm).

entrained air. Mixes of the stiffest consistency that can be placed efficiently should be used.

9.3.2 *Step 2, Choice of Maximum Size of Aggregate.*–Large maximum sizes of well graded aggregates have less voids than smaller sizes; therefore, concretes with the larger sized aggregates require less mortar per unit volume of concrete. Generally, the maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure. The maximum size aggregate should never exceed one-fifth the minimum dimension between sides of forms; one-third the depth of slabs; or two-thirds the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived if workability and methods of consolidation are such that the concrete can be placed without honeycombs or voids. When high strength concrete is desired, best results are usually obtained with smaller, reduced maximum sizes of clean aggregate. Concrete strength is usually limited by the bond developed between aggregate and paste. Smaller size aggregate has more surface area and can be expected to produce a higher strength at a given water-cement plus pozzolan ratio.

9.3.3 *Step 3, Estimate of Mixing Water and Air Content.*–The quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum size, particle shape, and grading of the aggregates; on the amount and class of pozzolan; amount and type of chemical admixtures; and on the amount of entrained air. The water quantity is not appreciably affected by the quantity of cement in the amounts normally used. Table 1 provides estimates of required mixing water for air-entrained concretes made with various maximum sizes of aggregate. Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below these tabulated values; however, these values are sufficiently accurate for initial estimate. Such differences in water quantity are not necessarily reflected in strength because other compensating factors may be involved. For example, a rounded and an angular coarse aggregate, both well graded and of good quality, can be expected to produce concrete of about the same compressive strength for the same cementitious materials factor regardless of differences in water-cement plus pozzolan ratio resulting from different mixing water requirements. Particle shape per se is not an indicator that an aggregate will be either above or below average in its strength-producing capacity.

9.3.3.1 Table 1 shows the recommended air contents for each aggregate size. The use of these recommended amounts of air entrainment in concrete with a specified strength above 5,000 lbf/in^2 (34.5 MPa) may not be possible because each additional percent of air lowers the maximum strength obtainable with a given combination of materials by about 5 percent. Therefore, exposure to water, deicing salts, and freezing temperatures should be carefully evaluated. If the concrete is not expected to be continually wet and will not be exposed to deicing salts, lower air content values may be appropriate even though the concrete is exposed to freezing and thawing temperatures. However, for an exposure condition where the concrete may be saturated prior to cycles of freezing and thawing, the use of air entrainment should not be sacrificed for strength.

9.3.3.2 When trial batches are used to establish strength relationships or verify the strength-producing capability of a mixture, the least favorable strength producing combination of mixing water and air content should be used. Air content should be the maximum permitted or likely to occur for the job conditions, and the slump should be the highest permissible by the specifications after considering slump loss from batch plant to placement. This will avoid developing an over-optimistic estimate of strength on the assumption that average rather than extreme conditions will prevail in the field.

9.3.4 *Step 4, Selection of Water-Cement Plus Pozzolan Ratio.*–The required water-cement plus pozzolan ratio is determined by strength requirements in addition to other factors such as durability and finishing properties. Because different aggregates and cementitious materials generally produce different strengths at the same ratio, it is desirable to have or develop the relationship between the strength and this ratio for the materials actually to be used. In the absence of such data, approximate values for concrete containing Type II portland cement can be taken from table 2. With satisfactory materials, the tabulated ratios should produce the strengths shown based on 28-day tests of 6- by 12-inch (152- by 305-mm) specimens that have been fabricated, cured, and tested under prescribed laboratory conditions. Keep in mind that the average strength selected must exceed the specified strength by a sufficient margin to keep the number of low tests within the specified limits, see table 4.

9.3.4.1 When pozzolan is used as a partial replacement of cement, about 15 to 25 percent by mass, the water-cement ratios shown in table 2 should be reduced by about 0.05 to account for the slower strength-gaining properties of many pozzolans and, consequently, the reduced 28-day strength normally expected for concrete containing pozzolan.

9.3.4.2 For severe conditions of exposure, the water-cement plus pozzolan ratio should be kept low to provide sufficient durability even when the strength requirements could be met by a higher ratio. Table 5 gives limiting values.

9.3.5 *Step 5, Calculation of Cementitious Materials Content.*–The amount of cementitious materials per unit volume of concrete is fixed by the determinations made in sections 9.3.3 and 9.3.4. The required cementitious materials are equal to the estimated mixing water content determined in section 9.3.3 divided by the water-cement plus pozzolan ratio determined in section 9.3.4. However, if the specifications include a separate minimum limit on the cementitious materials content in addition to the requirements for strength and durability, the mixture must be based on whichever criterion requires the greater amount of cementitious materials.

9.3.6 *Step 6, Estimate of Aggregate Content.*–Estimates for the fine aggregate content by the sand percentage method or for the coarse aggregate content by the dry-rodded or dry-jigged density method are presented in this section. Concrete of comparable workability can be expected with aggregates of comparable size and grading provided the volume of mortar remains constant. The solid volume of cement, pozzolan, water, air, and sand may be interchanged to maintain a constant mortar content and constant coarse aggregate content. The percentage of sand in a concrete mix has been used extensively as a means of identifying the proportions of sand and coarse aggregate for Bureau mixes. Recommended percentages of sand for each maximum size of coarse aggregate are listed in table 1, along with suggested sand adjustments to maintain a constant mortar content, to allow for effects of varying sand fineness modulus, and to allow for improved workability obtained from fly ash. In section 9.3.6.1, it is demonstrated that aggregates can be proportioned by computing the total solid volume of sand and coarse aggregate in the concrete mix and multiplying this total volume by the recommended percentage of sand or, as described in 9.3.6.2, by estimating quantity of coarse aggregate and paste initially, and then determining amount of sand. Either method is satisfactory, and will result in about the same proportions for most conditions. However, basing amount of coarse aggregate on a fixed percentage of the dry-rodded or dry-jigged density may be easier because it automatically makes allowances for differences in most materials. For example, angular aggregates have a higher void content, and therefore require more mortar than rounded aggregates. The higher void content results in a lower dry-rodded or dry-jigged density and therefore decreases the amount of coarse aggregate obtained from the fixed percentage, which automatically produces a greater amount of mortar.

Table 4a. – Average strength that must be maintained to meet design requirements (inch-pound units).

Design strength (f'_c) lbf/in²	Percent of strength greater than design strength	Average strength required (f_{cr}) in lbf/in² so that 75, 80, 85, or 90 percent of tests are greater than design strength (f'_c)				
		Coefficient of variation, percent				
		5	10	15	20	25
2,000	75	2,070	2,150	2,230	2,320	2,410
	80	2,090	2,190	2,290	2,410	2,540
	85	2,110	2,240	2,380	2,530	2,720
	90	2,140	2,300	2,490	2,710	2,980
2,500	75	2,590	2,680	2,790	2,900	3,010
	80	2,610	2,730	2,870	3,010	3,180
	85	2,640	2,790	2,970	3,170	3,400
	90	2,680	2,880	3,110	3,390	3,720
3,000	75	3,110	3,220	3,340	3,470	3,620
	80	3,130	3,280	3,440	3,620	3,810
	85	3,170	3,350	3,560	3,800	4,070
	90	3,210	3,450	3,730	4,070	4,460
3,500	75	3,620	3,760	3,900	4,050	4,220
	80	3,660	3,830	4,010	4,220	4,450
	85	3,690	3,910	4,160	4,440	4,750
	90	3,750	4,030	4,360	4,740	5,210
4,000	75	4,140	4,290	4,460	4,630	4,820
	80	4,180	4,370	4,590	4,820	5,090
	85	4,220	4,470	4,750	5,070	5,430
	90	4,280	4,600	4,980	5,420	5,950
4,500	75	4,660	4,830	5,010	5,210	5,430
	80	4,700	4,920	5,160	5,430	5,720
	85	4,750	5,030	5,350	5,700	6,110
	90	4,820	5,180	5,600	6,100	6,690
5,000	75	5,180	5,370	5,570	5,790	6,030
	80	5,220	5,470	5,730	6,030	6,360
	85	5,280	5,590	5,940	6,340	6,790
	90	5,350	5,750	6,220	6,780	7,440
5,500	75	5,690	5,900	6,130	6,370	6,630
	80	5,750	6,010	6,310	6,630	6,990
	85	5,810	6,150	6,530	6,970	7,470
	90	5,890	6,330	6,850	7,450	8,180
6,000	75	6,210	6,440	6,680	6,950	7,240
	80	6,270	6,560	6,880	7,240	7,630
	85	6,330	6,710	7,130	7,600	8,150
	90	6,420	6,910	7,470	8,130	8,930

NOTE: For an explanation on how this table was developed, see appendix X1 of USBR 4094.

Table 4b. – Average strength that must be maintained to meet design requirements (SI-metric units).

Design strength (f'_c) MPa	Percent of strength greater than design strength	Average strength required (f_{cr}) in megapascals so that 75, 80, 85, or 90 percent of tests are greater than design strength (f'_c)				
		Coefficient of variation, percent				
		5	10	15	20	25
10	75	10.35	10.75	11.15	11.60	12.05
	80	10.45	10.95	11.45	12.05	12.70
	85	10.55	11.20	11.90	12.65	13.60
	90	10.70	11.50	12.45	13.55	14.90
15	75	15.55	16.10	16.70	17.35	18.10
	80	15.65	16.40	17.20	18.10	19.05
	85	15.85	16.75	17.80	19.00	20.35
	90	16.05	17.25	18.65	20.35	22.30
20	75	20.70	21.45	22.30	23.15	24.10
	80	20.90	21.85	22.95	24.10	25.45
	85	21.10	22.35	23.75	25.35	27.15
	90	21.40	23.00	24.90	27.10	29.75
25	75	25.90	26.85	27.85	28.95	30.15
	80	26.10	27.35	28.65	30.15	31.80
	85	26.40	27.95	29.70	31.70	33.95
	90	26.75	28.75	31.10	33.90	37.20
30	75	31.05	32.20	33.40	34.75	36.20
	80	31.35	32.80	34.40	36.20	38.15
	85	31.65	33.55	35.65	38.00	40.75
	90	32.10	34.55	37.35	40.65	44.65
35	75	36.25	37.55	39.00	40.55	42.20
	80	36.55	38.25	40.15	42.20	44.50
	85	36.95	39.15	41.60	44.35	47.55
	90	37.45	40.30	43.55	47.45	52.05
40	75	41.40	42.95	44.55	46.35	48.25
	80	41.80	43.75	45.90	48.25	50.85
	85	42.25	44.70	47.50	50.70	54.35
	90	42.80	46.05	49.80	54.20	59.50
45	75	46.60	48.30	50.15	52.10	54.25
	80	47.00	49.20	51.60	54.25	57.20
	85	47.50	50.30	53.45	57.05	61.10
	90	48.15	51.80	56.00	61.00	66.95
50	75	51.75	53.65	55.70	57.90	60.30
	80	52.25	54.65	57.35	60.30	63.55
	85	52.80	55.90	59.40	63.35	67.90
	90	53.50	57.55	62.25	67.75	74.40

Table 5. – Maximum water-cement plus pozzolan ratios for exposure condition (durability) shown.

Class	Type or location of concrete or structure, and degree of exposure	W/(C+P) by mass: Severe climate, wide range of temperature, long periods of freezing, or frequent freezing and thawing	W/(C+P) by mass: Mild climate, rainy or arid, rare snow or frost
A	Concrete in portions of structures subject to exposure of extreme severity such as bridge decks exposed to deicing salts; top 2 feet (0.6 m) of walls, boxes, piers, and parapets; all of curbs, sills, ledges, copings, corners, and cornices; and concrete in range of fluctuating water levels or spray such as parts of dams, spillways, wasteways, blowoff boxes, tunnel inlets and outlets, tailrace walls, valve houses, canal structures, and other concrete work.	0.45±0.02	0.55±0.02
B	Concrete in exposed structures and parts of structures where exposure is less severe than in A, such as portions of tunnel linings and siphons subject to freezing, exterior of mass concrete, and other exposed parts of structures not covered by A.	0.50±0.02	0.55±0.02
C	Concrete in structures or parts of structures to be covered with backfill or to be continually submerged or otherwise protected from weather, such as cutoff walls and foundations, and parts of substructures, dams, trashracks, gate chambers, outlet works, and control houses. If severe exposure during construction appears likely to last several seasons, reduce W/(C+P) by 0.05 for parts most exposed.	0.58±0.02	0.58±0.02
D	Concrete subject to attack by sulfate alkalies in soil and ground water, and placed during moderate weather.	–	0.50±0.02
E	Concrete subject to attack by sulfate alkalies in soil and ground water, but placed during freezing weather when calcium chloride would normally be used in mix. Do not employ $CaCl_2$, but decrease W/(C+P) value shown.	0.45±0.02	–
F	Concrete deposited under water using tremies or pumps.	0.45±0.02	–
G	Canal lining	0.53±0.02	0.58±0.02
H	Concrete for interior of dams	The W/(C+P) ratio for this concrete will be governed by strength, thermal properties, and volume change requirements established for each structure.	

9.3.6.1 *Percentage of Sand Method.*–Example 1 in section 9.3.7 uses the percentage of sand method. To use this method, first calculate volume of water, cement, pozzolan, and air per cubic yard or per cubic meter of concrete. Then, calculate total volume of aggregate by subtracting the volume of paste initially calculated. The volume of sand is obtained by multiplying total volume of aggregate by percentage of sand recommended in table 1. The volume of coarse aggregate is determined last, by subtracting volume of paste and sand from unity. If more than one nominal size fraction of coarse aggregate is used, it is desirable to determine the optimum proportion of each by density comparisons of various proportions of the combined nominal size fractions. Then, the volume of each nominal size of coarse aggregate is computed using the optimum percentages obtained by the comparison. Finally, the mass of each size aggregate is determined by multiplying volume of aggregate by bulk density of aggregate.

9.3.6.2 *Dry-Rodded or Dry-Jigged Density of Coarse Aggregate Method.*–Example 2 in section 9.3.7 uses this method. Initially, determine dry-rodded or dry-jigged density of the coarse aggregate. If more than one nominal size fraction of coarse aggregate is used, determine optimum proportion of each by density comparisons of various proportions of the combined nominal size fractions. Then, select percentage of dry-rodded or dry-jigged density of coarse aggregate per unit volume of concrete from table 1. Calculate mass of coarse aggregate per cubic yard or per cubic meter of concrete by multiplying this percentage by the optimum dry-rodded or dry-jigged density of the coarse aggregate. The volume of coarse aggregate is obtained by dividing this mass by the bulk density. To obtain the volume of sand, add volume of coarse aggregate to volume of paste and subtract from unity. The mass of the sand is obtained by multiplying volume of sand by bulk density of sand.

9.3.7 *Computations of Proportions and Batch Masses for Trial Mixes.*–Computations for determining the proportions for concrete mixes are initially based on the SSD (saturated-surface-dry) aggregates, and later adjusted for actual moisture conditions. The following materials and values shall be used for the computations:

- Water with a specific gravity of 1.00 and density of 1,685 lbm/yd^3 (1000 kg/m^3).
- Type II portland cement with a specific gravity of 3.15.
- Fly ash with a specific gravity of 2.50.
- Sand with a specific gravity of 2.63, fineness modulus of 2.75, and moisture content of 5.0 percent wet of SSD.
- Coarse aggregate with a specific gravity of 2.68. The No. 4 to 3/4-inch (4.75- to 19.0-mm) size fraction has a moisture content of 1.0 percent wet of SSD, and the 3/4- to 1-1/2-inch (19.0- to 37.5-mm) size fraction has a moisture content of 0.5 percent wet of SSD. The optimum combination of No. 4 to 1-1/2-inch (4.75- to 37.5-mm) aggregate is 45 percent 3/4-inch nominal MSA (maximum size aggregate) and 55 percent 1-1/2-inch nominal MSA.
- The dry-rodded or dry-jigged density of the combined No. 4 to 3-inch (4.75- to 75-mm) aggregate is 2,990 lbm/yd^3 (1774 kg/m^3).
- A neutralized, vinsol resin, air-entraining admixture. The manufacturer recommends 2 fluid ounces per 100 pounds (130 mL/100 kg) of the cementitious materials.

NOTE 2.–The conversion factor for fluid ounces to milliliters is 29.57.

9.3.7.1 *Example 1.*–This example, which uses the percentage of sand method, is shown in table 6 using inch-pound units. This example is a 1-1/2-inch nominal MSA concrete mix for a reinforced retaining wall having a minimum thickness of 12 inches (305 mm) and a minimum rebar spacing of 2.5 inches (64 mm). The concrete will be exposed to severe climatic conditions (many cycles of freezing and thawing) but will not often be saturated, which puts it into class B, see table 5. The structural design is based on 90 percent of the standard 6- by 12-inch (152- by 305-mm) test cylinders having 28-day compressive strengths greater than 4,000 lbf/in^2 (27.6 MPa). Average Bureau control, which is considered as having a coefficient of variation no more than 15 percent, requires an average 28-day strength of 4,980 lbf/in^2 (34.3 MPa), see table 4. When designing a mix with new materials or for a new batch plant or contractor, a coefficient of variation of 20 percent should be assumed similar to the recommendations in ACI 214.

9.3.7.2 *Example 2.*–This example, which uses the dry-rodded or dry-jigged density method, is shown in table 7 using SI metric units. This example is a 75-mm (3-inch) nominal MSA concrete mix for a pumping plant foundation having a minimum thickness of 610 mm (24 inches) and a minimum rebar spacing of 102 mm (4 inches). The concrete will be exposed to mild climatic conditions. The design is based on 80 percent of the 152- by 305-mm (6- by 12-inch) standard test cylinders having 28-day compressive strengths greater than 30.0 MPa (4,350 lbf/in^2). Assuming average Bureau control (coefficient of variation of 15 percent), requires an average 28-day strength of 34.4 MPa (4,990 lbf/in^2), see table 4. The contractor is required by the specifications to use a water reducing admixture. In addition, the contractor has elected to use a suitable fly ash to replace, by mass, 20 percent of the cement.

9.3.8 *Batch Masses.*–The trial-mix computations in sections 9.3.7.1 and 9.3.7.2 provided batch quantities for one cubic yard and one cubic meter of concrete. It is seldom possible to mix concrete in exactly one unit batches; therefore, these quantities must be converted to the size batch to be used. Figure 1 illustrates a convenient form for recording computations when converting design masses to batch masses. This conversion can be accomplished by multiplying unit quantity of each ingredient by volume of batch. For example, assume that a 0.10-cubic yard mixer is available for the laboratory trial mixes, and use the trial mix design of example 1, section 9.3.7.1. The batch proportions would be:

Water:	(0.10) (245) = 24.5 lbm
Cement:	(0.10) (557) = 55.7 lbm
Sand:	(0.10) (1,055) = 105.5 lbm
No. 4 to 3/4-inch aggregate:	(0.10) (939) = 93.9 lbm
3/4- to 1-1/2-inch aggregate:	(0.10) (1,147) = 114.7 lbm

Aggregates were assumed to be in SSD condition for initial computations. Under field conditions, the aggregates would generally be moist (due to sprinkling stock piles and the use of spray bars on rescreens) and quantities to be batched must be adjusted accordingly. Assume tests show sand contains 5.0 percent free moisture, No. 4 to 3/4-inch aggregate contains 1.0 percent free moisture, and 3/4- to 1-1/2-inch aggregate contains 0.5 percent free moisture. Since the quantity of SSD sand required is 105.5 lbm, the amount of moist sand that must be determined is 110.8 lbm (105.5)(1.05). Similarly, the mass of moist coarse aggregate that must be determined is 94.8 lbm (93.9)(1.01) and 115.3 lbm (114.7)(1.005), respectively. Coarse aggregate is sometimes drier than SSD. Assuming the 3/4- to 1-1/2-inch

Table 6. - Example 1, computation of trial mix using percentage of sand method.

Mix ingredients	Mass, lbm/yd³	Conversion of mass to volume	Conversion of volume to mass	Solid volume, yd³/yd³ of concrete
Water:				
Estimated value from table 1 for a 3- to 4-inch slump at mixer = 245	245	$\frac{245}{1,685}$	-	0.145
Cement:				
W/C for durability, class B, from table 5 = 0.50				
W/C for strength, from table 2 = 0.44				
(Strength controls, use 0.44)				
Cement = $\frac{\text{water}}{W/C} = \frac{245}{0.44} = 557$	557	$\frac{557}{(3.15)(1,685)}$	-	0.105
Air:				
From table 1 = 5% = 0.050	-	-	-	0.050
Sand:				
From table 1 = 34% of volume of aggregate = [1.000-(0.145+0.105+0.050)](0.34) = (0.700)(0.34) = 0.238	1,055	-	(0.238)(2.63)(1,685)	0.238
Coarse Aggregate:				
Volume of all ingredients except coarse aggregate = 0.145+0.105+0.050+0.238 = 0.538				
Coarse aggregate = 1.000-0.538 = 0.462				
3/4-inch nominal MSA = 45% of coarse aggregate volume = (0.45)(0.462) = 0.208	939	-	(0.208)(2.68)(1,685)	0.208
1-1/2-inch nominal MSA = 55% of coarse aggregate volume = (0.55)(0.462) = 0.254	1,147	-	(0.254)(2.68)(1,685)	0.254
Totals	3,943	-	-	1.000

Note: W/C = water-cement ratio
MSA = maximum size aggregate

aggregate contains -0.5 percent free moisture (aggregate will absorb 0.5 percent moisture to reach SSD condition), the amount of dry aggregate that must be determined is 114.1 lbm (114.7)(0.995). Free water in the aggregate must be considered as part of the mixing water and theoretically removed from the quantity of water to be batched. Conversely, in the case of dry aggregate, water must be added to allow for absorption. In this example, the free water (mixing water) in the sand is 5.3 lbm, 110.8–105.5; the No. 4 to 3/4-inch aggregate contains 0.9 lbm, 94.8–93.9; and the 3/4- to 1-1/2-inch aggregate contains 0.6 lbm, 115.3–114.7. If the 3/4- to 1-1/2-inch aggregate were dry as mentioned previously, 0.6 lbm (114.7–114.1) of water would have to be added to the batch water to allow for absorption.

NOTE 3.–Theoretically, the aggregate masses should be reduced to a dry basis by dividing batching mass by 1 plus the percentage of moisture (as a decimal), determining quantity of water required to satisfy absorption, and then bringing material back to a SSD basis (mix design criteria). The method developed in this procedure for use in designing mixes based on SSD criteria eliminates several steps in determining the amount of added water; the magnitude of the error is so small that it will not affect the adequacy of the mix design. When designing low density concrete with low density aggregate and a high percentage of absorption, this error could be more significant.

9.3.9 *Adjustments to Trial Mix.*–When working with materials that the personnel involved have little or no experience with, several trial mixes will usually be necessary

Table 7. – Example 2, computation of trial mix using dry-rodded or dry-jigged density method.

Mix ingredients	Mass, kg/m³	Conversion of mass to volume	Conversion of volume to mass	Solid volume, m³/m³ of concrete
Water: Estimated value from table 1 = 120–13=107 (–5% when WRA is used, and –3% for every 10% of fly ash used)	107	$\frac{107}{1000}$	–	0.107
Cementitious Materials: W/(C+P) for durability, class C, from table 5=0.58				
W/(C+P) for strength from table 2 = 0.49–0.05=0.44 (reduce W/(C+P) by 0.05 when pozzolan is used)				
(Strength controls, use 0.44)				
Cementitious materials $= \frac{\text{water}}{W/(C+P)} = \frac{107}{0.44} = 243$				
Portland cement = 80% = (243)(0.80) = 194	194	$\frac{194}{(315)(1000)}$	–	0.062
Pozzolan =20%=(243)(0.20)=49	49	$\frac{49}{(2.50)(1000)}$	–	0.020
Air: From table 1 = 4.0% = 0.040	–	–	–	0.040
Coarse Aggregate: From table 1 =81+4=85 (+2% for every 10% of portland cement replaced by fly ash) Then, 85% of dry-rodded or dry-jigged density of coarse aggregate per unit mass of concrete =(0.85)(1744)=1482	1482	$\frac{1482}{(2.68)(1000)}$	–	0.553
Sand: Volume of all ingredients except sand =0.107+0.062+0.020+0.040+0.553=0.782 Sand = 1.000–0.782=0.218	573	–	(0.218)(2.63)(1000)	0.218
Totals	2405	–	–	1.000

Note: W/(C + P) = Water-cement plus pozzolan ratio.
WRA=Water-reducing admixture.

to establish the correct quantities, especially the water requirement and air-entraining admixture dosage. After the actual water requirement is established for the job materials, the mix must be redesigned by repeating the computations previously discussed beginning with the amount of cement. Figure 1 illustrates a convenient form for recording trial mix data. The data presented on figure 1a conform to the trial batches of example 1 (sec. 9.3.7.1) with appropriate adjustments made to the mix after testing the slump, entrained air content, and yield.

9.3.9.1 *Adjustment of Water.*–After performing tests on the fresh concrete and calculating actual composition of batch based on the yield, the mix should now be redesigned. Assume first trial batch had only a 2-inch slump and 4.0 percent air. Table 1 indicates that to increase the slump by the desired 1.5 inches, an increase in water content of 4.5 percent is necessary, 1.5 times 3 percent. Similarly, when increasing air content 1.0 percent, an adjustment in water content must be made. Because entrained air improves workability and consequently increases slump, this adjustment will be a decrease in water content of 3.0 percent, 1.0 times 3 percent. These two adjustments occur simultaneously and result in a net increase of 1.5 percent to the actual quantity of batch water used, (1.015)(248)=252 lbm.

9.3.9.2 *Adjustment of Air-Entraining Admixture.*–The percentage of entrained air in the mix can be measured directly with an air meter or obtained by computing the difference between the calculated (theoretical) volume of air and the measured volume. It is advantageous to record both air contents because any marked difference indicates an error and may lead to discovery of mistakes in mix design, trial mix computations, or test methods. A difference in the indicated air contents of as much as 0.3 percent is considered normal. The amount of air-entraining admixture required to produce the desired 5.0 percent can be easily calculated by assuming a straight-line adjustment of the dosage. Since 333 mL produced 4.0 percent air and 5.0 percent is desired, then (5.0/4.0)(333) or 416 mL should be used in trial batch number 2.

9.3.9.3 *Adjustment of Aggregate Proportions.*–It is usually necessary to adjust the aggregate proportions. This adjustment will be a judgment based on intended use of concrete mix and method of placement. If concrete mix appears too harsh or does not consolidate or finish well, the sand and fines should be increased. If mix appears too fat or is sticky, the mortar should be decreased.

9.3.9.4 *Adjustment of Water-Cementitious Materials Ratio.*–Once concrete strengths are known by testing cylinders cast from the mix, it will be necessary to adjust the water-cement plus pozzolan ratio to achieve the proper strength level consistent with the coefficient of variation. The average strengths obtained from the test cylinders may need to be increased by redesigning the mix with a lower ratio. Conversely, if strengths are above the average strength required (f_{cr}), the ratio may need to be higher to improve economy of mix. The field mix need not be adjusted for minor fluctuations in the ratio. A difference of ±0.02 is considered normal, and usually results from maintaining a constant slump. However, this variation should be considered when selecting the ratio so that, with the usual variation, the specified maximum is not exceeded.

MASS CONCRETE MIX PROPORTIONING

10. Scope

10.1 *Introduction.*–Mass concrete is defined as "any volume of concrete with dimensions large enough to require that measures be taken to allow for generation of heat of hydration from the cement and pozzolan and attendant volume change to minimize cracking" [26]. The purpose of the mass concrete proportioning procedure is to combine the available cementitious materials, water, fine and coarse aggregates, and admixtures such that the resulting mixture will not exceed some established allowable temperature rise and shall also meet requirements for strength and durability. In some cases, two mixtures may be required—an interior mass concrete, and an exterior concrete for resistance to the various conditions of exposure. Accordingly, the concrete technologists and designers should consider the effects of temperature on the properties of concrete during the design stage. For example, a 6-inch (152-mm) wall will dissipate generated heat quite readily, but as thickness and size of placement increase, a point is reached where the rate of heat generated far exceeds the rate of heat dissipated. This phenomenon produces a temperature rise within the concrete and may cause sufficient temperature differential between the interior and exterior of the mass or between the peak and ultimate stable temperatures to induce tensile stresses. The temperature differential between the interior and exterior of the concrete, generated by decreases in ambient air temperature conditions, may cause cracking at exposed surfaces. Also, as concrete reaches its peak temperature and subsequent cooling takes place, tensile stresses are induced by the cooling if the change in volume is restrained by the foundation or connections to other parts of the structure. The tensile stress developed by these conditions can be expressed by the equation:

$$S = REeT \qquad (1)$$

where:

S = tensile stress,
R = restraint factor,
E = modulus of elasticity,
e = thermal coefficient of expansion, and
T = temperature difference between interior and exterior of concrete, or temperature difference between concrete at maximum temperature and at ambient air temperature.

Detailed discussions on mass concrete can be found in references [22,23,24,25,28].

10.1.1 The thermal cracking of bridge piers, foundations, floor slabs, beams, columns, and other massive structures (powerplants and dams) may reduce the service life of a structure by promoting early deterioration or excessive maintenance. Furthermore, it should be recognized that the selection of proper mixture proportions is only one means of controlling temperature rise, and that other aspects of the concrete work should be studied and incorporated into the design and construction requirements. For additional information on heat problems and solutions, consult references [23, 28].

10.2 *Mass Concrete Properties.*–During the design stage of the proposed project, desired specified compressive strengths with adequate safety factors for various portions of the structure are normally first established. The designer will then expand on the other desired properties required of the concrete. The proportioning of ingredients to ensure that a mass concrete mixture will have the desired properties requires an evaluation of the materials to be used. If adequate data are not available from recent construction projects using the proposed materials, representative samples of all materials proposed for use must be tested to determine their properties and conformance with applicable specifications.

11. Properties of Materials Related to Heat Generation

11.1 *Cementitious Materials.*–The cementitious materials for mass concrete work may consist of portland cement or blended hydraulic cements as specified in ASTM C 150 and C 595, respectively, or a combination of portland cement and pozzolan. Pozzolans are specified in ASTM C 618.

11.1.1 *Portland Cement*.–The hydration of portland cement is exothermic; that is, heat is generated during the reaction of cement and water. The quantity of heat produced is a function of the chemical composition of the cement and the initial temperature, as shown on figure 2. Type II cement is most commonly used in mass concrete because it is a moderate heat cement and generally has favorable properties for most types of construction. When used with a pozzolanic material, which will be discussed later, the heat generated by the combination of type II cement and pozzolan is comparable to that of type IV cement. In addition, type II cement is more readily available than type IV. Optional heat of hydration requirements may be specified for type II cement by limiting the chemical compounds or actual heat of hydration at 7 days. A low initial concrete placing temperature, commonly used in mass concrete work, will generally decrease the rate of cement hydration and initial heat generated. Correspondingly, strength development in the first few days may also be reduced. The fineness of the cement also affects the rate of heat of hydration; however, it has little effect on the final heat generated. Fine-ground cements will produce heat more rapidly during the early ages than coarse-ground cement, all other cement properties being equal.

11.1.2 *Blended Hydraulic Cements.*–Type 1P blended hydraulic cements conforming to requirements of ASTM C 595 may be used effectively in mass concrete. These cements are composed of a blend of portland cement and pozzolan. The suffix (MH) or (LH) may be used with the designated type of blended cement to specify moderate heat or low heat requirements where applicable.

11.1.3 *Pozzolans.*–Major economic and temperature rise benefits have been derived from the use of pozzolans. Pozzolan is defined as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds that possess cementitious properties" [26], (note 4). Natural pozzolans include some diatomaceous earths, opaline cherts and shales, tuffs, and volcanic ashes or pumicites, any of which may or may not be processed by calcination, and other various materials requiring calcination to induce satisfactory properties such as some clays and shales. Fly ash, the finely divided residue that results from the combustion of ground or powdered coal and transported from combustion chamber by exhaust gases, is also a pozzolan. Fly ashes meeting the ASTM definition for a class C pozzolan in addition to having pozzolanic properties also have some cementitious properties. The use of pozzolans in concrete provides a partial replacement of the cement with a material that generates considerably less heat at early ages. The early-age heat contribution of a class N or F pozzolan may conservatively be estimated to range between 15 and 50 percent of that of an equivalent mass of cement.

NOTE 4.–Pozzolanic properties are defined as "the ability to combine with the free lime released in the hydration of cement and to then act as a cementing agent."

11.1.3.1 The effects of a pozzolan on the properties of freshly mixed concrete vary with the type and fineness; chemical, mineralogical, and physical characteristics of the pozzolan; fineness and composition of the cement; ratio of cement to pozzolan; and mass of the cement plus pozzolan used per unit volume of concrete. For example, it has been reported that some pozzolans may reduce water requirements by as much as 7 percent and may reduce the amount of air-entraining admixture required by as much as 20 percent. Because certain other pozzolans may require as much as 15 percent additional water and over 60 percent more air-entraining admixture, it is important to evaluate the pozzolan intended for use prior to the start of the proportioning.

11.1.3.2 The proportion of cement to pozzolan depends upon the strength desired at a given age, heat considerations, chemical and physical characteristics of both cement and pozzolan, and the cost of the respective materials.

11.1.4 *Aggregates.*–The largest aggregates recommended for use under various placing conditions should be used. A nominal maximum size aggregate up to 6 inches (150 mm) should be considered if large size aggregate is available, is economical, and placing conditions permit. Because larger aggregate provides less surface area to be coated by the cement paste, a reduction in the quantity of cement and water can be realized for the same water-cement plus pozzolan ratio.

11.1.4.1 *Coarse Aggregate Combination.*–After determining the nominal maximum size, the individual aggregate size groups available should be combined to produce a gradation approaching maximum density and minimum voids. This results in the maximum amount of mortar available for placeability, workability, and finishability. The dry-rodded or dry-jigged density method is the recommended procedure. If this procedure is not followed, table 8 may be helpful for combining the individual aggregate size fractions to approximate the ideal curve. This table is based on the work by Fuller and Thompson [27] on the packing characteristics of particulate materials. The ideal combined gradings for 3- and 6-inch (75- and 150-mm) crushed and rounded

Table 8. – Idealized combined coarse aggregate grading for 3- and 6-inch (75- and 150-mm) nominal maximum size aggregate.

Sieve size	6 inches (150 mm) Percent Retained Crushed	6 inches (150 mm) Percent Retained Rounded	3 inches (75 mm) Percent Retained Crushed	3 inches (75 mm) Percent Retained Rounded
6 inches (150 mm)	0	0	–	–
5 inches (125 mm)	15	11	–	–
4 inches (100 mm)	15	11	–	–
3 inches (75 mm)	16	14	0	0
2 inches (50 mm)	16	15	31	25
1-1/2 inches (37.5 mm)	10	10	17	14
1 inch (25.0 mm)	9	11	18	17
3/4 inch (19.0 mm)	6	7	9	11
3/8 inch (9.5 mm)	8	12	16	19
No. 4 (4.75 mm)	5	9	9	14

aggregates are shown in table 8. An acceptable grading for an aggregate that is partially crushed or partially rounded may be interpolated from this table. Using the individual gradation of each size group, 3 to 6 inches (75 to 150 mm), 1-1/2 to 3 inches (37.5 to 75 mm), 3/4 to 1-1/2 inches (19.0 to 37.5 mm), and No. 4 to 3/4 inch (4.75 to 19.0 mm), a trial and error method of selecting the percentage of each size group will be necessary to produce a combined grading of the total coarse aggregate approximating the idealized gradation. Selection of this percentage can usually be done such that the combined grading is generally within 2 or 3 percent of the ideal grading.

11.1.4.2 *Coarse Aggregate Content.*–The proportion of fine aggregate for mass concrete depends on the final combined grading of coarse aggregate, particle shape, fineness modulus of fine aggregate, and quantity of cementitious material. The coarse aggregate amount can be found using the sand percentage method or the dry-rodded or dry-jigged density of coarse aggregate method described in section 9.3.6.

11.1.5 *Admixtures.*–When proportioning mass concrete, the use of admixtures should always be considered. The two most commonly used admixtures in mass concrete are the air-entraining and water-reducing admixtures.

11.1.5.1 *Air Entrainment.*–Air entrainment meeting the requirements of ASTM C 260 in mass concrete is necessary if for no other reason than to increase the workability of lean concrete mixtures. The use of air entrainment in mass concrete, as in other concrete, permits a marked improvement in durability, improvement in plasticity and workability, and reduction in segregation and bleeding. The effect of air entrainment on the strength of mass concrete is minimized due to the reduction in the quantity of paste in concrete which contains 3- and 6-inch (75- and 150-mm) nominal maximum size aggregate. However, such effects should be considered in the design of mass concrete having 3/4- or 1-1/2-inch (19.0- or 37.5-mm) nominal maximum size aggregate. In the lean mixtures, strengths are not reduced as much when air entrainment is used and, in some cases, strengths may increase due to the reduction in mixing water requirements with air entrainment. Air contents should be in accordance with those recommended in table 1.

11.1.5.2 *Water-Reducing Admixture.*–Water-reducing admixtures meeting the requirements of ASTM C 494 have been found effective in mass concrete mixtures. The water reduction permits a corresponding reduction in the cementitious materials content while maintaining a constant water-cement plus pozzolan ratio. The amount of water reduction will vary with different concrete materials and different types of admixtures; however, 5 to 8 percent is normal. In addition, certain types of water-reducing admixtures tend to improve the mobility of concrete and its response to vibration, particularly in large aggregate mixtures.

12. Strength

12.1 The procedure for proportioning mass concrete is used primarily for controlling the generation of heat and temperature rise and still meet the requirements for strength and durability. The strength properties are primarily governed by the water-cementitious materials ratio. This is the ratio, by mass, of the amount of water (exclusive of that absorbed by aggregates) to the amount of cement and pozzolan in the concrete. Unless previous water-cement plus pozzolan ratios and compressive strength data are available, the approximate 28-day compressive strength for concrete tested using 6- by 12-inch (152- by 305-mm) cylinders for various water-cement ratios can be estimated from table 2. If compressive strength designs are given for the full mass mixture containing aggregate larger than 1-1/2-inches (37.5 mm), approximate relationships between the strength of the full mass mixture at ages up to 1 year and wet-screened 6- by 12-inch cylinders can be obtained using figure 3.

12.2 Design strengths of mass concrete are often based on ages other than 28 days to take advantage of the slower strength-producing and lower heat-producing properties desirable in mass concrete. Figure 4 shows rates of strength development for concrete made with various types of portland cement. Tests were not performed on concrete containing pozzolan or blended cement; however, experience has shown that concrete containing type II cement and 15 to 25 percent fly ash replacement develops strength beyond 28 days at a rate similar to the curve plotted for concrete containing type IV cement.

13. Durability

13.1 The recommended maximum permissible water-cement plus pozzolan ratio for concrete subject to various conditions of exposure are shown in table 5. Sometimes, the ratio required to obtain adequate strength or durability governs the proportions rather than heat generation. When this situation occurs, alternative measures to control heat are necessary. For example in gravity dam construction, an exterior-facing mix containing additional cementitious materials may be used to provide the required durability. Other measures may include a reduction in the initial concrete temperature at placement, a limitation on size of placements, or heat dissipative measures such as embedment of cooling pipes and circulation of cool water within the pipes.

14. Calculations

14.1 Refer to section 9 and figure 1.

15. Report

15.1 Figure 1, along with a cover letter, shall serve as a reporting form for this procedure.

16. Precision and Bias

16.1 The precision and bias statements for this procedure have not been established at this time.

17. References

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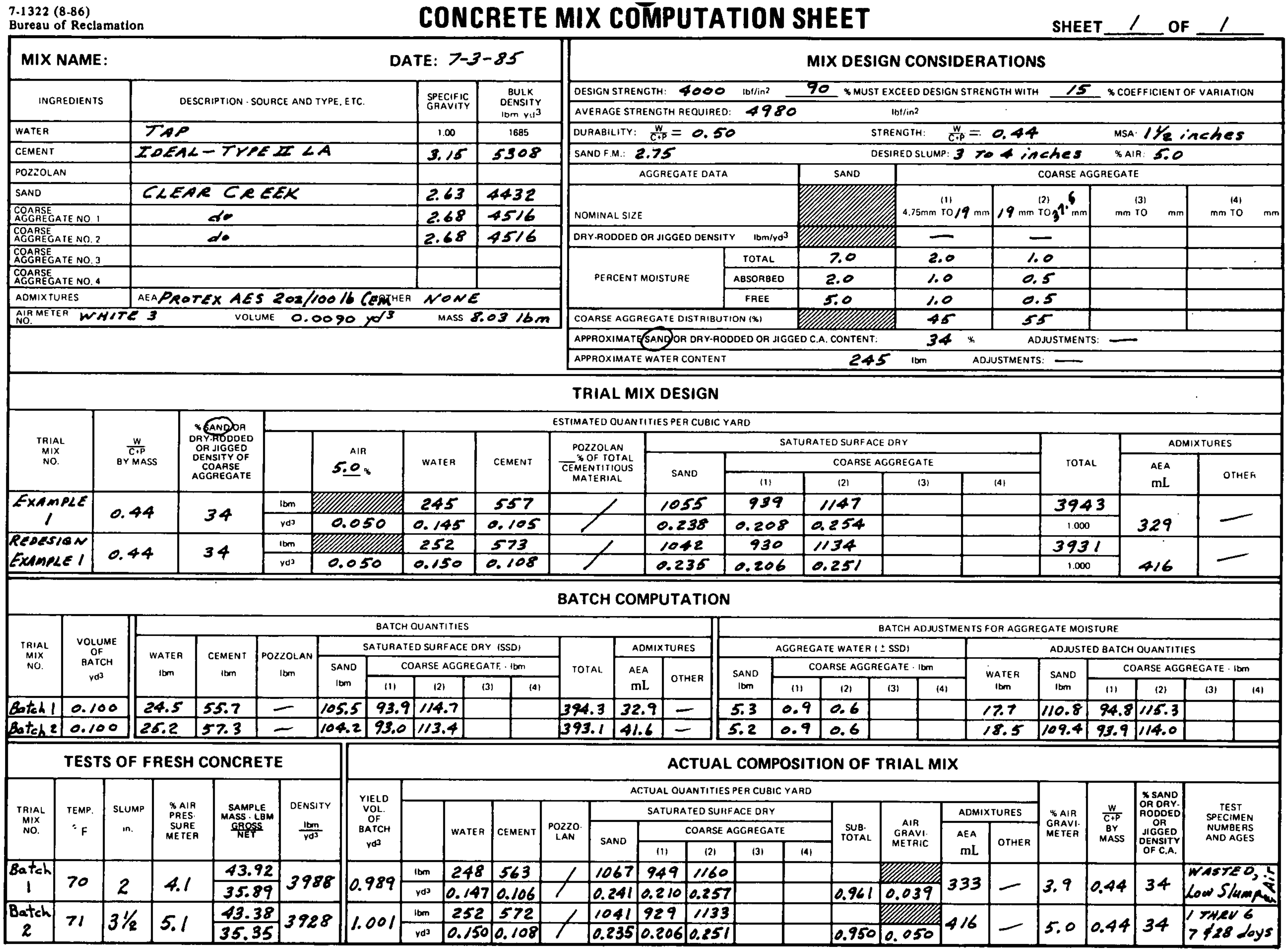


7-1322 (8-86)
Bureau of Reclamation

CONCRETE MIX COMPUTATION SHEET

SHEET / OF /

MIX NAME: DATE: 7-3-85

INGREDIENTS	DESCRIPTION - SOURCE AND TYPE, ETC.	SPECIFIC GRAVITY	BULK DENSITY lbm yd³
WATER	TAP	1.00	1685
CEMENT	IDEAL - TYPE II LA	3.15	5308
POZZOLAN			
SAND	CLEAR CREEK	2.63	4432
COARSE AGGREGATE NO. 1	do	2.68	4516
COARSE AGGREGATE NO. 2	do	2.68	4516
COARSE AGGREGATE NO. 3			
COARSE AGGREGATE NO. 4			
ADMIXTURES	AEA PROTEX AES 202/100 lb CEM OTHER NONE		

AIR METER NO. WHITE 3 VOLUME 0.0090 yd³ MASS 8.03 lbm

MIX DESIGN CONSIDERATIONS

DESIGN STRENGTH: 4000 lbf/in² 90 % MUST EXCEED DESIGN STRENGTH WITH 15 % COEFFICIENT OF VARIATION

AVERAGE STRENGTH REQUIRED: 4980 lbf/in²

DURABILITY: $\frac{W}{C+P} = 0.50$ STRENGTH: $\frac{W}{C+P} = 0.44$ MSA: 1½ inches

SAND F.M.: 2.75 DESIRED SLUMP: 3 TO 4 inches % AIR: 5.0

AGGREGATE DATA		SAND	COARSE AGGREGATE (1)	(2)	(3)	(4)
NOMINAL SIZE		▨	4.75mm TO 19 mm	19 mm TO 31.6 mm	mm TO mm	mm TO mm
DRY-RODDED OR JIGGED DENSITY lbm/yd³		▨	—	—		
PERCENT MOISTURE	TOTAL	7.0	2.0	1.0		
	ABSORBED	2.0	1.0	0.5		
	FREE	5.0	1.0	0.5		
COARSE AGGREGATE DISTRIBUTION (%)		▨	45	55		

APPROXIMATE [✓ SAND] OR DRY-RODDED OR JIGGED C.A. CONTENT: 34 % ADJUSTMENTS: —

APPROXIMATE WATER CONTENT 245 lbm ADJUSTMENTS: —

TRIAL MIX DESIGN

ESTIMATED QUANTITIES PER CUBIC YARD

TRIAL MIX NO.	$\frac{W}{C+P}$ BY MASS	% [✓ SAND] OR DRY-RODDED OR JIGGED DENSITY OF COARSE AGGREGATE		AIR 5.0 %	WATER	CEMENT	POZZOLAN __% OF TOTAL CEMENTITIOUS MATERIAL	SATURATED SURFACE DRY: SAND	COARSE AGGREGATE (1)	(2)	(3)	(4)	TOTAL	ADMIXTURES: AEA mL	OTHER
EXAMPLE 1	0.44	34	lbm	▨	245	557	/	1055	939	1147			3943	329	—
			yd³	0.050	0.145	0.105		0.238	0.208	0.254			1.000		
REDESIGN EXAMPLE 1	0.44	34	lbm	▨	252	573	/	1042	930	1134			3931	416	—
			yd³	0.050	0.150	0.108		0.235	0.206	0.251			1.000		

BATCH COMPUTATION

BATCH QUANTITIES

TRIAL MIX NO.	VOLUME OF BATCH yd³	WATER lbm	CEMENT lbm	POZZOLAN lbm	SATURATED SURFACE DRY (SSD): SAND lbm	COARSE AGGREGATE - lbm (1)	(2)	(3)	(4)	TOTAL	ADMIXTURES: AEA mL	OTHER
Batch 1	0.100	24.5	55.7	—	105.5	93.9	114.7			394.3	32.9	—
Batch 2	0.100	25.2	57.3	—	104.2	93.0	113.4			393.1	41.6	—

BATCH ADJUSTMENTS FOR AGGREGATE MOISTURE

TRIAL MIX NO.	AGGREGATE WATER (± SSD): SAND lbm	COARSE AGGREGATE - lbm (1)	(2)	(3)	(4)	ADJUSTED BATCH QUANTITIES: WATER lbm	SAND lbm	COARSE AGGREGATE - lbm (1)	(2)	(3)	(4)
Batch 1	5.3	0.9	0.6			17.7	110.8	94.8	115.3		
Batch 2	5.2	0.9	0.6			18.5	109.4	93.9	114.0		

TESTS OF FRESH CONCRETE

TRIAL MIX NO.	TEMP. °F	SLUMP in.	% AIR PRESSURE METER	SAMPLE MASS - LBM GROSS NET	DENSITY lbm/yd³
Batch 1	70	2	4.1	43.92 35.89	3988
Batch 2	71	3½	5.1	43.38 35.35	3928

ACTUAL COMPOSITION OF TRIAL MIX

ACTUAL QUANTITIES PER CUBIC YARD

TRIAL MIX NO.	YIELD VOL. OF BATCH yd³		WATER	CEMENT	POZZOLAN	SATURATED SURFACE DRY: SAND	COARSE AGGREGATE (1)	(2)	(3)	(4)	SUBTOTAL	AIR GRAVIMETRIC	ADMIXTURES: AEA mL	OTHER	% AIR GRAVIMETER	$\frac{W}{C+P}$ BY MASS	% SAND OR DRY-RODDED OR JIGGED DENSITY OF C.A.	TEST SPECIMEN NUMBERS AND AGES
Batch 1	0.989	lbm	248	563	/	1067	949	1160				▨	333	—	3.9	0.44	34	WASTED, Low Slump, AIR
		yd³	0.147	0.106		0.241	0.210	0.257			0.961	0.039						
Batch 2	1.001	lbm	252	572	/	1041	929	1133				▨	416	—	5.0	0.44	34	1 THRU 6 7 & 28 days
		yd³	0.150	0.108		0.235	0.206	0.251			0.950	0.050						

Figure 1a. - Sample concrete mix computation sheet (inch-pound units) (sheet 1 of 2).

INSTRUCTIONS FOR THE USE OF THE CONCRETE MIX COMPUTATION SHEET, FORM NO. 7-1322

NOTE: The accuracy of any number to be recorded is determined as follows:
(1) Densities within 1 lbm/yd^3
(2) Masses within Scale Accuracy
(3) (B) Volumes within 0.001 yd^3

1. The MIX NAME should be a maximum of 10 character spaces, for computer system-PCQCS, with the spaces to be used as follows: (1 2 3 4 5 6 7 8 9 10)

(A) Spaces number 1 and 2 identify the source name of the coarse aggregate.
(B) Spaces 3 and 4 are the percent sand in the mix.
(C) Spaces 5 and 6 are the water/cement-plus-pozzolan (W/C+P) ratio without the decimal point.
(D) Space 7 is a hyphen (-).
(E) Spaces 8, 9, and 10 are the slump and are left justified.
(F) Space 10 may be used for a mix additive (if not used for slump) or a change in the mix not involving % sand, W/C+P, or slump. It is to be used for any two mixes that have the same first nine numbers. The symbol to be used is optional.

Example: Coarse aggregate from Clear Creek
33% sand
0.45 water-cementitious ratio
3 in. slump
C C 3 3 4 5 - 3 _ _

Example: Coarse aggregate from Clear Creek
33% sand
0.45 water-cementitious ratio
3 in. slump
Added an Accelerator
C C 3 3 4 5 - 3 _ A

2. MIX DESIGN CONSIDERATIONS information is obtained from Tables 1, 2, 3, and 5 of USBR Procedure 4211, Vol. 2, of the Concrete Manual and from tests run on the aggregate. The percent free moisture is to be recorded as zero when SSD, plus when greater than SSD, and minus when less than SSD. AVERAGE STRENGTH REQUIRED can be found in table 4a, USBR Procedure 4211.

3. TRIAL MIX DESIGN COMPUTATIONS are outlined in Section 9 and table 6, USBR Procedure 4211.

4. BATCH CONPUTATIONS are outlined in Section 9 and table 6, USBR Procedure 4211.

5. Under TESTS OF FRESH CONCRETE, Sample Mass is the mass of a known volume of concrete (i.e., air meter bucket of 1/4 ft^3 or 1/2 ft^3). Gross Mass includes the mass of the container and Net Mass is the Gross Mass minus the mass of the container.

6. DENSITY of the fresh concrete is obtained by dividing the Net Mass (described in 5) by the volume of the container. The volume of the container must be in cubic yards.

7. YIELD VOLUME OF BATCH is found by dividing the TOTAL OF SSD BATCH QUANTITIES by the DENSITY of the fresh concrete.

8. Under ACTUAL QUANTITIES PER CUBIC YARD, the mass values are obtained by dividing the actual quantities batched by YIELD VOLUME OF BATCH.

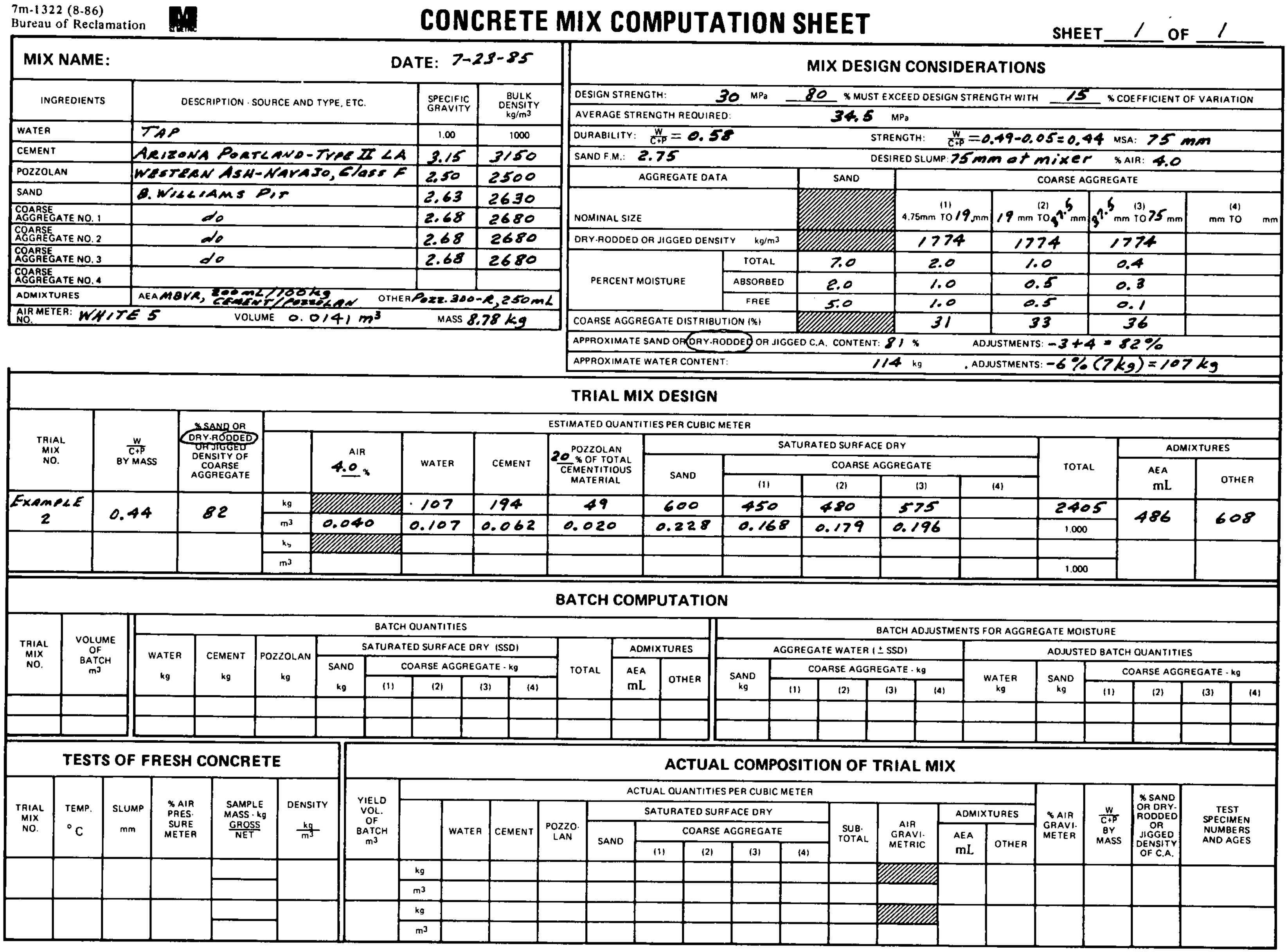
As a check, the mass under Sub-Total should approximate the number representing the DENSITY of the fresh concrete. The volume values are obtained by dividing the mass value of an ingredient by its density.

9. The AIR GRAVIMETRIC volume is obtained by subtracting the volume sub-total from 1.000. The % AIR GRAVIMETRIC is found by multiplying the AIR GRAVIMETRIC volume by 100.

MIX NOTES ____________________

☆ U.S. Government Printing Office: 1986—676-018/42029

Figure 1a. - Sample concrete mix computation sheet (inch-pound units) (sheet 2 of 2).



7m-1322 (8-86)
Bureau of Reclamation

CONCRETE MIX COMPUTATION SHEET

SHEET / OF /

MIX NAME: DATE: 7-23-85

INGREDIENTS	DESCRIPTION · SOURCE AND TYPE, ETC.	SPECIFIC GRAVITY	BULK DENSITY kg/m³
WATER	TAP	1.00	1000
CEMENT	ARIZONA PORTLAND-TYPE II LA	3.15	3150
POZZOLAN	WESTERN ASH-NAVAJO, Class F	2.50	2500
SAND	B. WILLIAMS PIT	2.63	2630
COARSE AGGREGATE NO. 1	do	2.68	2680
COARSE AGGREGATE NO. 2	do	2.68	2680
COARSE AGGREGATE NO. 3	do	2.68	2680
COARSE AGGREGATE NO. 4			
ADMIXTURES	AEA MBVR, 200 mL/100 kg CEMENT/POZZOLAN OTHER Pozz. 300-R, 250 mL		

AIR METER: NO. WHITE 5 VOLUME 0.0141 m³ MASS 8.78 kg

MIX DESIGN CONSIDERATIONS

DESIGN STRENGTH: 30 MPa 80 % MUST EXCEED DESIGN STRENGTH WITH 15 % COEFFICIENT OF VARIATION

AVERAGE STRENGTH REQUIRED: 34.5 MPa

DURABILITY: $\frac{W}{C+P} = 0.58$ STRENGTH: $\frac{W}{C+P} = 0.49 - 0.05 = 0.44$ MSA: 75 mm

SAND F.M.: 2.75 DESIRED SLUMP: 75 mm at mixer % AIR: 4.0

AGGREGATE DATA		SAND	COARSE AGGREGATE (1)	COARSE AGGREGATE (2)	COARSE AGGREGATE (3)	COARSE AGGREGATE (4)
NOMINAL SIZE		▨	4.75 mm TO 19 mm	19 mm TO 37.5 mm	37.5 mm TO 75 mm	mm TO mm
DRY-RODDED OR JIGGED DENSITY kg/m³		▨	1774	1774	1774	
PERCENT MOISTURE	TOTAL	7.0	2.0	1.0	0.4	
	ABSORBED	2.0	1.0	0.5	0.3	
	FREE	5.0	1.0	0.5	0.1	
COARSE AGGREGATE DISTRIBUTION (%)		▨	31	33	36	

APPROXIMATE SAND OR [✓ DRY-RODDED] OR JIGGED C.A. CONTENT: 81 % ADJUSTMENTS: -3+4 = 82%

APPROXIMATE WATER CONTENT: 114 kg, ADJUSTMENTS: -6% (7 kg) = 107 kg

TRIAL MIX DESIGN

ESTIMATED QUANTITIES PER CUBIC METER

TRIAL MIX NO.	$\frac{W}{C+P}$ BY MASS	% SAND OR [✓ DRY-RODDED] OR JIGGED DENSITY OF COARSE AGGREGATE		AIR 4.0 %	WATER	CEMENT	POZZOLAN 20 % OF TOTAL CEMENTITIOUS MATERIAL	SATURATED SURFACE DRY SAND	SSD COARSE AGGREGATE (1)	(2)	(3)	(4)	TOTAL	ADMIXTURES AEA mL	ADMIXTURES OTHER
EXAMPLE 2	0.44	82	kg	▨	107	194	49	600	450	480	575		2405	486	608
			m³	0.040	0.107	0.062	0.020	0.228	0.168	0.179	0.196		1.000		
			kg	▨											
			m³										1.000		

BATCH COMPUTATION

TRIAL MIX NO.	VOLUME OF BATCH m³	BATCH QUANTITIES: WATER kg	CEMENT kg	POZZOLAN kg	SSD SAND kg	SSD COARSE AGGREGATE - kg (1)	(2)	(3)	(4)	TOTAL	ADMIXTURES AEA mL	ADMIXTURES OTHER	BATCH ADJUSTMENTS FOR AGGREGATE MOISTURE: AGGREGATE WATER (± SSD) SAND kg	AGGREGATE WATER COARSE AGGREGATE - kg (1)	(2)	(3)	(4)	ADJUSTED BATCH QUANTITIES: WATER kg	SAND kg	COARSE AGGREGATE - kg (1)	(2)	(3)	(4)

TESTS OF FRESH CONCRETE

TRIAL MIX NO.	TEMP. °C	SLUMP mm	% AIR PRESSURE METER	SAMPLE MASS - kg GROSS / NET	DENSITY kg/m³

ACTUAL COMPOSITION OF TRIAL MIX

ACTUAL QUANTITIES PER CUBIC METER

YIELD VOL. OF BATCH m³		WATER	CEMENT	POZZOLAN	SATURATED SURFACE DRY SAND	SSD COARSE AGGREGATE (1)	(2)	(3)	(4)	SUB-TOTAL	AIR GRAVIMETRIC	ADMIXTURES AEA mL	ADMIXTURES OTHER	% AIR GRAVIMETER	$\frac{W}{C+P}$ BY MASS	% SAND OR DRY-RODDED OR JIGGED DENSITY OF C.A.	TEST SPECIMEN NUMBERS AND AGES
	kg										▨						
	m³																
	kg										▨						
	m³																

Figure 1b. – Sample concrete mix computation sheet (SI-metric) (sheet 1 of 2).

INSTRUCTIONS FOR THE USE OF THE CONCRETE MIX COMPUTATION SHEET, FORM NO. 7m-1322

NOTE: The accuracy of any number to be recorded is determined as follows:
(1) Densities within 1 kg/m^3
(2) Masses within Field Scale Accuracy
(3) (B) Volumes within 0.001 m^3

1. Conversions to be used:
   1 inch = 25.4 mm
   1 lbm/ft^3 = 16.185 kg/m^3
   1 lbm/yd^3 = 0.5933 kg/m^3
   2.2 lbm = 1 kg
   1 ft^3 = 0.02832 m^3
   1 yd^3 = 0.7646 m^3

2. The MIX NAME should be a maximum of 10 character spaces, for computer system-PCQCS, with the spaces to be used as follows: (1 2 3 4 5 6 7 8 9 10)
   (A) Spaces number 1 and 2 identify the source name of the coarse aggregate.
   (B) Spaces 3 and 4 are the percent sand in the mix.
   (C) Spaces 5 and 6 are the water/cement-plus-pozzolan (W/C+P) ratio without the decimal point.
   (D) Space 7 is a hyphen (-).
   (E) Spaces 8, 9, and 10 are the slump and are left justified.
   (F) Space 10 may be used for a mix additive (if not used for slump) or a change in the mix not involving % sand, W/C+P, or slump. It is to be used for any two mixes that have the same first nine numbers. The symbol to be used is optional.

   Example: Coarse aggregate from Clear Creek
   33% sand
   0.45 water-cementitious ratio
   75 mm slump
   C C 3 3 4 5 - 7 5

   Example: Coarse aggregate from Clear Creek
   33% sand
   0.45 water-cementitious ratio
   75 mm slump
   Added an Accelerator
   C C 3 3 4 5 - 7 5 A

3. MIX DESIGN CONSIDERATIONS information is obtained from Tables 1, 2, 3, and 5 of USBR Procedure 4211, Vol. 2, of the Concrete Manual and from tests run on the aggregate. The percent free moisture is to be recorded as zero when SSD, plus when greater than SSD, and minus when less than SSD. AVERAGE STRENGTH REQUIRED can be found in table 4b, USBR Procedure 4211.

4. TRIAL MIX DESIGN computations are outlined in Section 9 and table 7, USBR Procedure 4211.

5. BATCH CONPUTATIONS are outlined in Section 9 and table 7. USBR Procedure 4211.

6. Under TESTS OF FRESH CONCRETE, Sample Mass is the mass of a known volume of concrete (i.e., air meter bucket of 0.007 m^3 or 0.014 m^3). Gross Mass includes the mass of the container and Net Mass is the Gross Mass minus the mass of the container.

7. DENSITY of the fresh concrete is obtained by dividing the Net Mass (described in 6) by the volume of the container. The volume of the container must be in cubic meters.

8. YIELD VOLUME OF BATCH is found by dividing the TOTAL OF SSD BATCH QUANTITIES by the DENSITY of the fresh concrete.

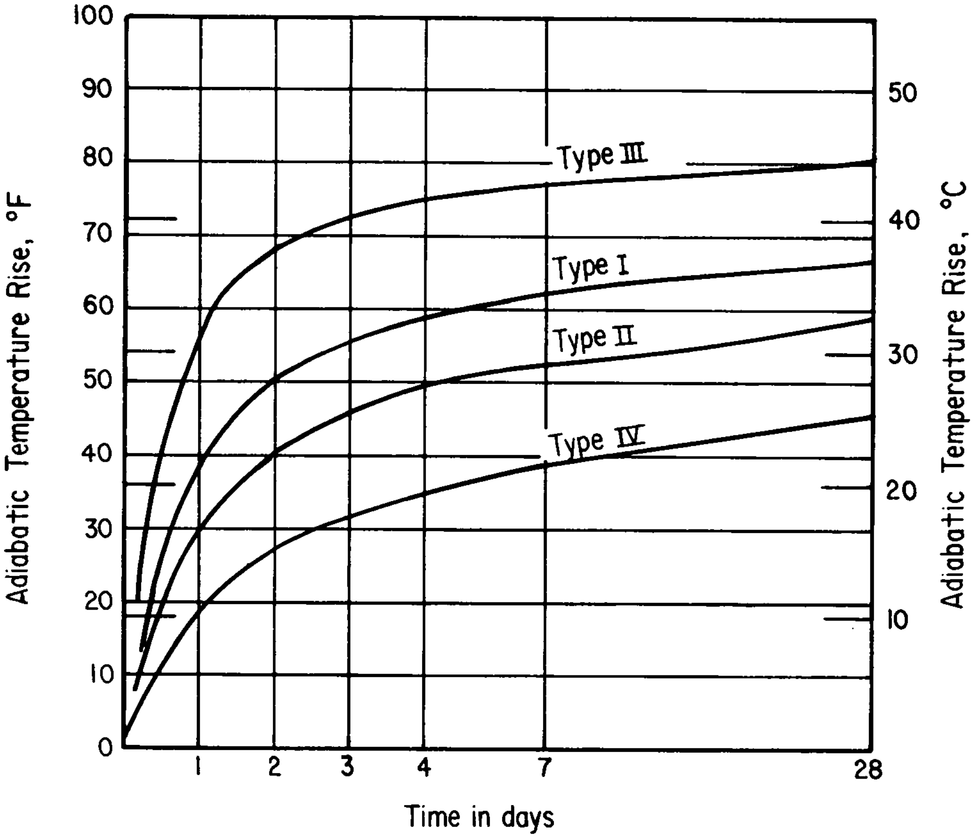
9. Under ACTUAL QUANTITIES PER CUBIC METER, the mass values are obtained by dividing the actual quantities batched by YIELD VOLUME OF BATCH.

   As a check, the mass under Sub-Total should approximate the number representing the DENSITY of the fresh concrete. The volume values are obtained by dividing the mass value of an ingredient by its density.

10. The AIR GRAVIMETRIC volume is obtained by subtracting the volume sub-total from 1.000. The % AIR GRAVIMETRIC is found by multiplying the AIR GRAVIMETRIC volume by 100.

MIX NOTES ____________________

Figure 1b. - Sample concrete mix computation sheet (SI-metric) (sheet 2 of 2).



Cement Type	Fineness ASTM C 115 m^2/g	28-Day Heat of Hydration	
		Calories per gram	Joules per gram
I	179	87	364
II	189	76	318
III	203	105	439
IV	191	60	251

Figure 2. – Temperature rise of mass concrete containing 376 lbm/yd³ (223 kg/m³) of cement.

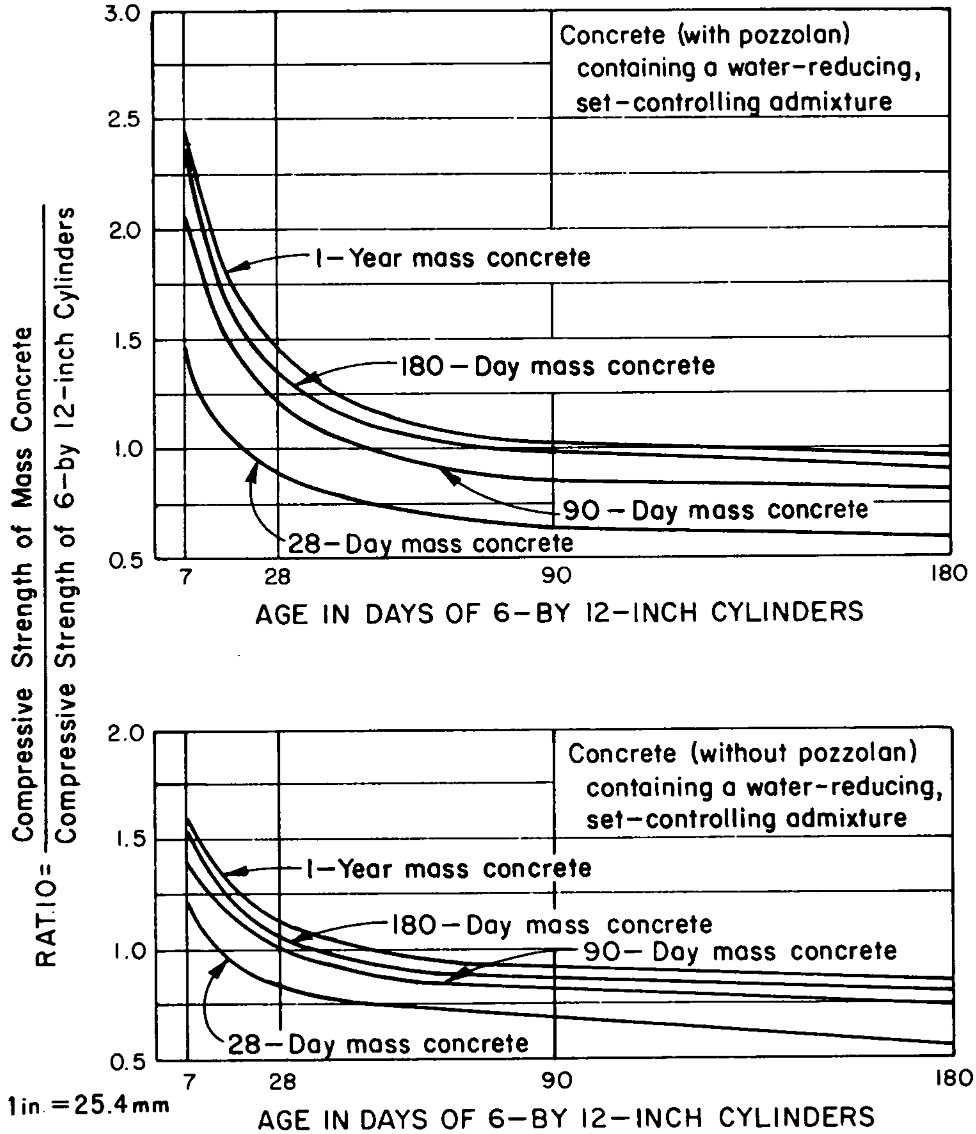


Figure 3. - Ratios of mass concrete compressive strengths in seal-cured cylinders to compressive strengths of 6- by 12-inch, fog-cured cylinders fabricated from minus 1-1/2-inch, MSA, wet-screened concrete.

1 inch = 25.4 millimeters
1 yard = 0.9144 meters
1 pound force per square inch = 0.0068476 megapascals
1 pound mass = 0.45359 kilograms
70 degrees Fahrenheit = 21 degrees Celsius; 73.4 degrees Fahrenheit = 23.4 degrees Celsius

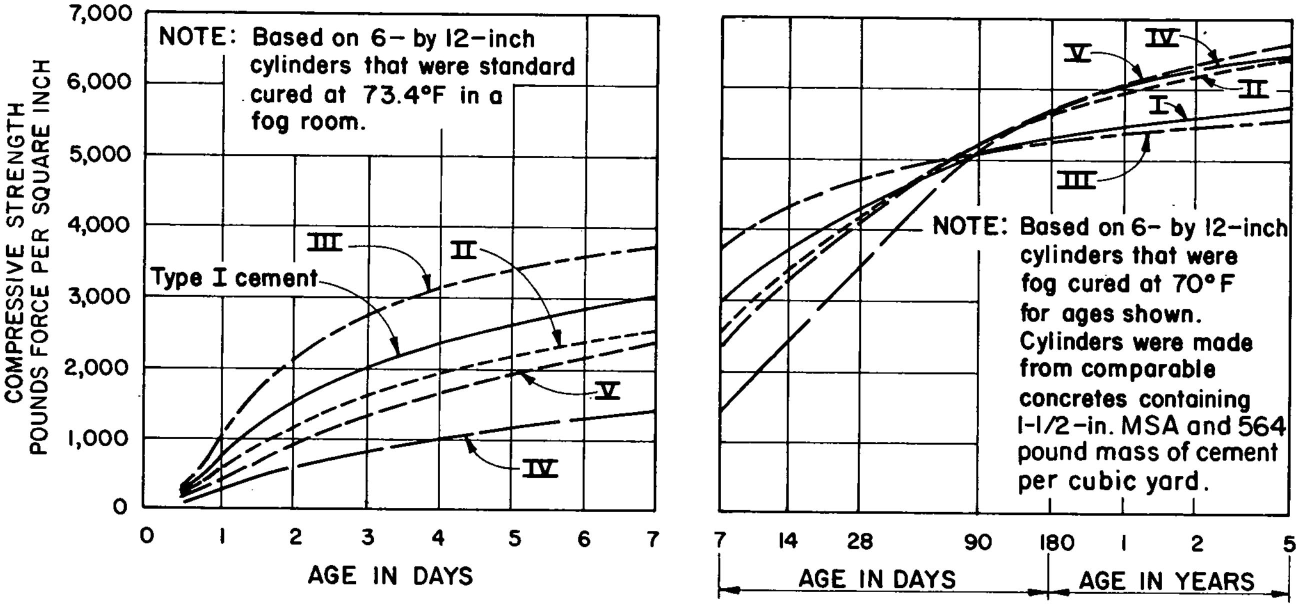


Figure 4. – Rates of strength development for concrete made with various types of cement.

APPENDIX

XI. THEORETICAL EQUATIONS FOR PREDICTING CONCRETE STRENGTHS BASED ON ACTUAL MATERIALS IN MIX

(Nonmandatory Information)

X1.1 The equations shown in this appendix can be used to troubleshoot, evaluate, predict, or estimate concrete strengths. They can also be used to determine which material in the concrete mix has caused a strength problem, to compare performance of various selections of materials with costs to determine most economical material, and to predict concrete strengths based on actual materials in mix once their effects on strength are known. However, because of the numerous variables involved in a concrete mixture, strengths calculated by any method must always be considered subject to revision on the basis of experience with field or trial batches.

X1.2 The basic equation for concrete strength is the one proposed by Feret in 1896, and is:

$$F_c = K\left(\frac{C_v}{C_v + W_v + A_v}\right)^2 \qquad (1)$$

where:

F_c = compressive strength in pound force per square inch,
C_v = volume of cement in cubic yards,
W_v = volume of water in cubic yards,
A_v = volume of air in cubic yards, and
K = a constant.

The constant K in equation (1) includes all factors that affect strength except for the effects of water, cement, and air, which are already included in the equation. Many of the factors that affect or modify K will be discussed in this appendix; however, it is impossible to account for all of the factors that affect the strength of concrete.

X1.3 The value of K can be calculated from strength data. Equation (1) can also be shown as:

$$K = \frac{F_c}{\left(\frac{C_v}{C_v + W_v + A_v}\right)^2} \qquad (2)$$

For example, if a cubic yard of concrete has a strength of 3,130 lbf/in², contains 6.0 percent total air content, 470 lbm of cement, and 280 lbm of water, the value of K can be calculated:

$$C_v = \frac{470}{(3.15)(1,685)} = 0.088 \text{ yd}^3$$

$$W_v = \frac{280}{(1.0)(1,685)} = 0.166 \text{ yd}^3$$

$$A_v = (0.06)(1) = 0.06 \text{ yd}^3$$

NOTE: Values for specific gravity and density used in the above equations were obtained from section 9.3.7.

$$K = \frac{3,130}{\left(\frac{0.088}{0.088 + 0.166 + 0.06}\right)^2} = 39,850$$

This is approximately the average K-value for this example. The 28-day value for this K may vary from 30,000 to 45,000. A conservative value for K could be assumed to be about 35,000.

X1.4 The K-value can be used to compare aggregates. If the same cement, water, and air content are used and aggregate is changed, a change in the K-value indicates the change in aggregate. In theory, the actual cement, water, and air content per cubic yard do not have to be the same for the two different aggregate mixes; therefore, concretes with widely different quantities of cement and air can be used to compare aggregates.

X1.5 Equation (1) can also be modified to include the effects of admixtures. Admixtures include pozzolanic type materials such as fly ash, silica fume, and blast furnace slag; and chemical admixtures such as water-reducing and/or set-controlling admixtures.

X1.5.1 Secondary cementitious materials (pozzolanic type materials) can be described by the following modification of equation (1):

$$F_c = K \quad 1+\left(\frac{E_m\, f(1-f)^n}{1-f}\right)\left(\frac{C_v}{C_v + W_v + A_v}\right)^2 \qquad (3)$$

$$f = \frac{C_w}{C_w + F_w} \qquad (4)$$

where:

E_m = maximum efficiency of secondary material,
n = lime fixation factor,
f = the decimal percent of secondary material,
C_w = mass of cement per cubic yard, and
F_w = mass of fly ash or secondary material per cubic yard.
All other terms as previously defined.

The value for E_m describes the total strength contribution of all reactions by the secondary material, which include reactions with lime given off by the cement and reactions by the secondary material, which require nothing from the cement. Pure pozzolanic materials, such as many class F pozzolans and silica fume, gain strength by reacting with lime given off by the cement. Conversely, class C pozzolans and blast furnace slags may have a high lime content and require little or no lime from the cement. Some suggested values for E_m and n are:

Material	28-day E_m	n
Class F fly ash	0.50 to 2.00	0.5 to 1.5
Class C fly ash	0.75 to 1.75	0.1 to 1.25
Silica fumes	5.00 to 7.00	1.0 to 2.0
Blast furnace slag	1.00 to 3.00	0.1 to 0.6

Note: Because this concept is relatively new (1985), these values may change with further evaluation.

It is possible to calculate E_m and n from strength data, and an example is shown later in this appendix. A minimum of two mixes with different percentages of secondary material are required because of the two unknowns, E_m and n. Any two percentages may work, but reasonable accuracy is assured only with wide differences in the percentages of the secondary material. Suggested percentages are about 20 and 80 percent of secondary material. If only one mix is available containing the secondary material, the best approach is to assume a value of n from the previous tabulation. The most common secondary material currently used by the Bureau is class F pozzolan, which has an n-value from 0.5 to 1.5. However, very reactive siliceous fly ashes and a few very reactive natural pozzolans may have an n-value as high as 2.0. A very appropriate n-value may be the average value 1.00. If $n=1$, the strength equation would be:

$$F_c = K(1 + E_m f)\left(\frac{C_v}{C_v + W_v + A_v}\right)^2 \tag{5}$$

For estimation purposes, an average value for E_m could be used, or calculated from strength data as follows: Assume a concrete mix with a strength of 3,130 lbf/in², 400 lbm of cement, 85 lbm of class F fly ash ($n=1.0$), and 270 lbm of water. Using the following modification of equation (5), E_m can be calculated:

$$E_m = \frac{\dfrac{F_c}{K\left(\dfrac{C_v}{C_v + W_v + A_v}\right)^2} - 1}{f} \tag{6}$$

$$f = \frac{85}{400 + 85} = 0.175$$

$$C_v = \frac{400}{(3.15)(1{,}685)} = 0.075 \text{ yd}^3$$

$$W_v = \frac{270}{1{,}685} = 0.160 \text{ yd}^3$$

$$A_v = (0.06)(1) = 0.06 \text{ yd}^3$$

$$K = 39{,}850 \text{ (sec. X1.3)}$$

$$E_m = \frac{\dfrac{3{,}130}{39{,}850\left(\dfrac{0.075}{0.075 + 0.160 + 0.06}\right)^2} - 1}{0.175} = 1.23$$

The value of E_m for many fly ashes after 28 days is between 0.50 and 2.00, as shown in previous tabulation. When E_m can not be calculated, assume an average value of 1.25.

X1.5.2 Fly ashes normally reduce the water requirement of a concrete mix by about 20 percent of the actual fly ash replacement. For example, if fly ash is 17.5 percent of the cementitious material, the water reduction from that of cement only (of equal cementitious material) will be (0.20) (17.5) = 3.5 percent. The new water requirement will be 100–3.5 = 96.5 percent. In the example of section X1.3, the control (no fly ash mix) had 280 lbm of water and the second mix (17.5 percent fly ash) (sec. X1.5.1) had (280) (0.965) = 260 lbm of water per cubic yard. If two concrete mixes are available, both E_m and n can be calculated. Use the mix from the example in section X1.5.1 as the first mix. The second mix has a strength of 680 lbf/in², 94 lbm of cement, 480 lbm of fly ash, and 233 lbm of water per cubic yard with a 6.0 percent total air. The equation can be modified to the following form:

$$E_f = E_m(1-f)^n = \left[\frac{F_c}{K\left(\dfrac{C_v}{C_v + W_v + A_v}\right)^2} - 1\right]\frac{1-f}{f} \tag{7}$$

where:

E_f = efficiency value of secondary material at percentage used in concrete mix, and all other terms are as previously defined.

The use of equation (7) provides the following results: For the first mix with 0.175 decimal percent of fly ash,

$$E_{0.175} = E_f = E_m(1-f)^n = 1.11$$

For the second mix with 0.836 decimal percent fly ash,

$$E_{0.836} = E_f = E_m(1-f)^n = 0.31$$

These two values can now be used to calculate E_m and n. The value for E_m is a constant, and is the same in both of the above equations. Setting E_m from both equations equal to each other yields:

$$\frac{E_{0.175}}{(1-f)^n} = E_m = \frac{E_{0.836}}{(1-f)^n}$$

From this relationship,

$$\frac{1.11}{(1-f)^n} = \frac{0.31}{(1-f)^n}$$

Solving for n,

$$n = \frac{\log\left(\frac{1.11}{0.31}\right)}{\log\left(\frac{1-0.175}{1-0.836}\right)} = \frac{\log 3.58}{\log 5.03} = 0.80$$

For $n = 0.80$ then,

$$E_m = \frac{E_{0.175}}{(1-0.175)^{0.80}} = \frac{1.11}{0.857} = 1.29$$

Therefore for this example, the actual values are $E_m = 1.29$ and $n = 0.80$ rather than the assumed value of $n = 1.0$, which produced an E_m of 1.35.

X1.5.3 The equation may also be modified to include chemical admixtures:

$$F_c = K\left(1 + K_a \frac{D}{N}\right)\left(\frac{C_v}{C_v + W_v + A_v}\right)^2 \quad (8)$$

where:

K_a = factor for chemical admixture,
D = dosage of admixture in ounces per 100 lbm, and
N = dosage of admixture to calculate K_a in ounces per 100 lbm (assumed to be normal dosage).
All other terms as previously defined.

The relationship $1 + K_a D/N$ provides an estimate for the chemical admixture effect for up to two or three times the normal dosage, possibly even higher. This relationship assumes a straight-line relationship that will not hold true for very high dosages, such as five times the normal dosage. The factor K_a can be calculated from the strength data. Assume a concrete mix, with no secondary material such as fly ash, that has a strength of 3720 lbf/in², 470 lbm of cement, and 265 lbm of water per cubic yard with 6.0 percent total air. Then, K_a can be calculated by the following modification of equation (8):

$$K_a = \frac{\left[\frac{F_c}{K\left(\frac{C_v}{C_v + W_v + A_v}\right)^2}\right] - 1}{\frac{D}{N}} \quad (9)$$

If dosage rate is normal, $D/N = 1$ and,

$$C_v = \frac{470}{(3.15)(1{,}685)} = 0.088 \text{ yd}^3$$

$$W_v = \frac{265}{1{,}685} = 0.157 \text{ yd}^3$$

$$A_v = (0.06)(1) = 0.06 \text{ yd}^3$$

$$K_a = \left[\frac{3{,}720}{39{,}850\left(\frac{0.088}{0.088+0.157+0.06}\right)^2}\right] - 1 = 0.12$$

A conservative value for K_a would be 0.10. The water reduction for a chemical admixture for dosages up to two or three times the normal dosage, 3 to 6 ounces per 100 lbm, can be assumed to be a straight line. That is, if water reduction at the normal or recommended dosage is 5 percent, then a double dosage would produce 10 percent water reduction. This can be assumed to be true for estimation purposes up to two or three times the normal dosage. When a chemical admixture is used with fly ash, the total water reduction may be about 75 percent of that calculated for the total of the two admixtures (chemical and fly ash).

X1.5.4 When both a chemical admixture and fly ash (n-value assumed to be 1.0) are used in the mix, equation (8) can be modified as follows:

$$F_c = \left(1 + K_a \frac{D}{N}\right)(1 + E_m f)(K)\left(\frac{C_v}{C_v + W_v + A_v}\right)^2 \quad (10)$$

X1.5.5 Equation (10) is very useful for estimating quantities, such as determining what cement content is required to obtain a required compressive strength. Equation (10) can be shown as:

$$C_w = \frac{(3.15)(1{,}685)\left(\frac{W_w}{1{,}685} + A_v\right)(A)}{1-A} \quad (11)$$

$$A = \left[\frac{F_c}{\left(1 + K_a \frac{D}{N}\right)(1 + E_m f)(K)}\right]^{1/2} \quad (12)$$

where:

W_w = mass of water, and
A = a value as defined by equation (12).
All other terms as previously defined.

Then,

$$F_w = \frac{C_w f}{1-f} \quad (13)$$

For example, determine fly ash and cement contents to produce a strength of 4,275 lbf/in², assuming a 6.0 percent total air content. The fly ash maximum efficiency is estimated to be 1.35, the K_a of normal dosage of admixture estimated at 0.10, estimated water is 260 lbm per cubic yard, and fly ash percentage estimated to be 18. Then,

$$A = \left(\frac{4{,}275}{(1+0.1)[1+(1.35)(0.18)](39{,}850)}\right)^{1/2} = 0.292$$

$$C_w = \frac{(3.15)(1{,}685)\left(\frac{260}{1{,}685} + 0.06\right)(0.292)}{1-0.292}$$

$$= 469 \text{ lbm/yd}^3$$

$$F_w = \frac{(469)(0.18)}{1-0.18} = 103 \text{ lbm/yd}^3$$

X1.6 There are many other factors that affect strength such as age of testing, cylinder size, length-to-diameter ratio, changes in maximum size aggregate, and many other less significant effects.

X1.6.1 The age of testing is very significant. The *K*-value of 39,850 in previous examples varies with age. For example, at 1-day age the *K*-value would be much smaller, and at 90-day age, much larger. An estimate of the age effect often follows the 20-, 40-, 60-, 80-, and 100-percent rule of thumb. That is, the 1-day strength is 20 percent of the 28-day strength, the 3-day strength is 40 percent, 7-day is 60, 14-day is 80, and 28-day strength is 100 percent. At 7 days, the *K*-value would be about 60 percent of the 28-day value, or (0.60) (39,850)=23,910. This estimate can be approximated for type II cement by the following relationship:

$$K_{age} = (K_{28})[0.684 \log (P + 1)]$$

where:

K_{age} = *K*-value for age desired,
K_{28} = 28-day *K*-value, and
P = age in days.

For example, the 7-day *K*-value would be:

$$K_7 = (39{,}850)[0.684 \log (7+1)] = 24{,}616$$

For many type I and III cements, the early ages will produce higher percentages than shown in the previous relationship, and type V cement may produce lower percentages at early ages, see figure 4.

X1.6.2 The size, shape, and type of cure of test specimen also affects strength, and the *K*-value will vary with each of these variables. For example, consider figures 3 and X1.1. On both of theses figures, a comparison to a 6- by 12-inch cylinder is made. Figure 3 compares the standard cure 28-day cylinder to mass concrete specimens. Figure X1.1 compares effect of cylinder diameter and effect of cylinder length-to-diameter ratio. How would the *K*-value change if length-to-diameter ratio was 1.0 rather than 2.0 for the standard cylinder? From figure X1.1, the value shown is about 118 percent; therefore, the *K*-value would be (1.18) (39,850)=47,025.

X1.7 *Summary.*–The equations shown in this appendix provide a tool for concrete technologists to fully evaluate each concrete strength situation. Each material in the mix can be evaluated in addition to testing age, specimen shape, type of cure, and many other factors. As mentioned in the introduction, any equation is subject to revision based on experience with trial batches; however, the examples show how to adjust the equations to fit a specific application. The equations can also be modified to describe field or trial batches for the investigator. When an equation conforms to field data, it is a useful tool for making a multitude of evaluations.

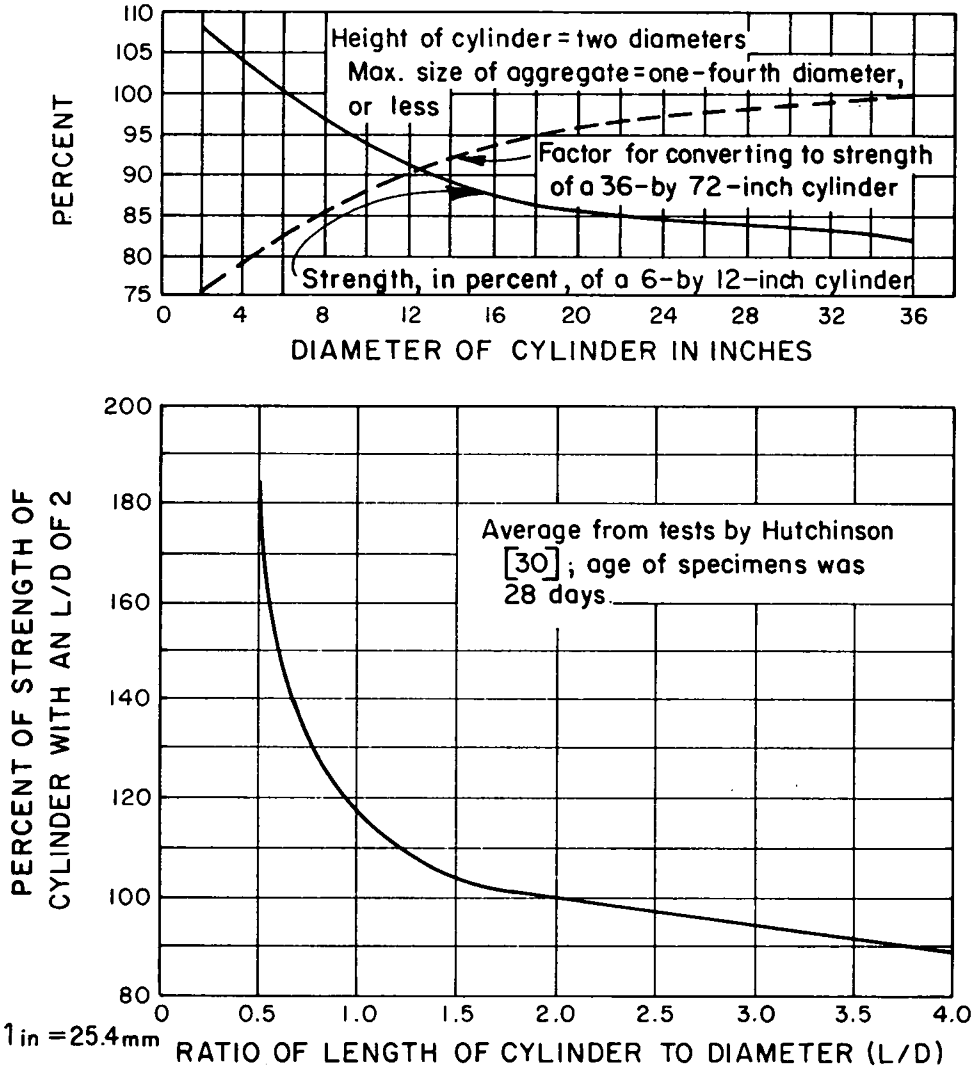


Figure X1.1. - Relationship of length and diameter of specimen to compressive strength.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4215-92

PROCEDURE FOR

FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4215; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 215-85.

1. Scope

1.1 This designation covers the procedure for measurement of fundamental transverse, longitudinal, and torsional frequencies of concrete prisms and cylinders for the purpose of calculating the dynamic Young's modulus of elasticity, dynamic modulus of rigidity (sometimes called "the modulus of elasticity in shear"), and the dynamic Poisson's ratio.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standards*:

C 215 Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]

3. Significance and Use

3.1 This procedure is intended primarily for detecting significant changes in the dynamic modulus of elasticity of laboratory or field test specimens that are undergoing exposure to weathering or other types of potentially deteriorating influences.

3.2 This procedure may be used to assess uniformity of field concrete, but it should not be considered as an index of compressive or flexural strength nor as an adequate test for establishing compliance of modulus of elasticity of field concrete with that assumed in design.

3.3 The conditions of manufacturing, moisture content, and other characteristics of test specimens (sec. 6) materially influence results obtained.

3.4 Comparison of results from specimens of different sizes or shapes should be made with caution because different computed values for dynamic modulus of elasticity may result from widely different resonant frequencies of specimens of different sizes and shapes made of same concrete.

3.5 Although used primarily for concrete, this procedure may also be used to determine the dynamic modulus of elasticity of rock cores.

4. Apparatus

4.1 *Driving Circuit*.-The driving circuit shall consist of a variable frequency audio oscillator, an amplifier, and a driving unit. The oscillator shall be calibrated to read within ±2 percent of true frequency over range of use, about 0.1 to 10 kHz. The combined oscillator and amplifier shall be capable of delivering sufficient power output to induce vibrations in test specimen at frequencies other than the fundamental, and shall be provided with a means for controlling the output. The driving unit for creating vibration in specimen shall be capable of handling full power output of oscillator and amplifier. This unit may be used in contact with test specimen or separated from specimen by an air gap. When test specimen is contact-driven, vibrating parts of driving unit shall be small in mass as compared to mass of specimen. Oscillator and amplifier shall be capable of producing a voltage that does not vary more than ±20 percent over frequency range and, in combination with driving unit, shall be free from spurious resonances that will be reflected in output.

4.2 *Pickup Circuit*.-The pickup circuit shall consist of a pickup unit, amplifier, and indicator. The pickup unit shall generate a voltage proportional to amplitude, velocity, or acceleration of test specimen, and vibrating parts shall be small in mass as compared to mass of test specimen. Either a piezoelectric or magnetic pickup unit meeting these requirements may be used. Amplifier shall have a controllable output of sufficient magnitude to actuate indicator. The indicator shall consist of a voltmeter, milliammeter, or cathode-ray oscilloscope. For routine testing of specimens whose fundamental frequency may be anticipated within reasonable limits, a meter-type indicator is satisfactory and may be more convenient to use than a cathode-ray oscilloscope. However, it is strongly recommended that whenever feasible, a cathode-ray

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

oscilloscope be provided for supplementary use or to replace meter-type indicator. Use of an oscilloscope as an indicator may be necessary when specimens are to be tested for which fundamental frequency range is unpredictable. The oscilloscope is also valuable for checking equipment for drift and for use in the event that it should be desired to use equipment for certain other purposes than those specifically contemplated by this procedure. The response of pickup unit shall be proportional to motion of test specimen in accordance with characteristics of type of pickup selected, and shall be free from spurious resonances in normal operating range.

4.3 *Specimen Support.*-The support shall permit specimen to vibrate without significant restriction. This may be accomplished by supporting specimen on knife-edges located near nodal points or on a thick pad of sponge rubber. The support shall be so dimensioned that its fundamental frequency falls outside frequency range of use.

4.4 *Scales.*-The scales shall meet requirements of section 6.2.

4.5 *Measurement Devices.*-The measuring devices shall meet requirements of section 6.2.

5. Precautions

5.1 This test method may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5.2 Precautions on vibrations are given in note 1 (sec. 9.1.2).

6. Test Specimens

6.1 *Preparation.*-Test specimens shall be made in substantial accordance with USBR 4192 unless another procedure is specified (see sec. 3 and fig. 1).

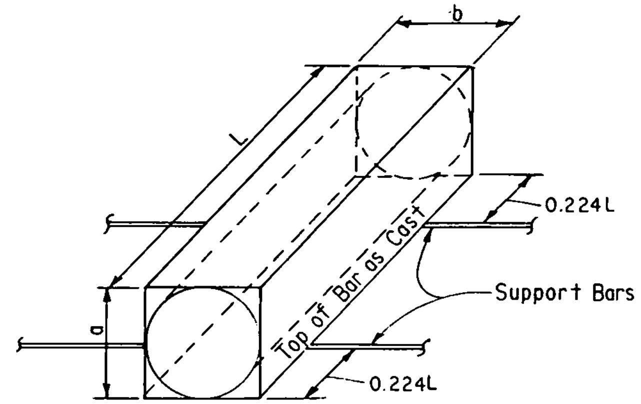
6.2 *Measurement of Mass and Dimensions.*-The mass and average length of specimens shall be determined within ±0.5 percent. The average cross-sectional dimensions shall be determined within ±1 percent.

6.3 *Limitations on Dimensional Ratio.*-Specimens having either very small or very large ratios of length to maximum transverse direction are frequently difficult to excite in fundamental mode of vibration. Best results are obtained when this ratio is between 3 and 5. For application of indicated calculations (sec. 10), the ratio must be at least 2.

7. Calibration and Standardization

7.1 Calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

7.2 The calibration of the variable frequency audio oscillator shall be checked periodically against signals transmitted by the NIST (National Institute of Standards and Technology)[2] radio station WWV, or against suitable electronic equipment such as a frequency counter, calibration of which has been previously checked and found to be adequate.



Note: The "a" dimension must be less than the "b" dimension.

Figure 1. - Specimen configuration.

7.3 Scales shall meet requirements of section 6.2 by calibration in accordance with USBR 1012.

7.4 Measuring devices shall meet requirements of section 6.2 by calibration in accordance with USBR 1000.

8. Conditioning

8.1 No special conditioning of specimens is required.

9. Procedure

9.1 *Determination of Transverse Frequency:*

9.1.1 Place specimen on support in such a manner that it may vibrate without significant restriction in a free-free transverse mode. The specimen shall be so positioned that driving force is normal to a surface, and applied at a point distant from nodal points, generally midway between ends or near one end of specimen (fig. 1). Place pickup unit against a surface of the concrete so that it will be actuated in direction of vibration.

9.1.2 The test specimen shall be forced to vibrate at varying frequencies and, while doing this, observe indication of amplified output of pickup. Record frequency of test specimen that results in a maximum indication having a well-defined peak on indicator, and note which observation of nodal points indicates fundamental transverse vibration as the fundamental transverse frequency (note 1). Adjust amplifiers in driving and pickup circuits to provide a satisfactory indication. To avoid distortion, maintain driving force as low as feasible for good response at resonance.

NOTE 1.-For fundamental transverse vibration, nodal points are located 0.224 of length of specimen from each end (about

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[2] Formerly National Bureau of Standards

the quarter points). Vibrations are maximum at ends, about three-fifths of maximum at center, and zero at nodal points; therefore, movement of pickup along length of specimen will inform operator whether vibrations observed on indicator are from specimen vibrating in its fundamental transverse mode.

9.2 *Determination of Longitudinal Frequency*:

9.2.1 Place specimen on support in such a manner that it may vibrate without significant restriction in a free-free longitudinal mode. Position specimen such that driving force is normal to and in center of one end surface (fig. 1). Place pickup unit against a surface of the concrete so that it will be actuated in direction of vibration.

9.2.2 The test specimen shall be forced to vibrate at varying frequencies and, while doing this, observe indication of amplified output of pickup. Record frequency of test specimen that results in a maximum indication having a well-defined peak on indicator, and note which observation of nodal points indicates fundamental longitudinal vibration as the fundamental longitudinal frequency (note 2).

NOTE 2.–For fundamental longitudinal mode, there is one node at center of length of specimen. Vibrations are maximum at ends.

9.3 *Determination of Torsional Frequency*:

9.3.1 Place specimen on support in such a manner that it may vibrate without significant restriction in a free-free torsional mode. Position specimen so that driving force induces a torsional effect near one end of specimen (fig. 2). Place pickup unit against a surface of the concrete so that it will be actuated in direction of vibration.

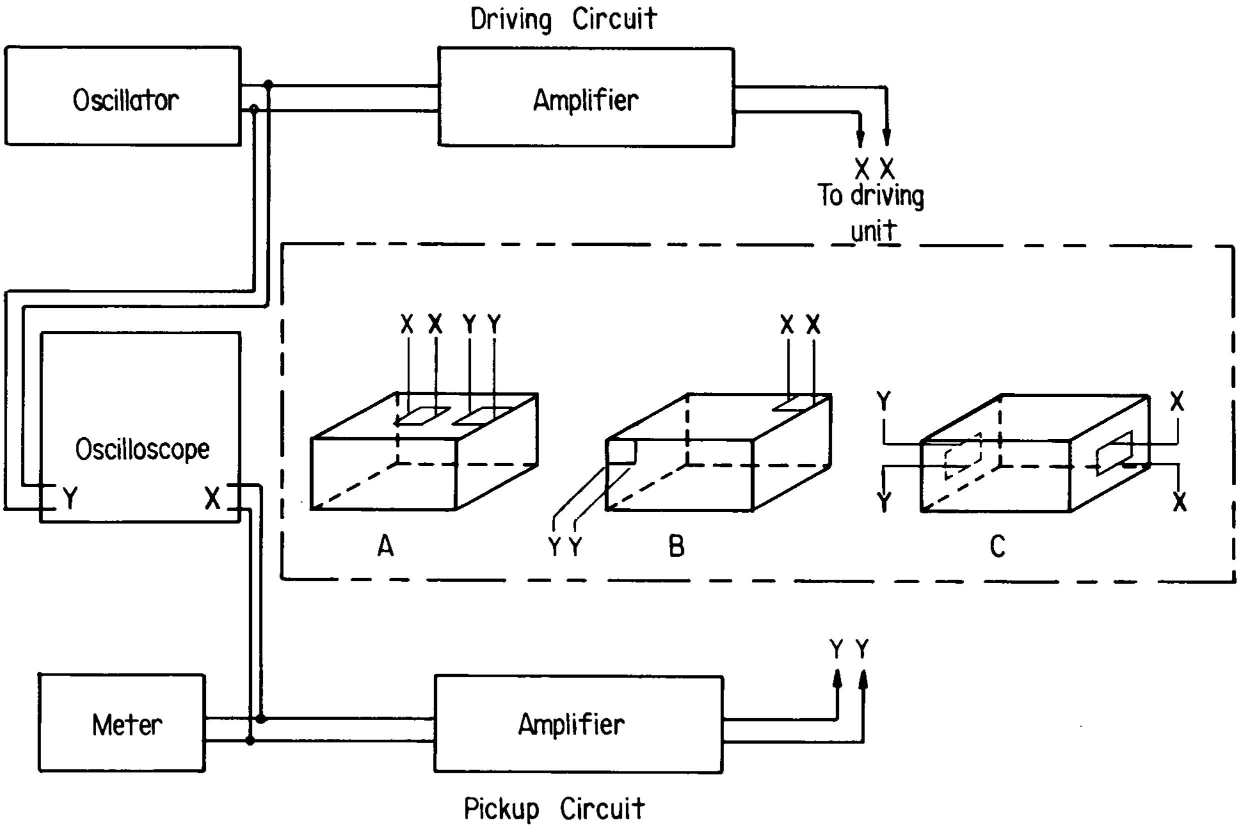
9.3.2 The test specimen shall be forced to vibrate at varying frequencies and, while doing this, observe indication of amplified output of pickup. Record frequency of test specimen that results in a maximum indication having a well-defined peak on indicator, and note which observation of nodal points indicates fundamental torsional vibration as the fundamental torsional frequency (note 3).

NOTE 3.–For fundamental torsional mode, there is one node at center of length of specimen. Vibrations are maximum at ends.

10. Calculations

10.1 Calculate the dynamic Young's modulus of elasticity from fundamental transverse frequency, mass, and dimensions of test specimen as follows:

$$E_T = CMn^2 \quad (1)$$



A — Driver and pickup positions for transverse resonance
B — Driver and pickup positions for torsional resonance
C — Driver and pickup positions for longitudinal resonance

Figure 2. – Schematic diagram of a typical apparatus showing driver and pickup positions for three types of vibration.

where:

E_T = dynamic Young's modulus of elasticity in pound force per square inch (gigapascals),
M = mass of specimen in pound mass (kilograms),
n = fundamental transverse frequency in hertz,
$C = (0.00416)\ \frac{L^3\,T}{d^4}$ in seconds squared per square inch, or
$= (0.16373)\ \frac{L^3\,T}{d^4}$ in seconds squared per square meter for a cylinder; or
$= (0.00245)\ \frac{L^3\,T}{ba^3}$ in seconds squared per square inch, or
$= (0.09646)\ \frac{L^3\,T}{ba^3}$ in seconds squared per square meter for a prism.

where:

L = length of specimen in inches (meters),
d = diameter of cylinder in inches (meters),
a,b = dimensions of cross section of prism in inches (meters), a being in direction that prism is driven, and
T = correction factor that depends on ratio of radius of gyration to length of specimen and on Poisson's ratio. Radius of gyration for a cylinder is $d/4$, and $a/3.464$ for a prism. Values of T for a Poisson's ratio of 1/6 may be obtained from table 1.

10.1.1 A typical calculation form is shown on figure 3.

10.2 Calculate the dynamic Young's modulus of elasticity from fundamental longitudinal frequency, mass, and dimensions of test specimen as follows:

$$E_L = DM(n')^2 \qquad (2)$$

where:

E_L = dynamic Young's modulus of elasticity in pound force per square inch (gigapascals),
n' = fundamental longitudinal frequency in hertz,
$D = (0.01318)\ \frac{L}{d^2}$ in seconds squared per square inch, or
$= (0.51890)\ \frac{L}{d^2}$ in seconds squared per square meter for a cylinder; or
$= (0.01035)\ \frac{L}{ba}$ in seconds squared per square inch, or
$= (0.40748)\ \frac{L}{ba}$ in seconds squared per square meter for a prism.

M, L,d, b, and a as defined in equation (1).

10.2.1 A typical calculation form is shown on figure 4.

Table 1.– Values of correction factor T* for Poisson's ratio.

K/L	T	K/L	T
0.00	1.00	0.09	1.60
.01	1.01	.10	1.73
.02	1.03	.12	2.03
.03	1.07	.14	2.36
.04	1.13	.16	2.73
.05	1.20	.18	3.14
.06	1.28	.20	3.58
.07	1.38	.25	4.78
.08	1.48	.30	6.07

* Values of T for a Poisson's ratio of 1/6 were derived from figure 1 of reference [1][3]. Poisson's ratio for water-saturated concrete may be higher than 1/6. The correction factor, T', for a different value of Poisson's ratio, μ, and given K/L, may be calculated from the following relationship:

$$T' = T\left[\frac{1 + (0.26\mu + 3.22\mu^2)\ K/L}{1 + 0.1328\ K/L}\right]$$

where T is taken from this table.

10.3 Calculate dynamic modulus of rigidity from fundamental torsional frequency, mass, and dimensions of test specimen as follows:

$$G = BM(n'')^2 \qquad (3)$$

where:

G = dynamic modulus of rigidity in pound force per square inch (gigapascals),
n'' = fundamental torsional frequency in hertz,
$B = \frac{4LR}{gA}$ in seconds squared per square inch (seconds squared per square meter),
R = a shape factor,
= 1 for a circular cylinder,
= 1.183 for a square, cross-section prism,

$$= \frac{\frac{a}{b} + \frac{b}{a}}{\frac{4a}{b} - 2.52\left(\frac{a}{b}\right)^2 + 0.21\left(\frac{a}{b}\right)^6}$$

for a rectangular prism whose cross-sectional dimensions are a and b in inches (meters), with a less than b ;

g = gravitational acceleration, 386.4 in/s^2 (9.81 m/s^2),
A = cross-sectional area of test specimen in square inches (square meters), and
M and L = as previously defined in equation (1).

10.3.1 A typical calculation form is shown on figure 5.

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[3] Number in brackets refers to entry in Reference, section 13.

10.4 Calculate Poisson's ratio, the ratio of lateral to longitudinal strain for an isotropic substance, μ, as follows:

$$\mu = \frac{E}{2G} - 1 \qquad (4)$$

where:

μ = Poisson's ratio,
E = Young's modulus of elasticity in pound force per square inch (gigapascals), and
G = as previously defined in equation (3).

10.4.1 When values of E and G in equation (4) are dynamic values, Poisson's ratio should be designated as the dynamic Poisson's ratio (note 4).

10.4.2 A typical calculation form is shown on figure 5, utilizing data from figure 4.

NOTE 4.-Values of Poisson's ratio for concrete normally vary between about 0.10 for dry specimens and 0.25 for saturated specimens.

11. Report

11.1 A typical reporting form is shown on figure 6.

12. Precision and Bias

12.1 The following precision statements are for fundamental transverse frequency only, determined on concrete prisms as originally cast. The statements do not necessarily apply to concrete prisms after they have been subjected to freezing-and-thawing tests. Data appropriate for determining the precision of fundamental torsional and longitudinal frequencies are not currently available.

12.2 *Single-Operator Precision.*-Criteria for judging the acceptability of measurements on fundamental transverse frequency obtained by a single operator in a single laboratory on concrete specimens made from the same materials and subjected to the same conditions are given in table 2. These limits apply over the range of fundamental transverse frequency from 1400 to 3300 Hz.

NOTE 5.-The coefficients of variation for fundamental transverse frequency have been found to be relatively constant over the range of frequencies given for a range of specimen sizes and age or condition of the concrete, within limits.

Table 2.-Test results for a single operator in a single laboratory.

	Coefficient of variation, percent	Acceptable range of two results,[1] percent of average
Within-batch single specimen	1.0	2.8
Within-batch, average of three specimens[2]	0.6	1.7
Between-batch, average of three specimens per batch	1.0	2.8

[1] These values represent, respectively, the 1S and D2S percentage limits as described in ASTM C 670.

[2] Calculated as described in ASTM C 670.

12.2.1 The different specimen sizes, with the first dimension being the direction of vibration, represented by the data include the following:

3 by 4 by 16 inches (76 by 102 by 406 mm)
4 by 3 by 16 inches (102 by 76 by 406 mm)
3-1/2 by 4-1/2 by 16 inches (89 by 114 by 406 mm)
3 by 3 by 11-1/4 inches (76 by 76 by 286 mm)
4 by 3-1/2 by 16 inches (102 by 89 by 406 mm)
3 by 3 by 16-1/4 inches (76 by 76 by 413 mm)

12.3 The multilaboratory coefficient of variation for averages of three specimens from a single batch of concrete has been found to be 3.9 percent for fundamental transverse frequencies over the range from 1400 to 3300 Hz (note 5). Therefore, two averages of three specimens from the same batch tested in different laboratories should not differ by more than 11.0 percent of their common average (note 6).

NOTE 6.-These numbers represent, respectively, the 1S and D2S limits as described in ASTM C 670, where 1S is the estimate of the standard deviation characteristic of the total statistical population and D2S is the difference between two individual test results that would be equaled or exceeded in the long run in only 1 case in 20 in the normal and correct operation of the method.

12.4 The bias for this procedure has not been established.

13. Reference

[1] Pickett, Gerald, "Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders," *Proceedings*, ASTEA, ASTM, vol. 45, p. 846, 1945.

Spec. or Solic. No. PREBID	Structure DAM	Tested by L. MITCHEL 10-10-50 TO 10-10-51 Date
Project PSMBP YELLOWTAIL UNIT	Item MIX DESIGN STUDIES Location DENVER LAB	Computed by L. MITCHEL 10-10-50 TO 10-10-51 Date
Feature YELLOWTAIL DAM	Station ~ Offset ~ Depth ~ to ~	Checked by G. HOAGLAND 10-10-50 TO 10-10-51 Date

FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS

Specimen Configuration:

☐ Circular Cylinder ☐ Square Cross Section Prism ☒ Rectangular Cross Section Prism

Specimen Moisture Condition:

☐ Air Dried ☐ Oven Dried ☐ Saturated (100% Humidity Room) ☒ Saturated (50% Humidity Room) ☐ Other

Specimen No.	L Length, inches ~~(m)~~	d Diameter, inches (m)	a Prism Depth, inches ~~(m)~~	b Prism Width, inches ~~(m)~~	T Correction Factor (a/3.464)	C (0.00245) $\frac{L^3T}{ba^3}$, s^2/in^2 ~~(s^2/m^2)~~
1	30	~	4	4	1.1547	0.2984
2	30	~	4 1/32 (4.03125)	4	1.1638	0.2956
						Avg. 0.2970

Date	Age, days	Specimen No. 1		Specimen No. 2		Average		E_T Modulus $CMn^2 \times 10^6$, lbf/in² ~~(GPa)~~
		M Mass, lbm ~~(kg)~~	n Frequency, hertz	M Mass, lbm ~~(kg)~~	n Frequency, hertz	M Mass, lbm ~~(kg)~~	n Frequency, hertz	
10-13-50	3	40.88	539	41.08	550	40.98	544	3.60
10-17	7	41.00	588	41.19	600	41.10	594	4.31
10-24	14	41.00	625	41.19	632	41.10	628	4.81
10-31	21	41.00	648	41.19	650	41.10	649	5.14
11-7	28	41.02	652	41.19	661	41.10	656	5.25
11-21	42	41.03	670	41.20	680	41.11	675	5.56
12-9	60	41.03	681	41.22	688	41.12	684	5.71
1-8-51	90	41.01	698	41.22	708	41.11	703	6.03
2-7	120	41.03	700	41.24	710	41.14	705	6.07
4-6	180	41.03	700	41.26	715	41.14	708	6.12
7-6	270	41.08	715	41.30	721	41.19	718	6.31
10-10	365	41.09	720	41.30	730	41.20	725	6.43

Figure 3. – Typical data and calculation form for sonic vibrations of cylindrical or prismatic specimens (Transverse Frequency).

Spec. or Solic. No. INVESTIGATIONS	Structure ROCK FOUNDATION	Tested by L. MITCHEL G. HOAGLAND Date 8-3-54
Project CASTLE ROCK, CO	Item STABILITY STUDIES Location DENVER LAB	Computed by L. MITCHEL Date 8-3-54
Feature ROCK INVESTIGATION	Station ~ Offset ~ Depth ~ to ~	Checked by A. COLLING Date 8-3-54

FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS

Specimen Configuration:
☒ Circular Cylinder ☐ Square Cross Section Prism ☐ Rectangular Cross Section Prism
Specimen Moisture Condition:
☒ Air Dried ☐ Oven Dried ☐ Saturated (100% Humidity Room) ☐ Saturated (50% Humidity Room) ☐ Other

Specimen No.	L Length, inches ~~(m)~~	d Diameter, inches ~~(m)~~	a Prism Depth, inches (m)	b Prism Width, inches (m)		D (0.01318) $\frac{L}{(d^2)}$, s²/in² ~~(s²/m²)~~
1	$8\frac{7}{16}$ (8.4375)	$2\frac{1}{8}$ (2.125)	~	~		0.024627
2	$8\frac{1}{2}$ (8.5000)	$2\frac{1}{8}$ (2.125)	~	~		0.024809
						Avg: 0.024768

Date	Age, days	Specimen No. 1		Specimen No. 2		Average		E_L Modulus $DM(n')^2 \times 10^6$, lbf/in² ~~(GPa)~~
		M Mass, lbm ~~(kg)~~	n' Frequency, hertz	M Mass, lbm ~~(kg)~~	n' Frequency, hertz	M Mass, lbm ~~(kg)~~	n' Frequency, hertz	
8-3-54	~	2.136	6410	2.150	6610	2.143	6510	2.24

Figure 4. - Typical data and calculation form for sonic vibrations of cylindrical or prismatic specimens (Longitudinal Frequency).

Spec. or Solic. No. INVESTIGATIONS	Structure ROCK FOUNDATION	Tested by L. MITCHEL G. HOAGLAND Date 8-3-54
Project CASTLE ROCK, CO	Item STABILITY STUDIES Location DENVER LAB	Computed by L. MITCHEL Date 8-3-54
Feature ROCK INVESTIGATION	Station No ID Offset No ID Depth No ID to No ID	Checked by A. COLLING Date 8-3-54

FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS

Specimen Configuration:
☒ Circular Cylinder ☐ Square Cross Section Prism ☐ Rectangular Cross Section Prism
Specimen Moisture Condition:
☒ Air Dried ☐ Oven Dried ☐ Saturated (100% Humidity Room) ☐ Saturated (50% Humidity Room) ☐ Other

Specimen No.	L Length, inches ~~(m)~~	d Diameter, inches ~~(m)~~	a Prism Depth, inches (m)	b Prism Width, inches (m)	R Shape Factor	B $\frac{4LR}{gA}$ s²/in² ~~(s²/m²)~~
1	8 7/16 8.4375	2 1/8 2.125	~	~	1.0000	0.024628
2	8 1/2 8.5000	2 1/8 2.125	~	~	1.0000	0.024810
		$A = \pi d^2/4$ $= 3.5466$				Avg. 0.024719

Date	Age, days	Specimen No. 1		Specimen No. 2		Average		G
		M Mass, lbm ~~(kg)~~	n'' Frequency, hertz	M Mass, lbm ~~(kg)~~	n'' Frequency, hertz	M Mass, lbm ~~(kg)~~	n'' Frequency, hertz	Modulus $BM(n'')^2 \times 10^6$ lbf/in² ~~(GPa)~~
8-3-54	~	2.136	4500	2.150	4450	2.143	4475	1.06
DYNAMIC POISSON'S RATIO, $\mu = (E_L/2G) - 1 = [2.24/(2)(1.06)] - 1.0000 = 0.057$								

Figure 5. - Typical data and calculation form for sonic vibrations of cylindrical or prismatic specimens (Torsional Frequency).

Spec. or Solic. No. INVESTIGATIONS	Structure ROCK FOUNDATION	Tested by L. MITCHEL G. HOAGLAND Date 8-3-54
Project CASTLE ROCK, CO	Item STABILITY STUDIES Location DENVER LAB	Computed by L. MITCHEL Date 8-3-54
Feature ROCK INVESTIGATION	Station ~ Offset ~ Depth ~ to ~	Checked by A. COLLING Date 8-3-54

FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS

E_T = Dynamic Young's modulus of elasticity (Transverse Frequency)
E_L = Dynamic Young's modulus of elasticity (Longitudinal Frequency)
G = Dynamic modulus of rigidity (Torsional Frequency)
μ = Dynamic Poisson's ratio

Specimen Ident.	Specimen Configuration	Specimen Size				Moisture Condition	$E_T \times 10^6$ lbf/in^2 (GPa)	$E_L \times 10^6$ lbf/in^2 ~~(GPa)~~	$G \times 10^6$ lbf/in^2 ~~(GPa)~~	μ
		Length, inches ~~(m)~~	Width, inches (m)	Depth, inches (m)	Diameter, inches ~~(m)~~					
1 E2 OF 8-3-54	ROCK CORE	8.46875	~	~	2.125	AIR DRIED	~	2.24	1.06	0.057

Figure 6. - Typical reporting form for dynamic modulus determinations.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4227-92

PROCEDURE FOR

POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (MORTAR-BAR METHOD)

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4227; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 227-81.

1. Scope

1.1 This designation covers the procedure for determination of susceptibility of cement-aggregate combinations to expansive reactions involving hydroxyl ions associated with the sodium and potassium alkalies by measurement of the increase or decrease in length of mortar bars during storage under prescribed conditions of test.

1.2 Alkalies participating in expansive reactions usually are derived from the cement; under some circumstances they may be derived from other constituents of the concrete or from external sources. Two types of alkali reactivity of aggregates are recognized: (1) an alkali-silica reaction involving certain siliceous rocks, minerals, and natural or artificial glasses, and (2) an alkali-carbonate reaction involving dolomite in certain calcitic dolomites and dolomitic limestones. This procedure is not recommended as a means to detect the latter reaction because expansions produced in the mortar-bar test by the alkali-carbonate reaction (see ASTM C 586) are generally much less than those produced by the alkali-silica reaction for combinations having equally harmful effects in service.

2. Applicable Documents

2.1 *USBR Procedures*:

4075 Sampling Aggregates
4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens
4183 Sampling and Acceptance of Hydraulic Cement
4192 Making and Curing Concrete Test Specimens in Laboratory
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 227 Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)[1]
C 230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement[1]
C 289 Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,3]
C 511 Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1,3]
C 586 Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,3,4]

3. Summary of Procedure

3.1 Mortar bars containing cement-aggregate combinations are stored over water at 100 °F (37.8 °C), and expansion of the bars is measured at specified time intervals.

4. Significance and Use

4.1 Data correlating results of tests performed using this procedure with the performance of cement-aggregate combinations in concrete in service, results of petrographic examination of aggregates, and results of tests for potential reactivity of aggregates by chemical methods have been published in ASTM C 289; and should be consulted in connection with using test results from this procedure as the basis for conclusions and recommendations concerning use of cement-aggregate combinations in concrete.

4.2 The results of tests by this procedure furnish information on the likelihood that a cement-aggregate

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.03.

[3] *Annual Book of ASTM Standards*, vol. 04.01.

[4] *Annual Book of ASTM Standards*, vols. 04.06, 05.05, 14.02.

combination is potentially capable of harmful alkali-silica reactivity with consequent deleterious expansion of concrete. Criteria to determine potential deleterious alkali-silica reactivity of cement-aggregate combinations from results of this procedure are: (1) aggregates causing a linear mortar expansion in excess of 0.2 percent in 1 year should be expected to cause rapid, intense, and readily recognizable expansive deterioration of concrete if used with a high-alkali cement in exposed situations, see figure 1; (2) aggregates used with a high-alkali cement which cause a mortar expansion less than 0.1 percent in 1 year have been found to be innocuous, so far as alkali-aggregate reactivity is concerned; and (3) aggregates causing expansion of from 0.1 to 0.2 percent in 1 year do not show clearcut evidences of alkali-aggregate reactions in structures, but several aggregates of this character are associated with concrete deterioration, the cause of which is conjectural. Consequently, aggregates causing mortar expansion in excess of 0.1 percent in 1 year should be used only with cements low in alkalies or with the aid of other remedial measures. Usually, aggregates causing mortar expansion of 0.1 percent at 6 months must be regarded as deleterious; whereas those causing expansions in excess of 0.04 percent should be regarded with suspicion.

4.3 Insignificant expansion may result when potentially deleteriously reactive, siliceous rocks are present in comparatively high proportion even when a high-alkali cement is used, probably because the alkali-silica reaction products are characterized by an alkali to silica ratio that is so low as to minimize uptake of water and swelling. Dolomitic aggregates that are deleteriously affected by the alkali-carbonate reaction when employed as coarse aggregate in concrete may not produce notable expansion in this procedure. Also, significant expansion may occur rarely in the test for reasons other than alkali-aggregate reaction, particularly the presence of sulfates in the aggregate that produce a sulfate attack upon the cement paste, ferrous sulfides (pyrite, marcasite, or pyrhotite) that oxidize and hydrate with the release of sulfate, and materials such as CaO (free lime) or MgO (free magnesia) in the cement or aggregate that progressively hydrate and carbonate.

4.4 When test results are inconclusive, it is strongly recommended that supplementary information be developed to confirm that expansion is actually due to alkali reactivity. Sources of such supplementary information include: (1) petrographic examination of aggregate to determine if known reactive constituents are present; normally, aggregates submitted to the Bureau's Denver Office for quality evaluation are examined petrographically, and the reactivity test is performed on the recommendations of the petrographic laboratory; (2) examination of specimens after tests to identify products of alkali reactivity; and (3) tests of aggregate for potential reactivity by chemical methods (ASTM C 289).

4.5 When it has been concluded from results by this procedure and from supplementary information that a given cement-aggregate combination should be considered potentially deleteriously reactive, additional studies may be appropriate to develop information on the potential reactivity of other combinations containing the same cement with other aggregates, same cement with same aggregate proportioned with a neutral aggregate, same aggregate with other cements, or same cement-aggregate combination with a mineral admixture.

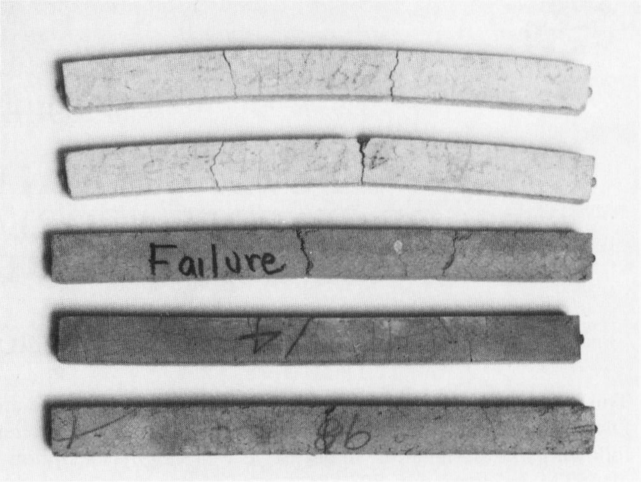


Figure 1. – Typical appearance of mortar-bar specimens at conclusion of moist storage.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 490.

6. Apparatus

6.1 The apparatus shall conform to ASTM C 490, except as follows:

6.1.1 *Molds.*–Molds may be constructed with one, two, or three compartments, and in compliance with figures 2, 3, and 4.

6.1.2 *Sieves.*–Square hole, woven-wire, cloth sieves conforming to ASTM E 11.

6.1.3 *Mixer, Paddle, Mixing Bowl, and Scraper.*–These items shall conform to requirements of USBR 4305, except that clearance between lower end of paddle and bottom of bowl shall be 0.20±0.01 inch (5.1±0.3 mm).

6.1.4 *Tamper and Trowel.*–The tamper and trowel shall conform to USBR 4109.

6.1.5 *Flow Table and Flow Mold.*–The flow table and flow mold shall conform to ASTM C 230.

6.1.6 *Inserts and Gauge Points.*–The inserts and gauge points may be threaded to permit adjustment to an exact predetermined length or may be fixed where exact length determination is made and length change is calculated, see figures 2, 3, and 4.

6.1.7 *Containers.*–Covered containers for storing test specimens shall be constructed of material that is resistant to corrosion under conditions of use. When containers are

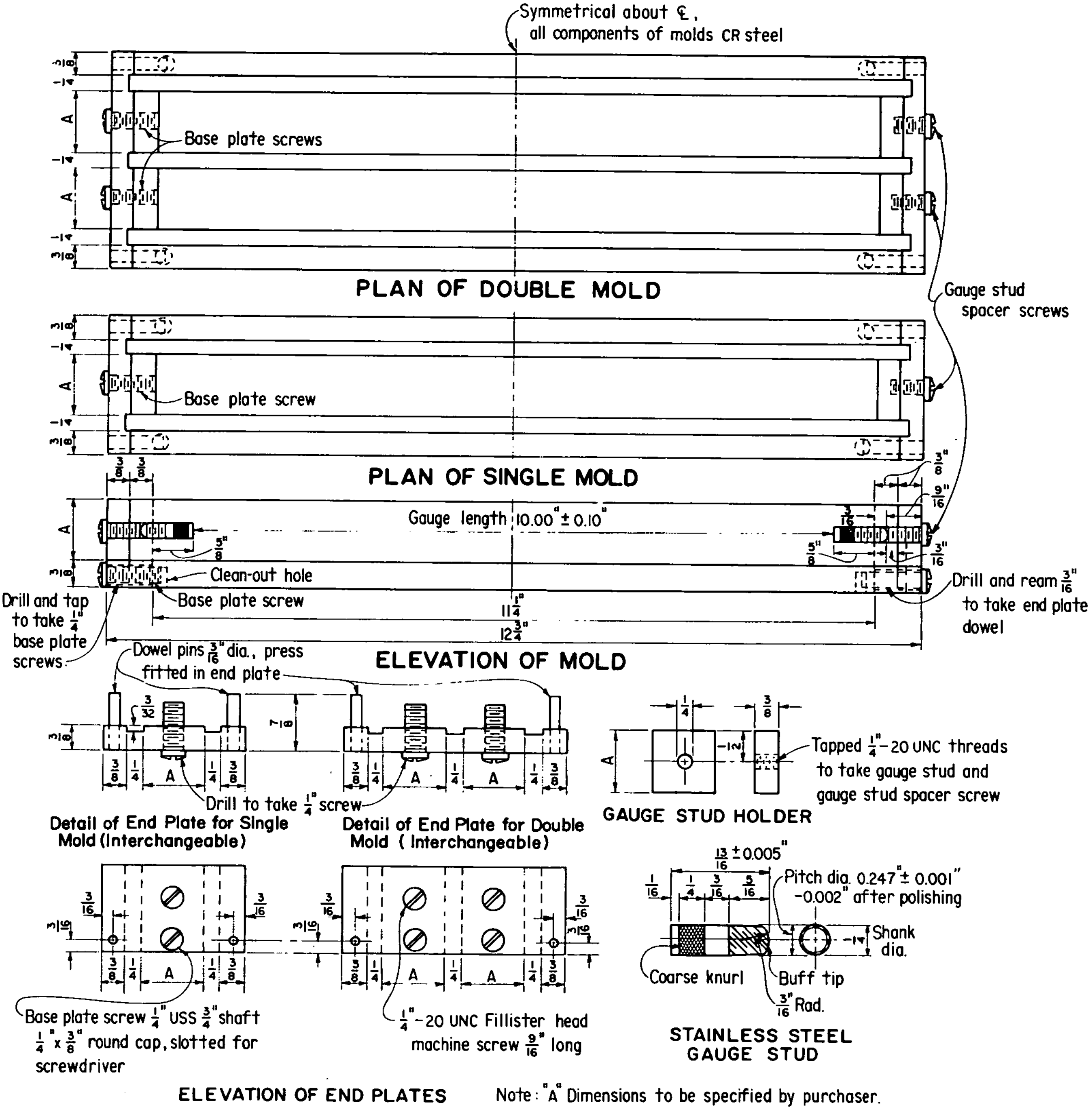
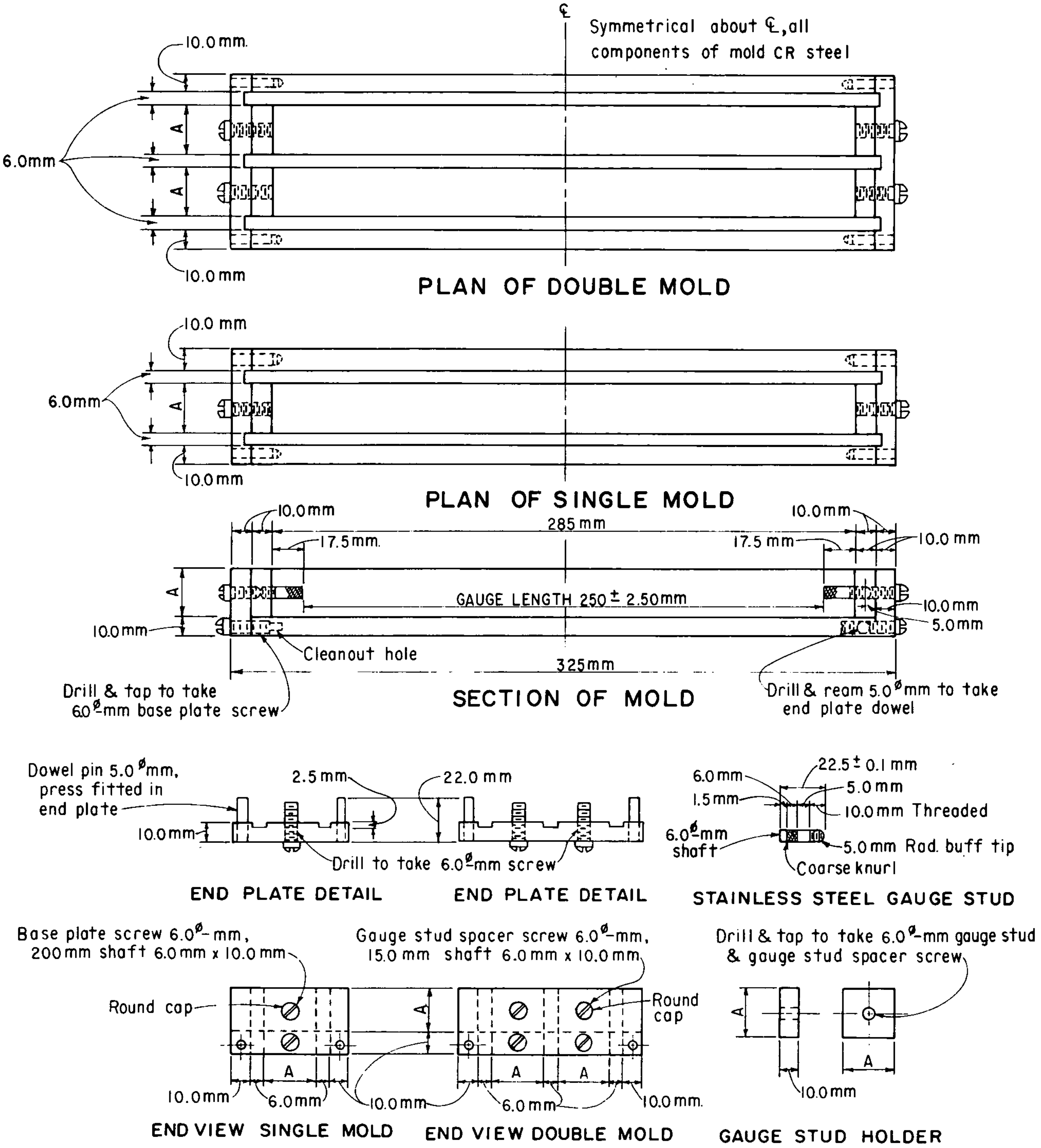


Figure 2a. – Single and double molds (inch-pound units). From ASTM C 490.

in use, it is important to maintain a tight seal between cover and container wall or top. The inner sides of containers shall be lined with an absorbent material, such as blotting paper, to act as a wick and to ensure that atmosphere in container is quickly saturated with water vapor when container is sealed after specimens are placed therein. The liner shall extend into the water in bottom of container and extend above tops of specimens. Containers shall be so constructed that, when used for storing specimens, loss of moisture is prevented by tight-fitting covers and/or sealing. Provisions shall be made for supporting the mortar bars in a vertical position, with lower end of bars about 1 inch (25 mm) above surface of water in container. The mass of the mortar bar specimens shall not be supported on the metal gauge stud. Spacers shall be provided to ensure that specimens do not touch sides of container or each other. Provisions shall be made to prevent water splashing and condensate dripping onto



Note: "A" dimensions to be specified by purchaser.

Figure 2b. - Single and double molds (SI-metric). From ASTM C 490.

specimens. The provisions to prevent water splashing on specimens should not include baffle plates and supports to hold the specimens vertical that would substantially reduce opportunity for vapor transfer from water in bottom of container to atmosphere around specimens (note 1). If required to prevent growth of mold on liner, a suitable fungicide may be added to water in container. Containers currently in use by the Bureau are constructed of Plexiglass, as shown on figure 5.

NOTE 1.-One laboratory eliminated splash baffle and made the support for the bottoms of the bars out of galvanized, welded, square mesh, wire cloth made out of 0.080-inch (2.0-mm) diameter galvanized wire.

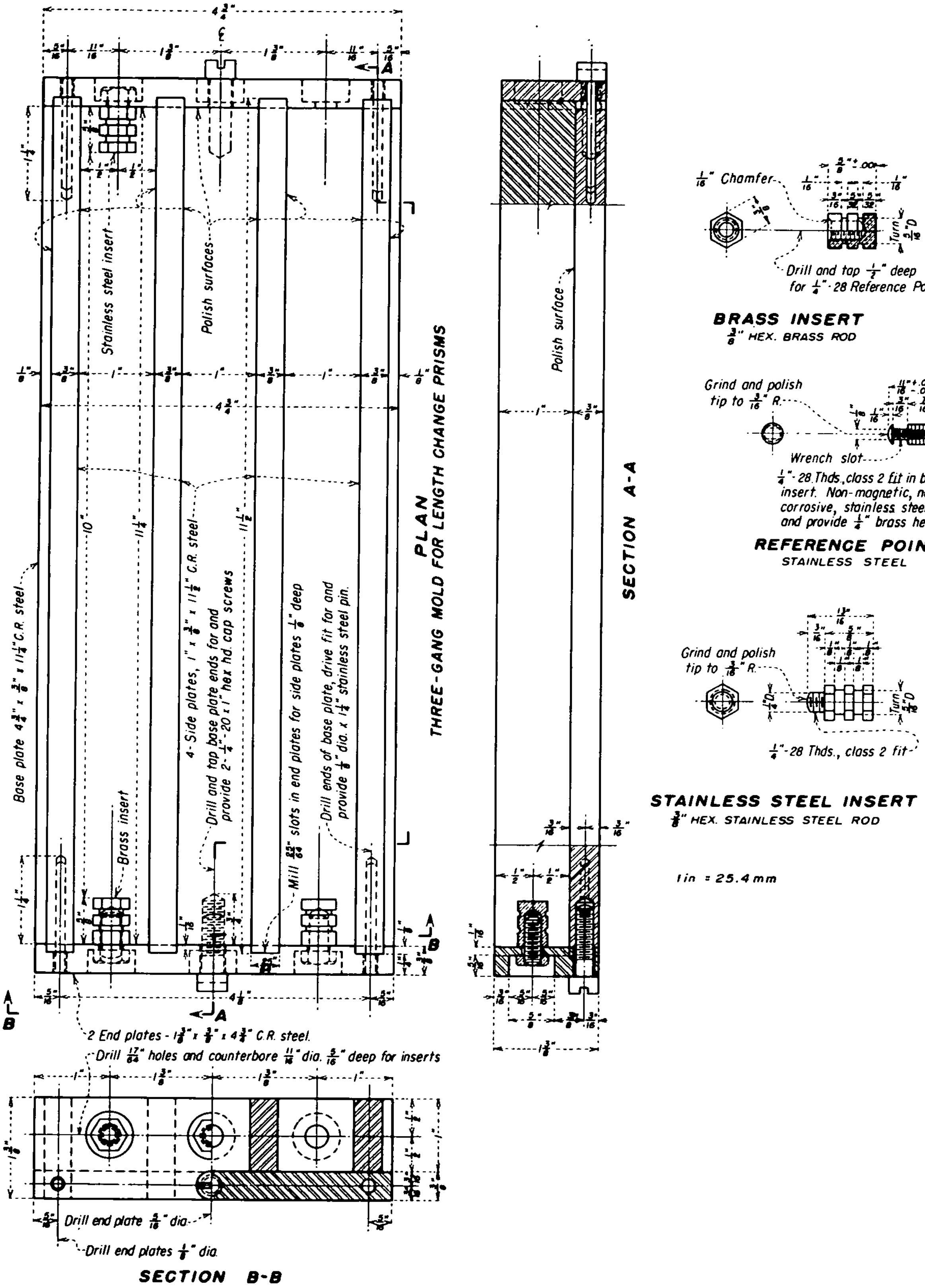


Figure 3. - Three-gang mold.

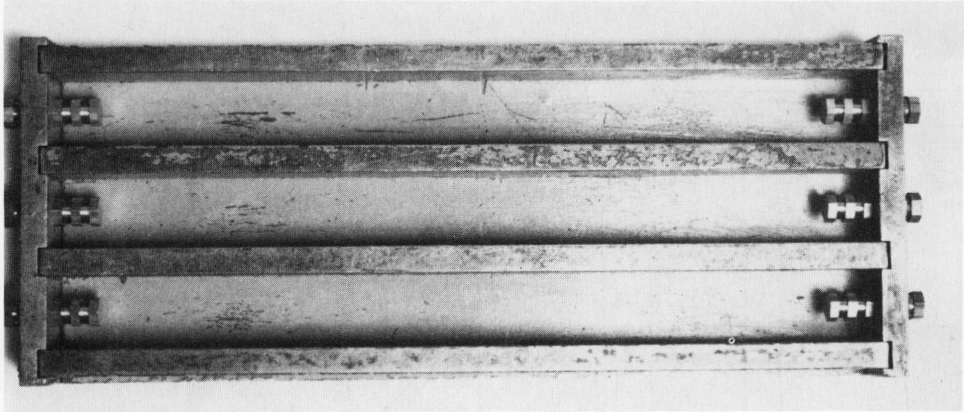


Figure 4. – View of a three-gang mold (with inserts) ready for preparation of mortar-bar speciments.

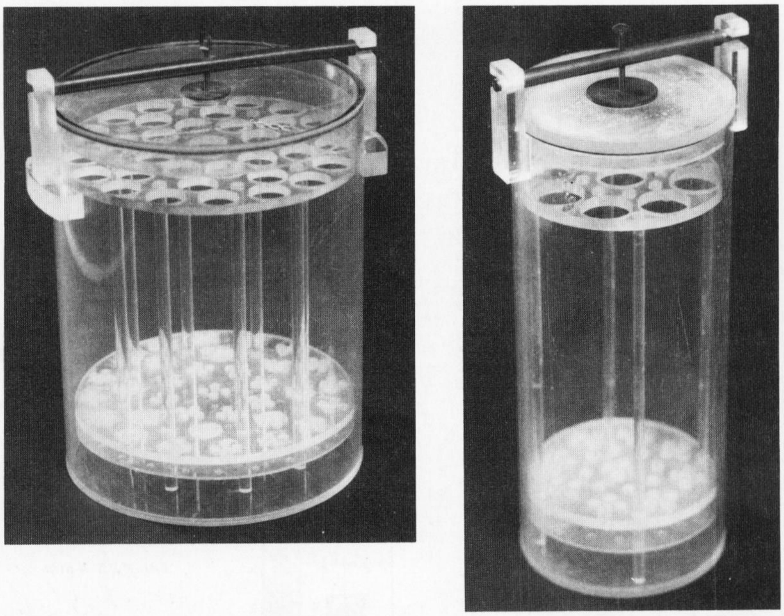


Figure 5. – Typical Plexiglass containers used for the moist-sealed storage of mortar-bar specimens.

7. Materials

7.1 *Selection of Aggregate.*–Materials proposed for use as fine aggregate in concrete shall be processed as described in section 7.2 with a minimum of crushing. Materials proposed for use as coarse aggregate in concrete shall be processed by crushing to produce, as nearly as practical, a graded product from which a sample can be obtained. The sample shall have the grading as prescribed in 7.2, and be representative of the composition of coarse aggregate as proposed for use.

7.1.1 When a given quarried material is proposed for use, both as coarse and fine aggregate, it will be tested only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that coarser size fractions will have a different composition than the finer sizes and these differences might significantly affect expansion due to reaction with alkalies in the cement. In this case, the coarser size fractions should be tested in a manner similar to that used for the finer sizes.

7.1.2 Coarse aggregate crushed to sand size may give increased expansion because of the increased surface exposed upon crushing. Therefore, if coarse aggregate tested by this procedure produces an excessive amount of expansion, the material shall not be classed as objectionably reactive with alkali unless tests of concrete specimens confirm such findings.

7.2 *Preparation of Aggregate.*–Fine aggregate shall be tested in a grading that meets requirements of specifications for the project, except that any material retained on the

No. 4 (4.75-mm) sieve shall be removed. Fine aggregates being tested for reasons other than to determine compliance with individual specifications, and all coarse aggregates to which this procedure is applied shall be graded in accordance with requirements shown in table 1. Aggregates for which sufficient quantities of sizes specified in table 1 do not exist shall be crushed until required material has been produced. In the case of aggregates containing insufficient amounts of one or more of the larger sizes listed in table 1, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size, as determined from table 1. When this method is necessary, it should be so noted in the test report. After the aggregate has been separated into the various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. The portions retained on the various sieves shall then be dried and, unless used immediately, each portion shall be stored individually in a clean container provided with a tight-fitting cover.

Table 1. - Grading requirements.

Sieve size		Mass,
Passing	Retained on	percent
No. 4 (4.75 mm)	No. 8 (2.36 mm)	10
No. 8 (2.36 mm)	No. 16 (1.18 mm)	25
No. 16 (1.18 mm)	No. 30 (600 µm)	25
No. 30 (600 µm)	No. 50 (300 µm)	25
No. 50 (300 µm)	No. 100 (150 µm)	15

7.3 *Cement.*-Cement used to determine the reactivity of aggregates with the cement alkalies shall be high-alkali cement with an alkali content of 1 percent or more expressed as sodium equivalent. Parallel tests using a cement with an alkali content of 0.60 percent are also usually conducted to determine the effectiveness of specifying low-alkali cement to control deleterious expansion.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Sampling, Test Specimens, and Test Units

9.1 Obtain samples of aggregate in accordance with applicable provisions of USBR 4075, cement in accordance with USBR 4183, and pozzolans in accordance with USBR 4311.

9.2 *Number of Specimens.*-Make at least four test specimens, two from each of two batches, for each cement-aggregate combination. Circumstances may dictate that more specimens than noted here be made.

9.3 *Preparation of Molds.*-Prepare molds in accordance with requirements of ASTM C 490.

9.4 *Proportioning of Mortar.*-Proportion dry materials for test mortar using 1 part cement to 2.25 parts of graded aggregate by mass. The quantities of dry materials to be mixed at one time in batch of mortar for making two specimens shall be 300 grams of cement and 675 grams of aggregate. The aggregate shall be made up by recombining portions retained on various sieves (sec. 7.2) as shown in table 1, or of a graded aggregate meeting requirements of the specifications for the project. Use an amount of mixing water to produce a flow of 105 to 120 percent as determined in accordance with USBR 4109, except that flow table shall be dropped 1/2-inch (12.7-mm) 10 times in about 6 seconds instead of 25 times within 15 seconds (sec. 11.3, USBR 4109). The amount of mixing water used shall be expressed as a mass percent of the cement.

9.5 *Mixing of Mortar.*-Mix the mortar in accordance with requirements of USBR 4305.

9.6 *Molding of Test Specimens.*-Immediately following completion of flow test, return mortar from flow table to mixing bowl. Mix entire batch for 15 seconds. Start molding specimens within 2.25 minutes after completion of original mixing of mortar batch. Fill molds with two approximately equal layers, compacting each layer with tamper. Work mortar into corners, around gauge studs, and along surfaces of mold with the tamper until a homogenous specimen is obtained. After top layer has been compacted, cut off mortar flush with top of mold and smooth surface with a few strokes of trowel.

9.6.1 When a duplicate batch of mortar is to be made immediately for additional specimens, flow test may be omitted and mortar allowed to stand in mixing bowl for 90 seconds and then remixed for 15 seconds before molding specimens.

9.7 *Sequence of Making Batches of Mortar.*-When more than one cement-aggregate combination is to be tested as part of a single investigation, make total number of batches of mortar (two per cement-aggregate combination) in random order, except that in no case shall the two batches representing a single cement-aggregate combination be made consecutively. When the making of all specimens for a single investigation requires that batches be made on 2 working days, each cement-aggregate combination shall be represented by one batch made each day. The order in which the combinations are represented by batches shall be different on the 2 days. When more than 2 days are required, one cement-aggregate combination shall be represented by a batch made on each day.

10. Calibration and Standardization

10.1 Permissible variations in the scales are outlined in ASTM C 490, and shall conform to requirements of USBR 4192.

10.2 Glass graduates shall conform to requirements of ASTM C 490.

10.3 Molds shall conform to requirements of ASTM C 490 and section 6.1.1 of this designation.

10.4 Sieves shall comply with section 6.1.2 of this designation and to ASTM E 11.

10.5 The mixer, paddle, mixing bowl, and scraper shall comply with section 6.1.3 of this designation and to USBR 4305.

10.6 The flow table and flow mold shall comply with requirements of ASTM C 230.

10.7 The tamper and trowel shall comply with requirements of USBR 4109.

10.8 Containers shall comply with requirements of section 6.1.7.

10.9 The length comparator shall meet requirements of ASTM C 490.

10.9.1 The specimens may be adjusted to a standard overall length (out-to-out of gauge points) by means of the adjustable insert screws.

10.10 Sand shall be standardized as outlined in section 7.

11. Conditioning

11.1 The temperature of molding room and dry materials shall be maintained at not less than 68 °F (20 °C) and not more than 81.5 °F (27.5 °C). Temperature of mixing water, moist closet or moist room, and room in which measurements are made shall not vary from 73.4 °F (23 °C) by more than 3 °F (1.7 °C).

11.2 The relative humidity of molding room shall be not less than 50 percent. The moist closet or room shall conform to ASTM C 511.

11.3 The storage room in which specimens in containers are stored shall be maintained at a temperature that shall not vary from 100 °F (37.8 °C) by more than 3 °F (1.7 °C).

11.4 *Initial Storage of Specimens.*-After each mold has been filled, place immediately in moist cabinet or room. Specimens shall remain in molds for 24±2 hours. Then, remove specimens from molds and, while protecting them from loss of moisture, properly identify and measure for initial length. The initial and all subsequent measurements shall be made and recorded to nearest 0.0001 inch (0.002 mm). If specimens appear too fragile to stand on end in container, return them to moist cabinet or room until such time as deemed feasible to place them in container.

11.5 *Subsequent Storage of Specimens.*-Stand specimens on end over, but not in contact with, water in storage container. Seal and place container in a cabinet or room maintained at 100±3 °F (37.8±1.7 °C).

12. Procedure

12.1 Remove specimens from container at least 4 hours (preferably 16 hours) before length measurements are to be made to permit them to cool to 73.4±3 °F (23±1.7 °C), the temperature at which measurements should be made. Make measurements at ages of 7 and 14 days; 1, 2, 3, 6, 9, and 12 months; and every 6 months thereafter until 2-years' age or until required data are obtained. These measurement ages may be varied to whatever circumstances are dictated. Record the measurement data on a form similar to the form shown on figure 6.

12.2 After each length measurement, specimens may be examined in same manner described in section 13 to provide supplemental information on their condition.

12.3 All specimens placed in a given container after initial length measurement shall have been made on same day, and shall be placed in the container at same time so that all specimens in a given container shall be due for measurement at same time. Each time length measurements are made, clean container and change water.

12.4 Always place specimens in comparator with same end uppermost; after measurement, replace specimens in container in inverted position as compared with previous period.

13. Examination at End of Test

13.1 After final length change measurements have been made, each specimen shall be examined and tested for warping.

13.1.1 *Warping.*-The warping, if any, that each specimen has manifested during the test period shall be determined by placing specimen on a plane surface and measuring maximum distance between specimen and surface. Specimen shall be placed so that its ends curve down to reference surface, and measurement made to nearest 0.01 inch (0.3 mm).

13.1.2 *Examination.*-Items to be noted in examination include:

- Presence, location, and type of cracking pattern.
- Appearance of surfaces and surface mottling.
- Surficial deposits or exudations, their nature, thickness, and continuity.

13.1.2.1 When it is believed that additional features of noteworthy importance are likely to be revealed thereby, a further examination of interior of specimen may be made, preferably by a petrographer. In such cases, the presence of gel-filled pores and fissures, evidence of reaction with aggregate particles of specific types, nature of such evidence, and properties of reaction products are among the items to be noted.

14. Calculation

14.1 Calculate the difference between initial length of specimen and the length at each period of measurement to nearest 0.001 percent of effective gauge length, and record this difference as the expansion of the specimen for that period. Report average of expansion of four specimens of a given cement-aggregate combination to nearest 0.01 percent as expansion for combination for a given period. Figure 6 shows a typical recording form.

15. Report

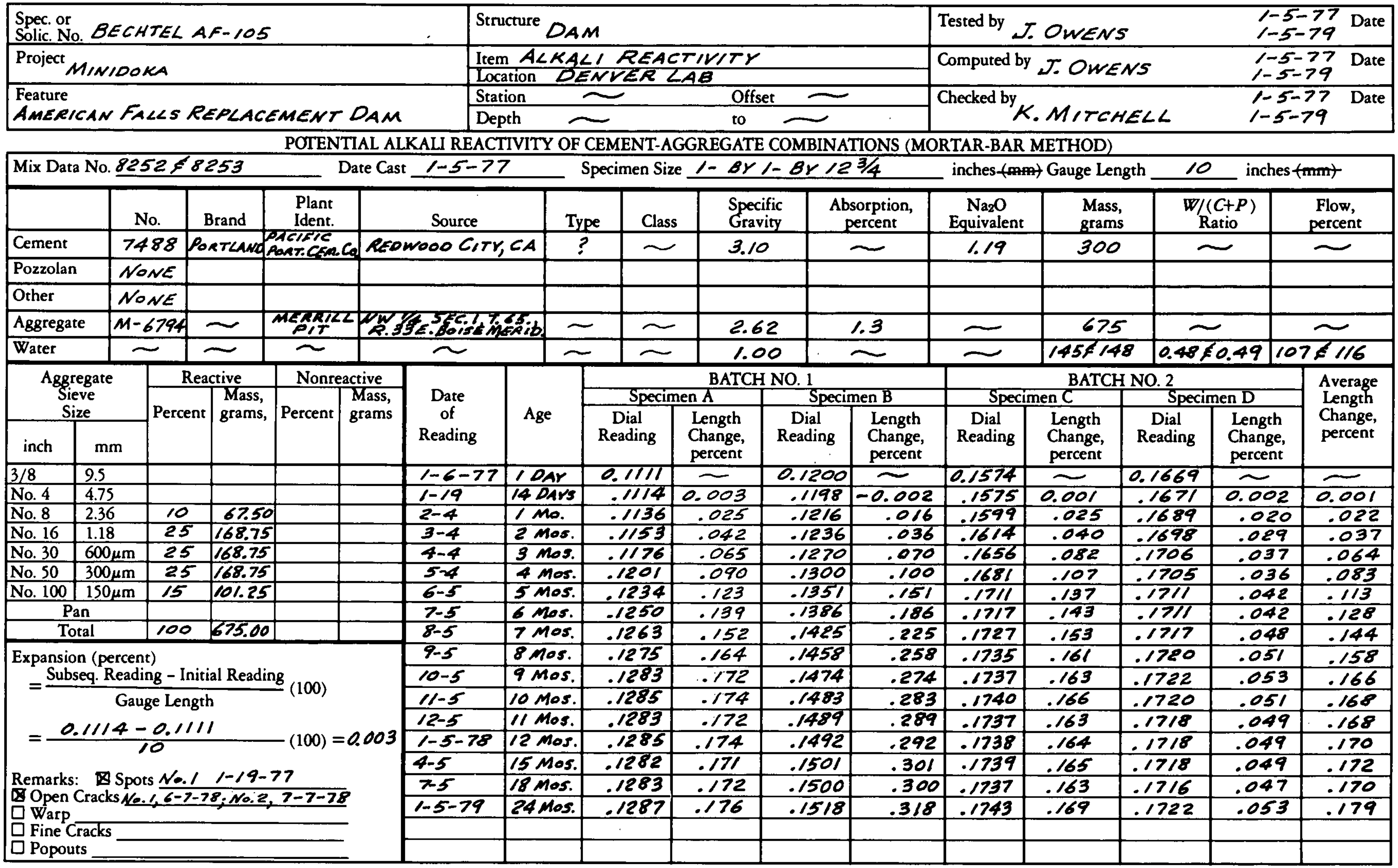
15.1 Figure 3 of USBR 4075 shows a typical reporting form. The report shall include:

- Type and source of aggregate.
- Type and source of portland cement.
- Alkali content of cement as percent K_2O (potassium oxide), Na_2O (sodium oxide), and calculated sodium oxide equivalent.
- Average length change in percent for each specimen measurement.
- Any relevant information concerning preparation of aggregate including grading of aggregate when it differs from that given in section 7.2.
- Any significant features revealed by examination of specimens during and after test.
- Amount of mixing water expressed as mass percent of the cement.
- Type, source, proportions, and chemical analyses, including Na_2O and K_2O, of any pozzolans employed in tests.

16. Precision and Bias

16.1 Precision shall be considered satisfactory if differences in the values for percentage expansion of any given specimen in a group, from average value for percentage expansion of group, does not exceed 0.003. An exception would be that, if average expansion exceeds 0.020 percent, the repeatability shall be considered satisfactory if percentage expansion of each specimen molded from same cement-aggregate combination is within 15 percent of average.

16.2 The test has no known bias.



Spec. or Solic. No. BECHTEL AF-105	Structure DAM	Tested by J. OWENS — Date 1-5-77 1-5-79
Project MINIDOKA	Item ALKALI REACTIVITY Location DENVER LAB	Computed by J. OWENS — Date 1-5-77 1-5-79
Feature AMERICAN FALLS REPLACEMENT DAM	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL — Date 1-5-77 1-5-79

POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (MORTAR-BAR METHOD)

Mix Data No. 8252 & 8253 Date Cast 1-5-77 Specimen Size 1- BY 1- BY 12 3/4 inches ~~(mm)~~ Gauge Length 10 inches ~~(mm)~~

	No.	Brand	Plant Ident.	Source	Type	Class	Specific Gravity	Absorption, percent	Na_2O Equivalent	Mass, grams	W/(C+P) Ratio	Flow, percent
Cement	7488	PORTLAND	PACIFIC PORT. CEM. Co	REDWOOD CITY, CA	?	~	3.10	~	1.19	300	~	~
Pozzolan	NONE											
Other	NONE											
Aggregate	M-6794	~	MERRILL PIT	NW 1/4 SEC. 1, T. 6S., R. 33E. BOISE MERID.	~	~	2.62	1.3	~	675	~	~
Water	~	~	~	~	~	~	1.00	~	~	145 & 148	0.48 & 0.49	107 & 116

Aggregate Sieve Size		Reactive		Nonreactive	
inch	mm	Percent	Mass, grams,	Percent	Mass, grams
3/8	9.5				
No. 4	4.75				
No. 8	2.36	10	67.50		
No. 16	1.18	25	168.75		
No. 30	600µm	25	168.75		
No. 50	300µm	25	168.75		
No. 100	150µm	15	101.25		
Pan					
Total		100	675.00		

Expansion (percent)

$$= \frac{\text{Subseq. Reading} - \text{Initial Reading}}{\text{Gauge Length}}(100)$$

$$= \frac{0.1114 - 0.1111}{10}(100) = 0.003$$

Remarks: ☒ Spots No. 1 1-19-77
☒ Open Cracks No. 1, 6-7-78; No. 2, 7-7-78
☐ Warp
☐ Fine Cracks
☐ Popouts

Date of Reading	Age	BATCH NO. 1				BATCH NO. 2				Average Length Change, percent
		Specimen A		Specimen B		Specimen C		Specimen D		
		Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	
1-6-77	1 DAY	0.1111	~	0.1200	~	0.1574	~	0.1669	~	~
1-19	14 DAYS	.1114	0.003	.1198	-0.002	.1575	0.001	.1671	0.002	0.001
2-4	1 Mo.	.1136	.025	.1216	.016	.1599	.025	.1689	.020	.022
3-4	2 Mos.	.1153	.042	.1236	.036	.1614	.040	.1698	.029	.037
4-4	3 Mos.	.1176	.065	.1270	.070	.1656	.082	.1706	.037	.064
5-4	4 Mos.	.1201	.090	.1300	.100	.1681	.107	.1705	.036	.083
6-5	5 Mos.	.1234	.123	.1351	.151	.1711	.137	.1711	.042	.113
7-5	6 Mos.	.1250	.139	.1386	.186	.1717	.143	.1711	.042	.128
8-5	7 Mos.	.1263	.152	.1425	.225	.1727	.153	.1717	.048	.144
9-5	8 Mos.	.1275	.164	.1458	.258	.1735	.161	.1720	.051	.158
10-5	9 Mos.	.1283	.172	.1474	.274	.1737	.163	.1722	.053	.166
11-5	10 Mos.	.1285	.174	.1483	.283	.1740	.166	.1720	.051	.168
12-5	11 Mos.	.1283	.172	.1489	.289	.1737	.163	.1718	.049	.168
1-5-78	12 Mos.	.1285	.174	.1492	.292	.1738	.164	.1718	.049	.170
4-5	15 Mos.	.1282	.171	.1501	.301	.1739	.165	.1718	.049	.172
7-5	18 Mos.	.1283	.172	.1500	.300	.1737	.163	.1716	.047	.170
1-5-79	24 Mos.	.1287	.176	.1518	.318	.1743	.169	.1722	.053	.179

Figure 6. – Typical data, recording, and calculation form (sheet 1 of 4).

Spec. or Solic. No. BECHTEL AF-105	Structure DAM	Tested by J. OWENS	1-5-77 1-5-79 Date
Project MINIDOKA	Item ALKALI REACTIVITY Location DENVER LAB	Computed by J. OWENS	1-5-77 1-5-79 Date
Feature AMERICAN FALLS REPLACEMENT DAM	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL	1-5-77 1-5-79 Date

POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (MORTAR-BAR METHOD)

Mix Data No. 8254 & 8255 Date Cast 1-5-77 Specimen Size 1- BY 1- BY 12¾ inches ~~(mm)~~ Gauge Length 10 inches ~~(mm)~~

	No.	Brand	Plant Ident.	Source	Type	Class	Specific Gravity	Absorption, percent	Na₂O Equivalent	Mass, grams	W/(C+P) Ratio	Flow, percent
Cement	M-5385	KAISER	KAISER CEM.&GYP.	MONTANA CITY, MT	II LA	~	3.19	~	0.44	300	~	~
Pozzolan	NONE											
Other	NONE											
Aggregate	M-6794	~	MERRILL PIT	NW¼ SEC.1, T.6S., R.33E, BOISE MERID.	~	~	2.62	1.3	~	675	~	~
Water	~	~	~	~	~	~	1.00	~	~	140 & 140	0.47 & 0.47	111 & 109

Aggregate Sieve Size		Reactive		Nonreactive	
inch	mm	Percent	Mass, grams,	Percent	Mass, grams
3/8	9.5				
No. 4	4.75				
No. 8	2.36	10	67.50		
No. 16	1.18	25	168.75		
No. 30	600µm	25	168.75		
No. 50	300µm	25	168.75		
No. 100	150µm	15	101.25		
Pan					
Total		100	675.00		

Date of Reading	Age	BATCH NO. 1				BATCH NO. 2				Average Length Change, percent
		Specimen A		Specimen B		Specimen C		Specimen D		
		Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	
1-6-77	1 DAY	0.1795	~	0.1632	~	0.1246	~	0.1539	~	~
1-19	14 DAYS	.1791	-0.004	.1630	-0.002	.1241	-0.005	.1535	-0.004	-0.004
2-4	1 MO.	.1796	.001	.1635	.003	.1250	.004	.1541	.002	.002
3-4	2 MOS.	.1800	.005	.1639	.007	.1252	.006	.1545	.006	.006
4-4	3 MOS.	.1801	.006	.1641	.009	.1255	.009	.1546	.007	.008
5-4	4 MOS.	.1798	.003	.1636	.004	.1250	.004	.1542	.003	.004
6-5	5 MOS.	.1802	.007	.1641	.009	.1253	.007	.1550	.011	.008
7-5	6 MOS.	.1801	.006	.1641	.009	.1253	.007	.1547	.008	.008
8-5	7 MOS.	.1804	.009	.1642	.010	.1253	.007	.1547	.008	.008
9-5	8 MOS.	.1806	.011	.1645	.013	.1256	.010	.1550	.011	.011
10-5	9 MOS.	.1806	.011	.1645	.013	.1260	.014	.1554	.015	.013
11-5	10 MOS.	.1806	.011	.1646	.014	.1258	.012	.1553	.014	.013
12-5	11 MOS.	.1803	.008	.1643	.011	.1256	.010	.1550	.011	.010
1-5-78	12 MOS.	.1806	.011	.1645	.013	.1258	.012	.1552	.013	.012
4-5	15 MOS.	.1804	.009	.1642	.010	.1251	.005	.1546	.007	.008
7-5	18 MOS.	.1803	.008	.1643	.011	.1255	.009	.1548	.009	.009
1-5-79	24 MOS.	.1808	.013	.1646	.014	.1257	.011	.1552	.013	.013

Expansion (percent)

$$= \frac{\text{Subseq. Reading - Initial Reading}}{\text{Gauge Length}}(100)$$

$$= \frac{0.1791 - 0.1795}{10}(100) = -0.004$$

Remarks: ☐ Spots ____

☐ Open Cracks ____

☐ Warp ____

☐ Fine Cracks ____

☐ Popouts ____

Figure 6. - Typical data, recording, and calculation form (sheet 2 of 4).

Spec. or Solic. No. BECHTEL AF-105	Structure DAM	Tested by J. OWENS	1-5-77 1-5-79	Date
Project MINIDOKA	Item ALKALI REACTIVITY Location DENVER LAB	Computed by J. OWENS	1-5-77 1-5-79	Date
Feature AMERICAN FALLS REPLACEMENT DAM	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL	1-5-77 1-5-79	Date

POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (MORTAR-BAR METHOD)

Mix Data No. 8256 & 8257 Date Cast 1-5-77 Specimen Size 1- BY 1- BY 12 3/4 inches ~~(mm)~~ Gauge Length 10 inches ~~(mm)~~

	No.	Brand	Plant Ident.	Source	Type	Class	Specific Gravity	Absorption, percent	Na₂O Equivalent	Mass, grams	W/(C+P) Ratio	Flow, percent
Cement	M-6795	KAISER	KAISER CEM. & GYP.	MONTANA CITY, MT	II LA	~	3.14	~	0.39	300	~	~
Pozzolan	NONE											
Other	NONE											
Aggregate	M-6794	~	MERRILL PIT	NW 1/4 SEC. 1, T.6S., R.33E., BOISE MERID	~	~	2.62	1.3	~	675	~	~
Water	~	~	~	~	~	~	1.00	~	~	144	0.48 & 0.48	109 & 109

Aggregate Sieve Size		Reactive		Nonreactive	
inch	mm	Percent	Mass, grams,	Percent	Mass, grams
3/8	9.5				
No. 4	4.75				
No. 8	2.36	10	67.50		
No. 16	1.18	25	168.75		
No. 30	600µm	25	168.75		
No. 50	300µm	25	168.75		
No. 100	150µm	15	101.25		
Pan					
Total		100	675.00		

Expansion (percent)

$$= \frac{\text{Subseq. Reading - Initial Reading}}{\text{Gauge Length}}(100)$$

$$= \frac{0.1433-0.1442}{10}(100) = -0.009$$

Remarks: ☐ Spots
☐ Open Cracks
☐ Warp
☐ Fine Cracks
☐ Popouts

Date of Reading	Age	BATCH NO. 1				BATCH NO. 2				Average Length Change, percent
		Specimen A		Specimen B		Specimen C		Specimen D		
		Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	
1-6-77	1 DAY	0.1442	~	0.1164	~	0.1035	~	0.0944	~	~
1-19	14 DAYS	.1433	-0.009	.1163	-0.001	.1026	-0.009	.0938	-0.006	-0.006
2-4	1 MO.	.1439	.003	.1162	-0.002	.1034	-0.001	.0944	0.000	-0.002
3-4	2 MOS.	.1443	.001	.1165	.001	.1037	.002	.0947	.003	.002
4-4	3 MOS.	.1443	.001	.1167	.003	.1037	.002	.0947	.003	.002
5-4	4 MOS.	.1443	.001	.1163	-0.001	.1033	-0.002	.0944	0.000	.000
6-5	5 MOS.	.1444	.002	.1167	.003	.1038	.003	.0949	.005	.003
7-5	6 MOS.	.1447	.005	.1168	.004	.1038	.003	.0950	.006	.004
8-5	7 MOS.	.1449	.007	.1168	.004	.1040	.005	.0952	.008	.006
9-5	8 MOS.	.1449	.007	.1173	.009	.1042	.007	.0953	.009	.008
10-5	9 MOS.	.1450	.008	.1174	.010	.1046	.011	.0955	.011	.010
11-5	10 MOS.	.1451	.009	.1174	.010	.1046	.011	.0955	.011	.010
12-5	11 MOS.	.1448	.006	.1172	.008	.1042	.007	.0951	.007	.007
1-5-78	12 MOS.	.1451	.009	.1174	.010	.1044	.009	.0954	.010	.010
4-5	15 MOS.	.1446	.004	.1171	.007	.1042	.007	.0950	.006	.006
7-5	18 MOS.	.1448	.006	.1171	.007	.1043	.008	.0952	.008	.008
1-5-79	24 MOS.	.1454	.012	.1176	.012	.1046	.011	.0956	.012	.012

Figure 6. - Typical data, recording, and calculation form (sheet 3 of 4).

Spec. or Solic. No. BECHTEL AF-105	Structure DAM	Tested by J. OWENS 1-5-77 1-5-79 Date
Project MINIDOKA	Item ALKALI REACTIVITY Location DENVER LAB	Computed by J. OWENS 1-5-77 1-5-79 Date
Feature AMERICAN FALLS REPLACEMENT DAM	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL 1-5-77 1-5-79 Date

POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (MORTAR-BAR METHOD)

Mix Data No. 8258 & 8259 Date Cast 1-5-77 Specimen Size 1- BY 1- BY 12 3/4 inches ~~(mm)~~ Gauge Length 10 inches ~~(mm)~~

	No.	Brand	Plant Ident.	Source	Type	Class	Specific Gravity	Absorption, percent	Na₂O Equivalent	Mass, grams	W/(C+P) Ratio	Flow, percent
Cement	M-6795	KAISER	KAISER CEM.& GYP.	MONTANA CITY, MT	II LA	~	3.14	~	0.39	240	~	~
Pozzolan	M-6796	LASSENITE	?	HALLELUJAH JUNCTION, CA	~	N	2.37	~	~	60	20% POZZ. REPLACE.	~
Other	NONE											
Aggregate	M-6794	~	MERRILL PIT	NW 1/4 SEC.1, T.6 S. R.33 E., BOISE MERID			2.62	1.3		675	~	~
Water	~	~	~	~	~	~	1.00		~	170 & 180	0.57 & 0.57	109 & 109

Aggregate Sieve Size		Reactive		Nonreactive	
inch	mm	Percent	Mass, grams,	Percent	Mass, grams
3/8	9.5				
No. 4	4.75				
No. 8	2.36	10	67.50		
No. 16	1.18	25	168.75		
No. 30	600μm	25	168.75		
No. 50	300μm	25	168.75		
No. 100	150μm	15	101.25		
Pan					
Total		100	675.00		

Expansion (percent)

$$= \frac{\text{Subseq. Reading} - \text{Initial Reading}}{\text{Gauge Length}} (100)$$

$$= \frac{0.1589 - 0.1596}{10} (100) = -0.007$$

Remarks: ☐ Spots ________

☐ Open Cracks ________

☐ Warp ________

☐ Fine Cracks ________

☐ Popouts ________

Date of Reading	Age	BATCH NO. 1				BATCH NO. 2				Average Length Change, percent
		Specimen A		Specimen B		Specimen C		Specimen D		
		Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	Dial Reading	Length Change, percent	
1-6-77	1 DAY	0.1596	~	0.1632	~	0.1566	~	0.1735	~	~
1-19	14 DAYS	.1589	-0.007	.1627	-0.005	.1560	-0.006	.1729	-0.006	-0.006
2-4	1 MO.	.1595	-0.001	.1633	.001	.1566	.000	.1734	-0.001	.000
3-4	2 MOS.	.1597	.001	.1635	.003	.1569	.003	.1738	.003	.002
4-4	3 MOS.	.1597	.001	.1635	.003	.1569	.003	.1738	.003	.002
5-4	4 MOS.	.1592	-0.004	.1630	-0.002	.1566	.000	.1734	-0.001	-0.002
6-5	5 MOS.	.1597	.001	.1636	.004	.1570	.004	.1739	.004	.003
7-5	6 MOS.	.1597	.001	.1636	.004	.1571	.005	.1739	.004	.003
8-5	7 MOS.	.1601	.005	.1642	.010	.1572	.006	.1740	.005	.006
9-5	8 MOS.	.1601	.005	.1642	.010	.1576	.010	.1743	.008	.008
10-5	9 MOS.	.1603	.007	.1643	.011	.1578	.012	.1747	.012	.010
11-5	10 MOS.	.1604	.008	.1644	.012	.1579	.013	.1747	.012	.011
12-5	11 MOS.	.1600	.004	.1640	.008	.1575	.009	.1744	.009	.008
1-5-78	12 MOS.	.1604	.008	.1643	.011	.1580	.014	.1748	.013	.012
4-5	15 MOS.	.1602	.006	.1642	.010	.1576	.010	.1744	.009	.009
7-5	18 MOS.	.1601	.005	.1639	.007	.1576	.010	.1745	.010	.008
1-5-79	24 MOS.	.1609	.013	.1648	.016	.1582	.016	.1750	.015	.015

Figure 6. - Typical data, recording, and calculation form (sheet 4 of 4).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4231-92

PROCEDURE FOR

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4231; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 231-82.

1. Scope

1.1 This designation covers the procedure for determination of the air content of freshly mixed concrete by observation of the change in volume of concrete with a change in pressure.

1.2 This procedure is intended for use with concretes and mortars made with relatively dense aggregates for which the aggregate correction factor can be satisfactorily determined by the technique described in section 7. This procedure is not applicable to concretes made with lightweight aggregates, air-cooled blast furnace slag, or aggregates of high porosity; see USBR 4173 for these cases.

2. Applicable Documents

2.1 *USBR Procedures*:

4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4094 Specifications for Ready-Mixed Concrete
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4192 Making and Curing Concrete Test Specimens in Laboratory
4211 Selecting Proportions for Concrete Mixtures

2.2 *ASTM Standard*:

C 231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[1]

3. Apparatus

3.1 *Air Meters*.–There are air meters available that satisfy the two basic operational designs employing the principle of Boyle's law. For purposes of reference, these two meters are designated Type A Meter and Type B Meter.

3.1.1 *Type A Meter*.–An air meter consisting of a measuring bowl and cover assembly (figs. 1, 2, and 3) conforming to requirements of sections 3.2 and 3.3. The operational principle of this meter consists of introducing water to a predetermined height above a sample of concrete of known volume, and the application of a predetermined air pressure over the water. The determination consists of the reduction in volume of air in concrete sample by observing the amount the water level is lowered under the applied pressure, which is calibrated in terms of percent of air in concrete sample.

3.1.2 *Type B Meter*.–An air meter consisting of a measuring bowl and cover assembly (figs. 4, 5, 6, and 7) conforming to requirements of sections 3.2 and 3.3. The operational principle of this meter consists of equalizing a known volume of air at a known pressure in a sealed air chamber with an unknown volume of air in concrete sample. The pressure gauge is calibrated in terms of percent of air for the observed pressure at which equalization takes place. Working pressures of 7.5 to 30.0 lbf/in^2 (51.7 to 206.8 kPa) have been used satisfactorily.

3.2 *Measuring Bowl*.–The measuring bowl shall be essentially cylindrical in shape, made of steel or other hard metal not readily attacked by the cement paste, have a minimum diameter of from 0.75 to 1.25 times height of bowl; and a capacity of at least 0.20 ft^3 (0.006 m^3) for 1-1/2-inch (37.5-mm) MSA (maximum size aggregate) or 0.40 ft^3 (0.012 m^3) for 3-inch (75-mm) MSA. (Refer to figs. 8 and 9.) Bowl shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly. Interior surfaces of bowl and surfaces of rims, flanges, and other component fitted parts shall be machined smooth. The measuring bowl and cover assembly shall be sufficiently rigid to limit the expansion factor, D, of the apparatus assembly to not more than 0.1 percent of air content on indicator scale when under normal operating pressure, refer to appendix X1 (sec. X1.6).

3.2.1 *Calibration Equipment*.–A piece of plate glass, preferably at least 1/4 inch (6 mm) thick and at least 1 inch (25 mm) larger than diameter of measure to be

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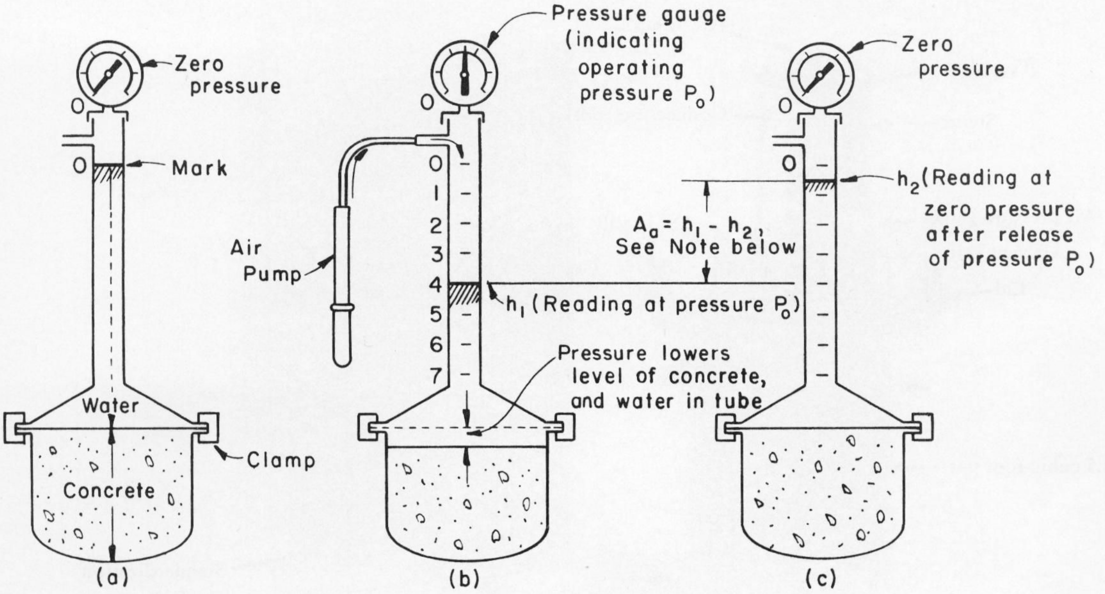
[1] *Annual Book of ASTM Standards*, vol. 04.02.



Note: $A_a = h_1 - h_2$ when bowl contains concrete as shown; when bowl contains only aggregate and water, $h_1 - h_2 = G_1$ (aggregate correction factor). $A_a - G_1 = A_s$ (true air content of concrete test sample).

Figure 1. – Illustration of pressure method for air content of a Type A meter.

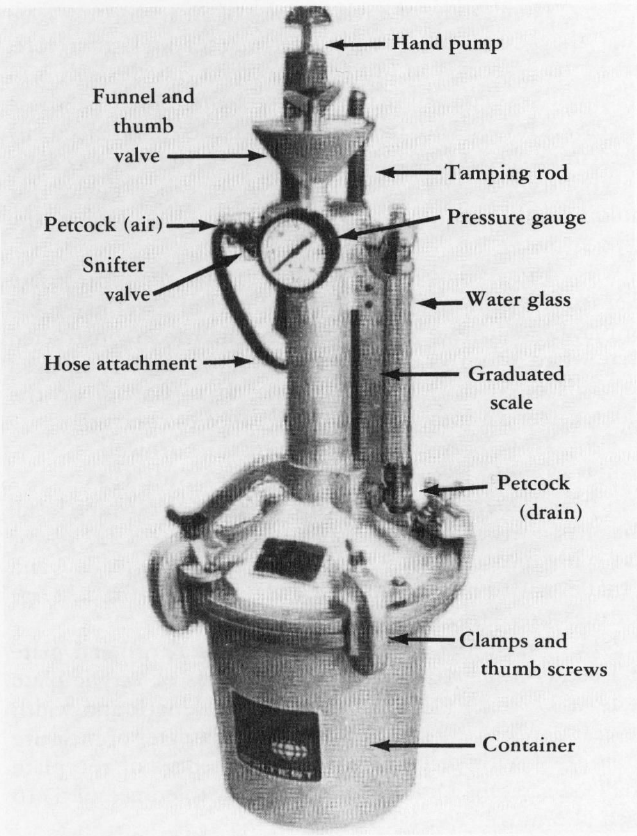


Figure 2. – Photograph of a typical Type A meter (commonly called an Acme Air Meter).

calibrated, is required. A supply of water-pump or chassis grease will be necessary to place on rim of container to prevent leakage.

3.3 *Cover Assembly*:

3.3.1 The cover assembly shall be made of steel or other hard metal not readily attacked by the cement paste. Cover shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly, and shall have interior surfaces machined smooth and contoured to provide an air space above top level of measuring bowl. Cover shall be sufficiently rigid to limit the expansion factor of the apparatus assembly (sec. 3.2).

3.3.2 Cover assembly shall be fitted with a means for direct reading of air content. The cover for the type A meter shall be fitted with a standpipe, which may be a transparent graduated tube or a metal tube of uniform bore with an attached glass water gauge. For the type B meter, dial of pressure gauge shall be calibrated to indicate percent of air. Graduations shall be provided for an air-content range of at least 8 percent and easily readable to 0.1 percent, as determined by proper air-pressure calibration test.

3.3.3 Cover assembly shall be fitted with air valves, air-bleeder valves, and petcocks for bleeding off or through which water may be introduced as necessary for particular meter design. Suitable means for clamping cover to bowl shall be provided to make a pressure-tight seal without entrapping air at the joint between flanges of cover and bowl. A suitable hand pump shall be provided with the cover either as an attachment or as an accessory.

3.4 *Calibration Vessel*.–A vessel having an internal volume equal to a percent of the volume of measuring

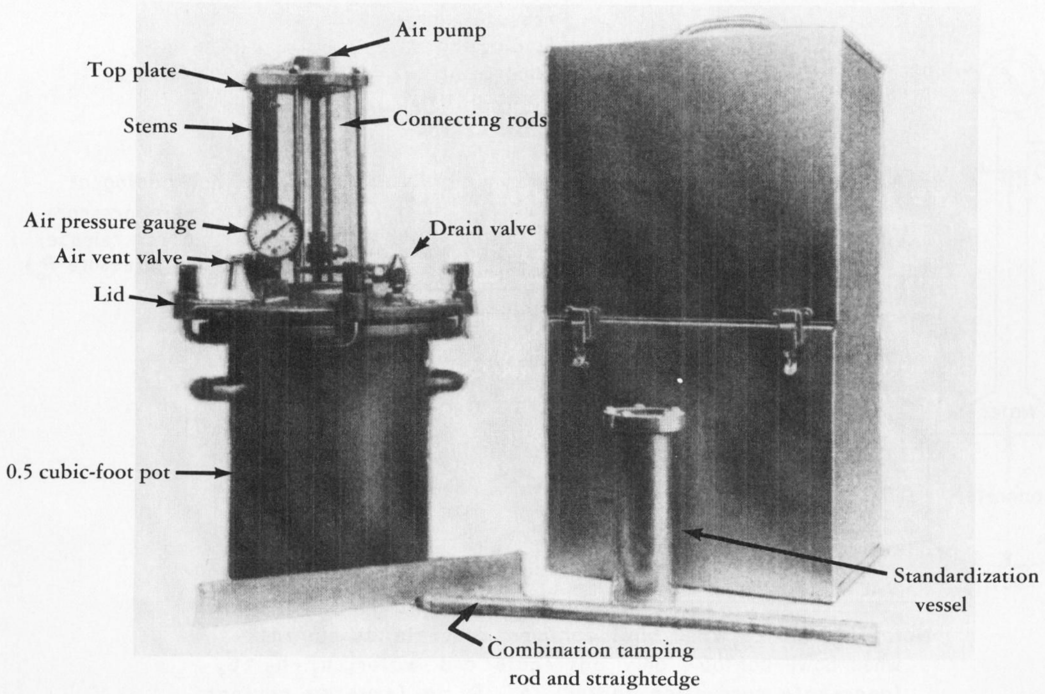


Figure 3. - Photograph of a typical Type A meter (commonly called Protex PAM-C25 or PAM-C50, or Precision CT-125 or CT-150.

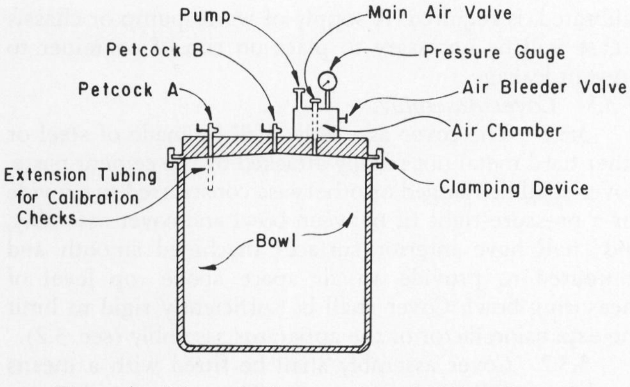


Figure 4. - Schematic diagram of a typical Type B meter.

bowl corresponding to the approximate percent of air in concrete to be tested; or, if smaller, it shall be possible to check calibration of air meter indicator at approximate percent of air in concrete to be tested by repeated filling of vessel. When design of air meter requires placing calibration vessel within measuring bowl to check calibration, the vessel shall be cylindrical in shape and have an inside depth 1/2 inch (13 mm) less than that of bowl. A satisfactory vessel of this type may be machined from No. 16 gauge brass tubing, of a diameter to provide volume desired, to which a 1/2-inch-thick brass disk is soldered to form an end. When design of air meter requires the withdrawal of water from water-filled bowl and cover assembly to check calibration, the vessel may be an integral part of the cover assembly or may be a separate vessel as previously described. (Refer to fig. 9.)

3.5 The designs of various types of air meters are such that they differ in operating techniques and; therefore, all items described in following sections 3.6 through 3.14 may not be required. The items required shall be those necessary for use with particular design used to satisfactorily determine the air content in accordance with this procedure.

3.6 *Coil Spring*.-A coil spring or other device for holding calibration vessel inverted in place within the type A meter.

3.7 *Spray Tube*.-A brass spray tube of appropriate diameter, which may be an integral part of cover assembly or may be a separate item. Spray tube shall be so constructed that when water is added to container, water is sprayed to walls of cover in such a manner as to flow down the sides, causing a minimum of disturbance to concrete.

3.8 *Trowel*.-A standard brick mason's trowel.

3.9 *Tamping Rod*.-As described in USBR 4143.

3.10 *Mallets*.-A mallet with a rubber or rawhide head, that has a mass of about 1.25±0.50 lbm (567±227 g) for use with measures of 0.5 ft^3 (0.014 m^3) or smaller, and a mallet with a mass of about 2.25±0.50 lbm (1020±227 g) for measures larger than 0.5 ft^3.

3.11 *Strike-Off Plate*.-A flat, rectangular, metal plate at least 1/4 inch (6 mm) thick or a glass or acrylic plate at least 1/2 inch (13 mm) thick with a length and width at least 2 inches (50 mm) greater than diameter of measure to be used with plate is required. The edges of the plate shall be straight and smooth within a tolerance of 1/16 inch (1.6 mm).

3.12 *Funnel*.-A funnel with a spout that will fit into spray tube.

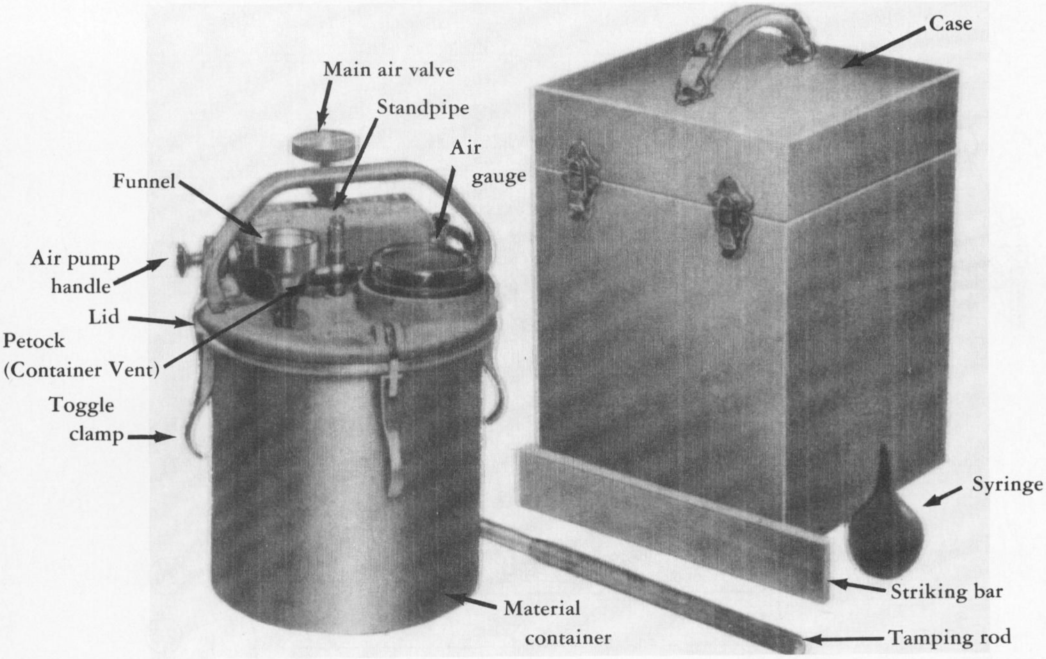


Figure 5. - Photograph of a typical Type B meter (commonly called a White, Techote, or Precision CT-126 Air Meter).

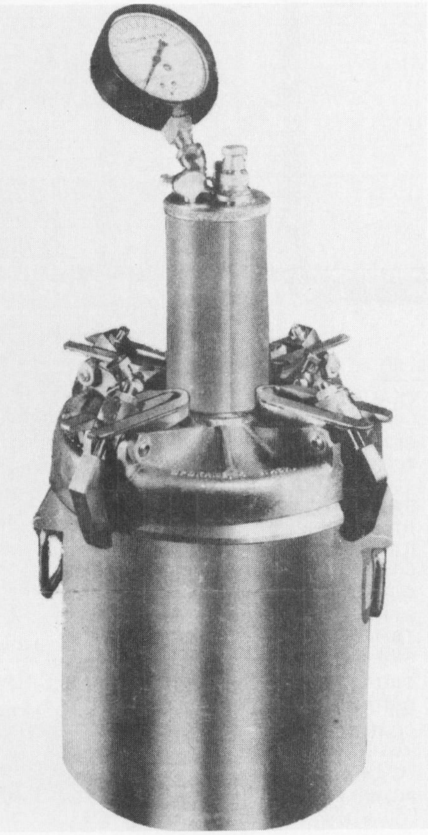


Figure 6. - Photograph of a typical Type B meter (commonly called a Press-Ur-Meter CT-129, Watts Press-Ur-Meter, or a WPC Press-Ur-Meter).

3.13 *Measure for Water*.–A measure that has the necessary capacity to fill indicator with water from top of concrete to zero mark.

3.14 *Vibrators* .–The vibrators shall comply with requirements of USBR 4031 or 4192.

3.15 *Sieve*.–A 1-1/2-inch (37.5-mm) sieve with not less than 2 ft² (0.18 m²) of sieving area, or a 3-inch (75-mm) sieve.

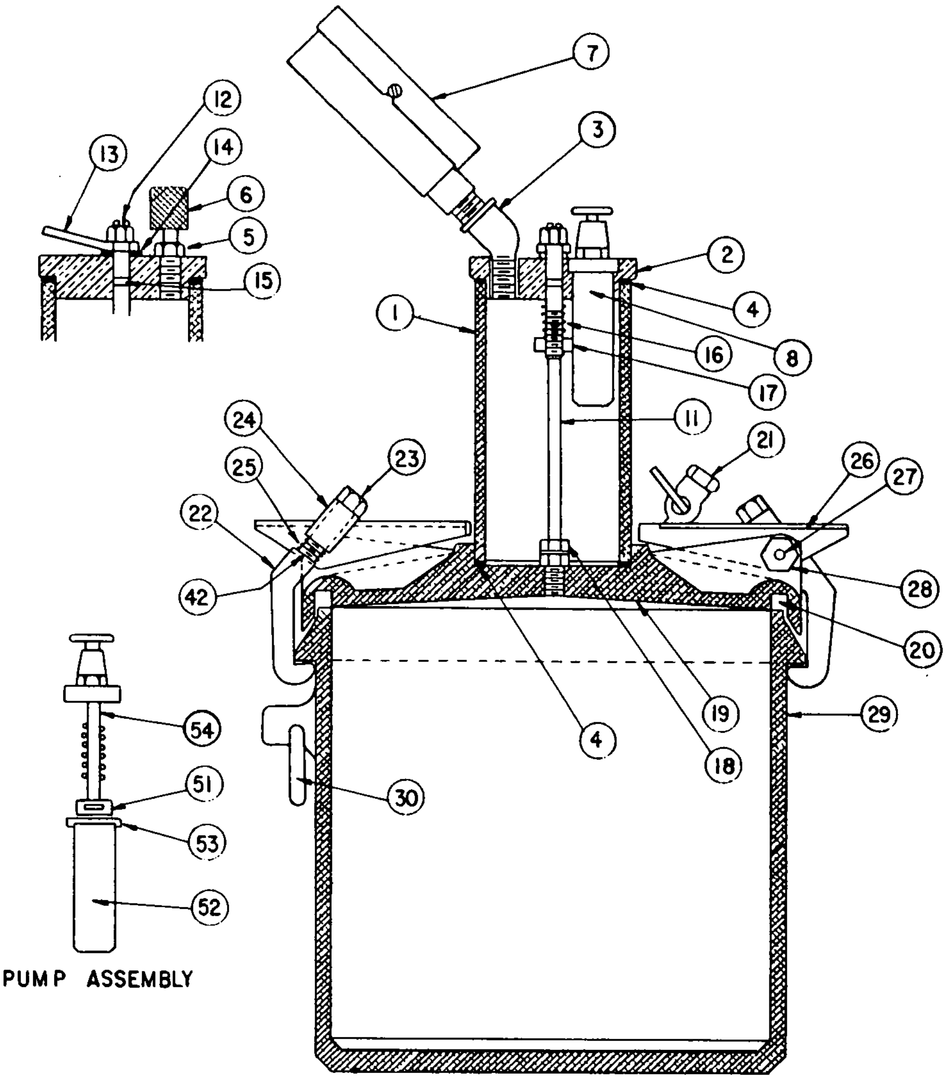
4. Precautions

4.1 No special precautions are applicable from the standpoint of safety.

4.2 Any special precautions in the calibration of equipment or in test procedure per se are outlined as necessary in section 5 and appendix X1.

5. Calibration of Apparatus

5.1 Make calibration tests in accordance with methods described in appendixes X1 and X2. Use care when using equipment because rough handling will affect the calibration of both the type A and B meters. Changes in barometric pressure will affect calibration of type A meter but not the type B meter. The steps described in appendix sections X1.3 through X1.7 and X2.3 through X2.7, as applicable to type of meter under consideration, are prerequisites for final calibration test to determine operating pressure on pressure gauge of type A meter or to determine accuracy of graduations indicating air content on dial face of pressure gauge of type B meter. Normally, the steps outlined in the appendix sections need only to be made once (at time of initial calibration), or to occasionally check volume constancy of calibration cylinder



PART NO.	
1.	PRESSURE CHAMBER
2.	PRESSURE CHAMBER CAP
3.	PRESSURE CHAMBER ELBOW
4.	PRESSURE CHAMBER GASKET
5.	PRESSURE CHAMBER AIR RELEASE STEM
6.	PRESSURE CHAMBER AIR RELEASE CAP
6A.	RELEASE CAP *
7.	COMPLETE GAUGE
8.	PUMP ASSEMBLY (COMPLETE)
9.	PUMP PISTON LEATHER *
10.	PUMP AIR CHECK GASKET *
11.	NEEDLE VALVE STEM
12.	NEEDLE VALVE NUT
13.	NEEDLE VALVE LEVER
14.	NEEDLE VALVE SPACER
15.	NEEDLE VALVE "O" RING
16.	NEEDLE VALVE SPRING
17.	NEEDLE VALVE SPRING RETAINER
18.	NEEDLE VALVE SEAT ASSEMBLY
19.	COVER
20.	COVER "O" RING
21.	COVER PETCOCK
22.	CLAMP
23.	CLAMP NUT
24.	CLAMP TRUNION
25.	CLAMP SPRING
26.	CLAMP TOGGLE
27.	TOGGLE SET SCREW
28.	TOGGLE LOCK NUT
29.	BASE
30.	BASE HANDLE
31.	CALIBRATING VESSEL *
32.	CALIBRATING TUBE (OUTER) *
33.	CALIBRATING TUBE (INNER) *
34.	STRIKE-OFF BAR *
35.	TAMPING ROD *
36.	SYRINGE *
37.	GAUGE GLASS *
38.	CARRYING CASE *
42.	CLAMP STUD
50.	PUMP PISTON *
51.	"O" RING FOR PUMP PISTON
52.	PUMP TUBE ASSEMBLY
53.	"O" RING FOR TUBE SEAL
54.	PUMP PISTON ASSEMBLY

*NOT ILLUSTRATED

Figure 7. - Schematic diagram of Type B meter shown on figure 6.

and measuring bowl. However, the calibration test described in appendix sections X1.8 and X2.8, as applicable to type of meter being checked, must be made as frequently as necessary to ensure that proper gauge pressure is being used for type A meter or that correct air contents are being indicated on pressure gauge air-content scale for type B meter. A change in elevation of more than 600 feet (183 m), from location at which type A meter was last calibrated, will require recalibration. (Refer to figs. 8, 9, and 10.)

6. Conditioning

6.1 *Fine and Coarse Aggregate.*-Conditioning of the fine and coarse aggregate moisture content for the aggregate correction factor is covered in section 7.2.

6.2 *Concrete Test Sample.*-Preparation of concrete test sample to exclude aggregate larger than 1-1/2 or 3 inches (37.5 or 75 mm) is covered in section 8.1.

7. Determination of Aggregate Correction Factor

7.1 *Aggregate Correction Factor.*-The determination of the aggregate correction factor has not been a standard practice for the Bureau of Reclamation. For sound, dense aggregates-the factor is assumed to be zero. However, some authorities believe this factor should not be ignored even with good aggregate because the correction factor may fall in the range of 0.2 to 0.4 percent. With porous or lightweight aggregates, the correction factor may be 0.8 percent or higher, in which case the procedure of USBR 4173 may be more appropriate.

7.1.1 It is recommended that the aggregate correction factor be determined for each aggregate source used. In the event of a controversy or borderline point of rejection, the aggregate correction factor must be determined and included in determination of air content.

7.2 *Procedure.*-Determine the aggregate correction factor on a combined sample of fine and coarse aggregate as directed in sections 7.3, 7.4, and 7.5. The factor is determined independently by applying calibrated pressure to a sample of inundated fine and coarse aggregate in about the same moisture condition, amount, and proportions occurring in concrete sample under test. Figure 11 shows a typical calculation form for determining the correction factor.

7.3 *Aggregate Sample Size.*-Calculate the mass of fine and coarse aggregate present in the sample for fresh concrete, for which the air content is to be determined:

$$F_s = \frac{S}{B}(F_b) \tag{1}$$

$$C_s = \frac{S}{B}(C_b) \tag{2}$$

where:

F_s = mass of fine aggregate in concrete sample, in pound mass (kilograms);

S = volume of concrete sample (same as volume of measuring bowl, V_B), in cubic feet or cubic meters;

B = volume of concrete produced per batch (note 1), in cubic feet, cubic yards, or cubic meters;

F_b = total mass of fine aggregate in the moisture condition used in batch, in pound mass (kilograms);

C_s = mass of coarse aggregate in concrete sample, in pound mass (kilograms); and

C_b = total mass of coarse aggregate in the moisture condition used in batch, in pound mass (kilograms).

NOTE 1.-The volume of concrete produced per batch can be determined in accordance with applicable provisions of USBR 4138.

7.4 *Placement of Aggregate in Measuring Bowl.*-Mix representative samples of fine aggregate F_s and coarse aggregate C_s and place in measuring bowl filled one-third full with water. Place mixed aggregate, a small amount at a time, into bowl. If necessary, add additional water so as to inundate all of the aggregate. Add each scoopful of aggregate in a manner that will entrap as little air as possible, and promptly remove accumulations of foam. After each addition of aggregate, stir mixture to eliminate entrapped air, tap sides of bowl, and lightly rod upper 1 inch (25 mm) of mixture about 10 times.

7.5 *Aggregate Correction Factor Determination*:

7.5.1 *Initial Procedure for Types A and B Meters.*-When all aggregate has been placed in measuring bowl, remove excess foam and keep aggregate inundated for a period approximately equal to time between introduction of water into bowl and time of performing the test for air content before proceeding with determination of factor as directed in 7.5.2 or 7.5.3.

7.5.2 *Type A Meter.*-Complete the test as described in sections 9.2.1 and 9.2.2. The aggregate correction factor, G_1, is equal to $h_1 - h_2$, see figure 1 (note 2).

NOTE 2.-The aggregate correction factor will vary with different aggregates. Factor can be determined only by test because it is not apparently directly related to absorption of the particles. The test can be easily performed, and the factor will usually remain reasonably constant for given aggregates. However, an occasional check test is recommended.

7.5.3 *Type B Meter.*-Perform the test as described in section 9.3.1. From the assembled and filled apparatus, remove a volume of water that is approximately equal to volume of air that would be contained in a typical concrete sample of a size equal to volume of bowl. Remove this water in the manner described in section X2.8 of appendix X2. Then, complete the test in accordance with section 9.3.2. The aggregate correction factor, G_2, is equal to reading on air-content scale minus the volume of water removed from bowl, expressed as a percent of volume of bowl.

8. Preparation of Concrete Test Sample

8.1 Obtain the sample of freshly mixed concrete in accordance with applicable procedures of USBR 4172. If concrete contains coarse aggregate particles that would be retained on a 1-1/2- or 3-inch (37.5- or 75-mm) sieve, wet sieve a sufficient amount of representative sample over one of these sieves, as described in USBR 4172, to yield somewhat more than enough material to fill measuring bowl with size selected for use. Perform the wet-sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on sieve.

9. Procedure for Determining Air Content of Concrete

9.1 *Placement and Consolidation of Sample*:

9.1.1 Place a representative sample of concrete, prepared as described in section 8, in measuring bowl in equal layers. Consolidate each layer by rodding (9.1.2) or by vibration (9.1.3). Strike off the final consolidated layer (9.1.4). Rod concretes with a slump greater than 3 inches (76 mm), rod or vibrate concretes with a slump of 1 to 3 inches (25 to 76 mm), and consolidate concretes with a slump of less than 1 inch (25 mm) by vibration. Determine the slump in accordance with USBR 4143

9.1.2 *Rodding*.-Place concrete in measuring bowl in three layers of approximately equal volume (3-inch MSA shall be placed only by vibration). Consolidate each layer using 25 strokes of tamping rod evenly distributed over the cross section. After each layer is rodded, tap sides of bowl sharply 10 to 15 times with the mallet to close any voids left by tamping rod and to release any large air bubbles that may have been trapped. Rod bottom layer throughout its depth; however, rod shall not forcibly strike bottom of bowl. When rodding second and final layers, use only enough force to cause rod to penetrate surface of previous layer about 1 inch (25 mm). Add final layer of concrete in a manner to avoid excessive overfilling (9.1.4).

9.1.3 *Vibration*:

9.1.3.1 *Internal Vibration*.-Place concrete in measuring bowl in two layers of approximately equal volume. Place all concrete for each layer before starting vibration of that layer. Consolidate each layer wih three insertions (six insertions for 3-inch MSA) of vibrator evenly distributed over the cross section. Add final layer in a manner to avoid excessive overfilling (9.1.4). When consolidating bottom layer, do not allow vibrator to rest on or touch bottom or sides of bowl. Take care when withdrawing vibrator to ensure that no air pockets are left in concrete. Observe a standard duration of vibration for the particular kind of concrete, vibrator, and measuring bowl involved. This duration will depend upon workability of concrete and effectiveness of vibrator. Continue vibration only long enough to achieve proper consolidation of concrete. Overvibration may cause segregation and loss of intentionally entrained air. Usually, sufficient vibration has been applied when surface of concrete becomes relatively smooth and has a glazed appearance. Never continue vibration long enough to cause escape of froth from sample.

9.1.3.2 *External Vibration*.-The external vibrators shall be operated in accordance with section 3.4 of USBR 4031 or section 3.6 of USBR 4192.

9.1.4 *Strike Off*.-After consolidation of concrete, strike off top surface by sliding strike-off plate across top flange or rim of measuring bowl with a sawing motion until bowl is just level full. On completion of consolidation, bowl must not contain a great excess or deficiency of concrete. Removal of about 1/8 inch (3 mm) of concrete during strike off is optimum. A small quantity of representative concrete may be added to correct a deficiency. If bowl contains a great excess of concrete, remove a representative portion with a trowel or scoop before strike off.

9.1.5 *Application of Test Method*.-Any portion of test method not specifically designated as pertaining to the type A or type B meter shall apply to both types.

9.2 *Procedure for Type A Meter*:

9.2.1 *Preparation for Test*.-Thoroughly clean flanges or rims of bowl and cover assembly so that when cover is clamped in place, a pressure-tight seal will be obtained. Assemble the apparatus and add water over the concrete using the spray tube until water rises to about the halfway mark in the standpipe. Incline apparatus assembly about 30° from vertical and, using bottom of bowl as a pivot, inscribe several complete circles with upper end of column, simultaneously tapping cover lightly to remove any entrapped air bubbles above concrete sample. Return assembly to a vertical position and fill water column slightly above zero mark, while lightly tapping sides of bowl. Bring water level to zero mark of graduated tube before closing vent at top of water column, see figure 1(a).

NOTE 3.-The internal surface of cover assembly should be kept clean and free from oil or grease; surface should also be wet to prevent adherence of air bubbles that might be difficult to dislodge after assembly of apparatus.

9.2.2 *Test Procedure*.-Apply slightly more than the desired test pressure, about 0.2 lbf/in^2 (1.38 kPa) more, to the concrete using the small hand pump. To relieve local restraints, tap sides of bowl sharply and, when pressure gauge indicates exact test pressure, P_o, as determined in accordance with appendix section X1.8, read the water level h_1, and record this level to the nearest division or half-division on the graduated precision-bore tube or gauge glass of standpipe, see figure 1(b). For extremely harsh mixes, it may be necessary to tap bowl vigorously until further tapping produces no change in indicated air content. Gradually release air pressure through vent at top of water column and tap sides of bowl lightly for about 1 minute. Record water level, h_2 to nearest division or half-division, see figure 1(c). Then, calculate the apparent air content:

$$A_a = h_1 - h_2 \tag{3}$$

where:

A_a = apparent air content of test sample, in percent;

h_1 = water level reading at pressure P_o, and
h_2 = water level reading at zero pressure after release of pressure P_o.

9.2.3 *Check Test*.-Repeat the steps described in section 9.2.2, except do not add water to reestablish water level at zero mark. The two consecutive determinations of apparent air content should check within 0.2 percent, and shall be averaged to give the value of A_a to be used in calculating the air content, A_s in accordance with section 10.

9.2.4 If air content exceeds range of meter when operating at normal test pressure P_o, reduce pressure to an alternative test pressure and repeat steps of 9.2.2 and 9.2.3, where P_o is the normal test or operating gauge pressure in pound force per square inch (kilopascals).

9.2.5 Figure 11 shows a typical calculation form.

9.3 *Procedure for Type B Meter*:

9.3.1 *Preparation for Test*.-Thoroughly clean flanges or rims of measuring bowl and cover assembly so that when cover is clamped in place, a pressure-tight seal will be obtained. Then, assemble the apparatus. Close air valve between air chamber and bowl, and open both petcocks on holes through cover. Using a rubber syringe, inject water through one petcock until water emerges from opposite petcock. Jar the meter gently until all air is expelled from petcock.

9.3.2 *Test Procedure*.-Close air-bleeder valve on air chamber and pump air into chamber until gauge hand is on initial pressure line. Allow a few seconds for compressed air to cool to normal temperature. Stabilize gauge hand at initial pressure line by pumping or bleeding off air as necessary, tapping gauge lightly. Close both petcocks on holes through cover. Open air valve between air chamber and bowl. Tap sides of bowl sharply to relieve local restraints. Lightly tap pressure gauge to stabilize gauge hand and read percentage of air on dial of pressure gauge. Failure to close main air valve before releasing pressure from either the container or air chamber will result in water being drawn into air chamber, thus introducing an error in subsequent measurements. If water enters air chamber, water must be bled from chamber through bleeder valve followed by several strokes of pump to blow out all traces of water. Release pressure by opening both petcocks before removing cover (fig. 5).

10. Calculations

10.1 *Air Content of Sample Tested*.-Calculate air content of concrete in measuring bowl as follows:

$$A_s = A_a - G_1 \text{ or } G_2 \tag{4}$$

where:

A_s = true air content of sample tested, in percent;
G_1 = aggregate correction factor for a Type A meter, in percent;
G_2 = aggregate correction factor for a Type B meter, in percent; and
A_a = as previously defined.

10.2 *Air Content of Full Mixture*.-When sample tested represents that portion of mixture that is obtained by wet sieving to remove aggregate particles larger than a 1-1/2- or 3-inch (37.5- or 75-mm) sieve, air content of full mixture may be calculated:

$$A_t = \frac{100\, A_s\, V_a}{100\, V_t - A_s V_o} \tag{5}$$

where:

A_t = air content of full mixture, in percent;
V_a = absolute volume of ingredients of mixture passing a 1-1/2- or 3-inch (37.5- or 75-mm) sieve, airfree, and as determined from corrected batch masses, in cubic feet, cubic yards, or cubic meters;
V_t = absolute volume of all ingredients of mixture, airfree, in cubic feet, cubic yards, or cubic meters;
V_o = absolute volume of aggregate in mixture coarser than 1-1/2- or 3-inch (37.5- or 75-mm) sieve, and as determined from corrected batch masses, in cubic feet, cubic yards, or cubic meters; and
A_s = as previously defined.

10.3 *Air Content of Mortar Fraction*.-When it is desired to know air content of mortar fraction of mixture, calculate as follows:

$$A_m = \frac{100\, A_s\, V_a}{100\, V_m + A_s\,(V_a - V_m)} \tag{6}$$

where:

A_m = air content of mortar fraction, in percent;
V_m = absolute volume of ingredients in mortar fraction of mixture, airfree, in cubic feet, cubic yards, or cubic meters; and
Other terms as previously defined.

NOTE 4.-The values in equations (5) and (6) are most conveniently obtained from data on concrete mixture tabulated as shown for a batch of any size on figure 11.

11. Report

11.1 The air content of the mortar may be reported on many different forms. Of prime concern to the Bureau of Reclamation are the following three main forms:

11.1.1 *Mix Design*.-The form included in USBR 4211 (fig. 1).

11.1.2 *Mix Data*.-The form included in USBR 4138 (fig. 3).

11.1.3 *Concrete Compressive Strength*.-The form included in USBR 4039 (fig. 5).

12. Precision and Bias

12.1 The precision and bias for this procedure have not been established.

Spec. or Solic. No. NA	Structure NA	Tested by K. FORBES Date 3-3-87
Project NA	Item DENVER OFFICE LAB EQUIPMENT Location CONCRETE LAB	Computed by K. FORBES Date 3-3-87
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by E. HARBOE Date 3-3-87

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

	Type A or [✓ B] Meter No.	Elevation Above Sea Level, [✓ ft] (m)	Water Temperature, [✓ °F] (°C)	Absolute Density of Water at Measured Temperature, [✓ lbm/ft³] (kg/m³)	B_T Tare Mass of Air-Meter Bowl, [✓ lbm] (kg)	G_T Tare Mass of Glass Plate Cover, [✓ lbm] (kg)	B_M Total Mass of Bowl, Cover, and Water, [✓ lbm] (kg)	W Water Mass $B_M - (B_T + G_T)$, [✓ lbm] (kg)	V_B Volume of Air-Meter Bowl, [✓ ft³], yd³, m³
Data	D991	5,280	61.2	62.360	7.94	2.54			
Trial No. 1							26.02	15.54	0.2492
Trial No. 2							26.03	15.55	0.2494
Trial No. 3							26.01	15.53	0.2490
Average									0.2492
Data									
Trial No. 1									
Trial No. 2									
Trial No. 3									
Average									
Data									
Trial No. 1									
Trial No. 2									
Trial No. 3									
Average									
Data									
Trial No. 1									
Trial No. 2									
Trial No. 3									
Average									

Notes:

Figure 8. – Sample worksheet for calibration of volume of air meter bowl.

Spec. or Solic. No. *NA*	Structure *NA*	Tested by *K. FORBES* Date *3-3-87*
Project *NA*	Item *DENVER OFFICE LAB EQUIP.* Location *CONCRETE LAB*	Computed by *K. FORBES* Date *3-3-87*
Feature *NA*	Station ~ Offset ~ Depth ~ to ~	Checked by *E. HARBOE* Date *3-3-87*

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

Air Meter		Elevation Above Sea Level, ([✓ ft])(m)	Water Temp., ([✓ °F])(°C)	Absolute Density of Water at Measured Temp., ([✓ lbm/ft³])(kg/m³)	C_T Tare Mass of Calibration Vessel, ([✓ lbm])(kg)	B_T Tare Mass of Air-Meter Bowl, ([✓ lbm])(kg)	G_T Tare Mass of Glass Plate Cover, ([✓ lbm])(kg)	C_M Mass of Water-Filled Calibration Vessel, ([✓ lbm])(kg)
No.	Type							
D-991	B	5,280	61.2	62.360	0.34	7.94	2.54	1.12

Air Meter		B_M Total Mass of Bowl, Cover, and Water ([✓ lbm])(kg)	Type A Meter		Type B Meter		Type A	Type B	V_B Volume of Air-Meter Bowl,
No.	Type		w $(C_M - C_T)$ Mass of Water to Fill Calib. Vessel, lbm (kg)	W $B_M - (B_T + G_T)$ Mass of Water to Fill Bowl, lbm (kg)	w $(C_M - C_T)$ Mass of Water to Fill Calib. Vessel, ([✓ lbm])(kg)	W $B_M - (B_T + G_T)$ Mass of Water to Fill Bowl, ([✓ lbm])(kg)	R_{A1} $\left(\ \right)\frac{w}{W}(100)$ at Pressure P_i, percent	R_B $\frac{w}{W}(100)$, percent	([✓ ft³])yd³, m³
D-991	B	26.02	—	—	0.78	15.54	—	5.02	0.2492

Notes: R_{A1} and R_B are constants, and are the effective volumes of the calibration vessels expressed as a percentage of the volume of the air-meter bowls.

Figure 9. - Sample worksheet for calibration of calibration vessel and air-meter bowl.

Spec. or Solic. No. NA	Structure NA	Tested by K. FORBES Date 3-3-87
Project NA	Item DENVER OFFICE LAB EQUIP. Location CONCRETE LAB	Computed by K. FORBES Date 3-3-87
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by E. HARBOE Date 3-3-87

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

Air meter No. ____________ TYPE A Use With Figures 1 and 2

w Mass of Water Req'd. to Fill Calibration Vessel, lbm (kg)	W Mass of Water Req'd. to Fill Air-Meter Bowl, lbm (kg)	R_{A1} $\frac{(\ )\,w}{W}$ (100) Effect. Volume of Calibration Vessel, %	K_1 (= R_{A1}) Calibration Reading	P_i Initial Pressure Req'd. to Determine K_1 lbf/in² (kPa)	First Trial		Second Trial	
					h_3 Reading at Pressure P_i %	h_4 Reading at Zero Pressure (After Release of P_i), %	h_3 Reading at Pressure P_i %	h_4 Reading at Zero Pressure (After Release of P_i), %

Remarks: The expansion factor D, which is the difference between the initial and zero water level marks, does not enter into the above calculations but should be checked.
Factory establishment of P_i is usually at 15 lbf/in² (103.4 kPa).

Air meter No. ____________ TYPE A Use With Figures 1 and 3

R_{A2} $\frac{(\ )\,w}{W}$ (100) Effect. Volume of Calib. Vessel, %	D_o Expansion Factor at pressure P_u	K_2 (= 0.98 R_{A2}) Calibration Reading at Pressure P_u	P_u Pressure Required to Produce K_2 lbf/in² (kPa)	First Trial		Second Trial		D_1 Determined Expansion Factor at h_6 - zero Reading	K_3 (= R_{A2} + D_1) Calib. Reading at Pressure P_1	P_1 Pressure Required to Produce K_3 lbf/in² (kPa)
				h_5 Reading at Pressure P_u %	h_6 Reading at Zero Pressure (After Release of P_u), %	h_5 Reading at Pressure P_u %	h_6 Reading at Zero Pressure (After Release of P_u), %			

Remarks: Calibration reading K_2 is assumed to be 0.98 R_{A2}, and expansion factor D_o is assumed to be zero.

Air meter No. D-991 TYPE B Use With Figures 4, 5, and 6

P_f Initial Pressure Line on Gauge	First Trial	Second Trial	P_a Adjusted Initial Pressure Line on Gauge	D_2 Expansion Factor $D_2 = A_o$	m_1 Mass of Water Removed From Air-Meter Bowl, [✓ lbm] (kg)	m_2 Total Mass of Water Removed From Air-Meter Bowl, [✓ lbm] (kg)	W Mass of Water Req'd. to Fill Air-Meter Bowl, [✓ lbm] (kg)	R_{B1} Effective Volume of Water Removed, %	R_{B2} Total Effective Volume of Water Removed, %	K_4 Air-Meter Readings During Calibration of Graduations of Air-Meter Bowl, %			
	A_o Air Content at Zero Pressure After Release of P_f, %	A_o Air Content at Zero Pressure After Release of P_f, %											
4.0	0.0	0.0	—	0.0	0.78	1.56	15.54	5.02	10.04	5.0	5.0	9.9	10.0

Remarks: Factory establishment of P_f is approximately 4.0.
D_2 = zero, if calibration is correct.

Figure 10. - Sample worksheet for calibration of Type A or B apparatus (sheet 1 of 2).

GLOSSARY OF TERMS USED ON SHEET 1 OF 2

w = mass of water required to fill calibration vessel, in pound mass (kilograms).
W = mass of water required to fill measuring bowl, in pound mass (kilograms).
R_{A1} = constant = effective volume of calibration vessel expressed as a percentage of the volume of the air-meter bowl for pressure P_i.
K_1 = R_{A1} = calibration reading at pressure P_i, in percent.
P_i = pressure to establish K_1, in pound force per square inch (kilopascals).
h_3 = water-level reading at pressure P_i.
h_4 = water-level reading after release of pressure P_i.
D = expansion factor, in percent.
R_{A2} = constant = effective volume of calibration vessel expressed as a percentage of the volume of the air-meter bowl for pressure P_u.
D_o = expansion factor at pressure P_u, in percent.
K_2 = $(0.98)\ (R_{A2})$ = calculated calibration reading at pressure P_u, in percent.
P_u = pressure to establish K_2, in pound force per square inch (kilopascals).
h_5 = water-level reading at pressure P_u.
h_6 = water-level reading after release of pressure P_u.
D_1 = determined expansion factor at h_6 - zero reading.
K_3 = $R_{A2} + D_1$ = calibration reading at pressure P_1, in percent.
P_1 = pressure to establish K_3, in pound force per square inch (kilopascals).
P_f = initial pressure line on gauge, a pure number.
A_o = air content at zero pressure after release of pressure P_f, in percent.
P_a = adjusted initial pressure line on gauge, a pure number.
D_2 = A_o = expansion factor, in percent.
m_1 = mass of water removed from air-meter bowl to check air content graduations, in pound mass (kilograms).
m_2 = total mass of water removed from air-meter bowl to check air content graduations, in pound mass (kilograms).
R_{B1} = effective volume of water removed with calibration vessel, in percent.
R_{B2} = total effective volume of water removed with calibration vessel, in percent.
K_4 = air meter readings in calibration of gauge graduations, in percent.

Figure 10. - Sample worksheet for calibration of Type A or B apparatus (sheet 2 of 2).

Spec. or Solic. No. DC-6820	Structure PUEBLO DAM	Tested by R. BURGER Date 12-18-70
Project FRY-ARK	Item NA Location NA	Computed by R. BURGER Date 12-18-70
Feature PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by D. OMAN Date 12-19-70

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

AGGREGATE CORRECTION FACTOR

Meter No. D817 Type of Meter B Concrete Volume $B =$ 3 yd^3 Volume of bowl sample $S =$ 0.2492 ft^3

Nominal Size Fraction	Mass for Batching Aggregates in Concrete Mix		Mass for Proportioning Aggregates in Meter Bowl to Determine G		Ingredients	A_d Design Air Content, %	Volume of Ingredients of Concrete Test Sample for Air Content Determination				
	F_b Mass of Fine Aggregate, lbm $B \div 27$	C_b Mass of Coarse Aggregate, lbm $B \div 27$	F_s $F_b\left(\frac{S}{B}\right)$ Mass of Fine Agg., lbm	C_s $C_b\left(\frac{S}{B}\right)$ Mass of Coarse Agg., lbm			V_{air} Volume of Air in Unit Batch, [✓ ft^3]/yd^3	V_c Absolute Volume of Cement in Unit Batch, [✓ ft^3]/yd^3	V_m Absolute Volume of Mortar in Unit Batch, [✓ ft^3]/yd^3	V_a Absolute Volume of Coarse Aggregate in Sample, [✓ ft^3]/yd^3	V_t Absolute Volume of All Materials in Sample, [✓ ft^3]/yd^3
Sand	125		10.4		Air	4.5	0.0471				
No. 4 to ⅜ inch					Cement			0.0769	0.0769	0.0769	0.0769
No. 4 to ½ inch					Water				0.1057	0.1057	0.1057
No. 4 to ¾ inch		97		8.1	Fine Aggregate				0.1906	0.1906	0.1906
No. 4 to 1 inch					No. 4 to 1½ inches					0.4062	0.4062
⅜ to ¾ inch					Plus 1½ inches, $V_o =$						0.1735
½ to 1¼ inches					Totals		0.0471	0.0769	0.3732	0.7794	0.9529
¾ to 1½ inches		146		12.1							
Plus 1½ inches		~		—	Air						
1 to 2 inches					Cement						
1¼ to 2½ inches					Water						
1½ to 3 inches					Fine Aggregate						
Plus 3 inches					No. 4 to ___ inches						
2 to 4 inches					Plus ___ inches, $V_o =$						
3 to 6 inches					Totals						
					Air						
					Cement						
					Water						
					Fine Aggregate						
					No. 4 to ___ inches						
					Plus ___ inches, $V_o =$						
					Totals						

Figure 11a. – Sample worksheet for aggregate correction factor and air content of concrete (inch-pound units, sheet 1 of 2).

Type A Meter			Type B Meter				
h_1 Reading at Press. P_o, %	h_2 Reading at Zero Press. (After Release of P_o), %	G_1 $h_1 - h_2$ Agg. Corr. Factor, %	A_d Design Air Content, %	Water Removed from Bowl		A_a Meter Reading for Agg. Corr. Factor, %	G_2 $A_a - A_d$ Agg. Corr. Factor, %
				m_1 Mass, lbm	R_{B1} Volume, %		
			4.5	0.70	4.5	4.7	0.2
			4.5	0.70	4.5	4.7	0.2

AIR CONTENT								
Concrete Sample No.	M_s Mass of Air-Meter Bowl and Test Sample, lbm	B_T Tare Mass of Air-Meter Bowl, lbm	D_c $\frac{M_s - B_T}{S}$ Density of Test Sample, lbm/ft³	A_a Air-Meter Reading of Test Sample, %	G_1 or [✓ G_2] Aggregate Correction Factor, %	A_s $A_a - G_1$ or [✓ G_2] True Air Content of Test Sample, %	A_t $\frac{100 A_s V_a}{100 V_t - A_s V_o}$ Air Content of Full Mixture, %	A_m $\frac{100 A_s V_a}{100 V_m + A_s (V_a - V_m)}$ Air Content of Mortar, %
—	44.82	7.94	148.0	4.4	0.2	4.2	3.5	8.4

Figure 11a. — Sample worksheet for aggregate correction factor and air content of concrete (inch-pound units, sheet 2 of 2).

Spec. or Solic. No. DC-6820	Structure PUEBLO DAM	Tested by R. BURGER Date 12-18-70
Project FRY-ARK	Item NA Location NA	Computed by R. BURGER Date 12-18-70
Feature PUEBLO DAM	Station ~ Offset ~ Depth ~ to ~	Checked by D. OMAN Date 12-19-70

AIR CONTENT OF FRESHLY MIXED CONCRETE BY PRESSURE METHOD

AGGREGATE CORRECTION FACTOR

Meter No. D817 Type of Meter B Concrete Volume $B =$ 3 m³ Volume of bowl sample $S =$ 0.007057 m³

Nominal Size Fraction	Mass for Batching Aggregates in Concrete Mix		Mass for Proportioning Aggregates in Meter Bowl to Determine G		Ingredients	A_d Design Air Content, %	Volume of Ingredients of Concrete Test Sample for Air Content Determination				
	F_b Mass of Fine Aggregate, kg	C_b Mass of Coarse Aggregate, kg	F_s $F_b\left(\frac{S}{B}\right)$ Mass of Fine Agg., kg	C_s $C_b\left(\frac{S}{B}\right)$ Mass of Coarse Agg., kg			V_{air} Volume of Air in Unit Batch, m³	V_c Absolute Volume of Cement in Unit Batch, m³	V_m Absolute Volume of Mortar in Unit Batch, m³	V_a Absolute Volume of Coarse Aggregate in Sample, m³	V_t Absolute Volume of All Materials in Sample, m³
Sand	2000		4.705		Air	4.5	0.0471				
4.75 to 9.5 mm					Cement			0.0769	0.0769	0.0769	0.0769
4.75 to 12.5 mm					Water				0.1057	0.1057	0.1057
4.75 to 19.0 mm		1561		3.672	Fine Aggregate				0.1906	0.1906	0.1906
4.75 to 25.0 mm					4.75 to 37.5 mm					0.4062	0.4062
9.5 to 19.0 mm					Plus 37.5 mm, $V_o =$						0.1735
12.5 to 31.5 mm					Totals		0.0471	0.0769	0.3732	0.7794	0.9529
19.0 to 37.5 mm		2334		5.490							
Plus 37.5 mm		—		—	Air						
25.0 to 50 mm					Cement						
31.5 to 63 mm					Water						
37.5 to 75 mm					Fine Aggregate						
Plus 75 mm					4.75 to ___ mm						
50 to 100 mm					Plus ___ mm, $V_o =$						
75 to 150 mm					Totals						
					Air						
					Cement						
					Water						
					Fine Aggregate						
					4.75 to ___ mm						
					Plus ___ mm, $V_o =$						
					Totals						

Figure 11b. – Sample worksheet for aggregate correction factor and air content of concrete (SI-metric units, sheet 1 of 2).

Type A Meter			Type B Meter				
h_1 Reading at Press. P_o, %	h_2 Reading at Zero Press. (After Release of P_o), %	G_1 $h_1 - h_2$ Agg. Corr. Factor, %	A_d Design Air Content, %	Water Removed from Bowl		A_s Meter Reading for Agg. Corr. Factor, %	G_2 $A_s - A_d$ Agg. Corr. Factor, %
				m_1 Mass, kg	R_{B1} Volume, %		
			4.5	0.318	4.5	4.7	0.2
			4.5	0.318	4.5	4.7	0.2

AIR CONTENT								
Concrete Sample No.	M_s Mass of Air-Meter Bowl and Test Sample, kg	B_T Tare Mass of Air-Meter Bowl, kg	D_c $\frac{M_s - B_T}{S}$ Density of Test Sample, kg/m³	A_s Air-Meter Reading of Test Sample, %	G_1 or G_2 Aggregate Correction Factor, %	A_s $A_s - G_1$ or G_2 True Air Content of Test Sample, %	A_t $\frac{100\,A_s\,V_s}{100\,V_t - A_s\,V_o}$ Air Content of Full Mixture, %	A_m $\frac{100\,A_s\,V_s}{100\,V_m + A_s\,(V_s - V_m)}$ Air Content of Mortar, %
—	20.33	3.60	2371	4.4	0.2	4.2	3.5	8.4

Figure 11b. — Sample worksheet for aggregate correction factor and air content of concrete (SI-metric units, sheet 2 of 2).

APPENDIX

X1. CALIBRATION OF TYPE A APPARATUS
(Mandatory Information)

X1.1 The symbols used in this appendix are of the generic type; more explicit use of the symbols, complete with subscripts, is shown on the worksheets, figures 8 through 11.

X1.2 Calibration tests shall be performed in accordance with the following methods as applicable to the meter type being used.

X1.3 *Calibration of Calibration Vessel.*-Determine accurately the mass of water, w, required to fill calibration vessel, using a scale accurate to 0.1 percent of mass of vessel filled with water.

X1.4 *Calibration of Measuring Bowl.*-Determine mass of water, W, required to fill measuring bowl, using a scale accurate to 0.1 percent of mass of bowl filled with water. Slide a glass plate carefully over flange of bowl in a manner to ensure that bowl is completely filled with water. A thin film of cup grease smeared on flange of bowl will make a watertight joint between glass plate and top of bowl.

X1.5 *Effective Volume of Calibration Vessel.*-The constant R represents effective volume of calibration vessel expressed as a percentage of volume of measuring bowl. Calculate R as follows:

$$R = \left(\frac{0.98\ w}{W}\right)(100) \qquad (1)$$

where:

R = effective volume of calibration vessel expressed as a percentage of volume of measuring bowl,
w = mass of water required to fill calibration vessel, in pound mass (kilograms); and
W = mass of water required to fill measuring bowl, in pound mass (kilograms).

NOTE X1.1.-The factor 0.98 in equation (1) is used to correct for the reduction in volume of air in calibration vessel when air is compressed by a depth of water equal to depth of measuring bowl. This factor is about 0.98 for an 8-inch (203-mm) deep measuring bowl at sea level. This value decreases to about 0.975

at 5,000 feet (1524 m) above sea level, and to 0.970 at 13,000 feet (3962.4 m) above sea level. The value of this constant will decrease by about 0.01 for each 4-inch (102-mm) increase in bowl depth.

X1.5.1 Figures 8 and 9 show typical calculation forms for determining volume of calibration vessel and air-meter bowl.

X1.6 *Determination of Allowance for Expansion Factor.*-Determine the expansion factor D (note X1.2) by filling apparatus with water only and applying an air pressure approximately equal to operating pressure P, as determined by calibration test described in section X1.8. Ensure that all entrapped air has been removed and that water level is exactly on zero mark (note X1.3). The amount the water column lowers will be the equivalent expansion factor, D, for that particular apparatus and pressure (note X1.4).

NOTE X1.2.-Although the bowl, cover, and clamping mechanism of the apparatus must necessarily be sturdily constructed so that it will be pressuretight, the application of internal pressure will result in a small increase in volume. This expansion will not affect the test results because, as described in sections 7 and 9, the amount of expansion is the same for the test for air in concrete as for the test for the aggregate correction factor on combined fine and coarse aggregates, and is thereby automatically cancelled. However, this expansion does enter into calibration test to determine air pressure to be used in testing fresh concrete.

NOTE X1.3.-The water columns on some type A meters are marked with an initial water level and a zero mark, the difference between these two marks being the allowance for the expansion factor. This allowance should be checked in the same manner as for meters not having these marks. For meters with such marks, the expansion factor should be omitted when computing the calibration readings in section X1.8.

NOTE X1.4.-For this procedure, it is sufficiently accurate to use an approximate value for P, as determined by making a preliminary calibration test as described in section X1.8 except that an approximate value for the calibration reading, K, should be used. For this test, $K = 0.98\ R$. The expansion factor D, as yet unknown, is assumed to be zero.

X1.7 *Calibration Reading.*-The calibration reading, K, is the final meter reading to be obtained when meter is operated at correct calibration pressure. This reading is determined:

$$K = R + D \qquad (2)$$

where:

K = calibration reading, in percent;
D = expansion factor (sec. X1.6 and note X1.5), in percent; and
R = as previously defined.

NOTE X1.5.-If water column indicator is graduated to include an initial water level and a zero mark, with the difference between the two marks being equivalent to expansion factor, the term D shall be omitted from equation (2).

X1.8 *Calibration Test to Determine Operating Pressure on Pressure Gauge for Meters Similar to Meter Shown on Figure 2.*-If rim of calibration vessel contains no recesses or projections, install three or more spacers equally spaced around circumference of vessel. Invert vessel and place at center of dry bottom of measuring bowl. The spacers will provide an opening for the flow of water into vessel when pressure is applied. Secure the inverted vessel against displacement and carefully lower cover assembly. For meters similar to the meter shown on figure 3, the calibration vessel is maintained in the upright position. Fill the meter bowl with water. After cover is clamped in place, carefully adjust apparatus assembly to a vertical position and add water at existing air temperature, using the tube and funnel, until water rises above zero mark on standpipe. Close the vent, and pump air into apparatus to approximate operating pressure. Incline the assembly about 30° from vertical and, using bottom of bowl as a pivot, inscribe several complete circles with upper end of standpipe. During this operation, tap the cover and sides of bowl lightly to remove any entrapped air adhering to inner surfaces of apparatus. Return apparatus to a vertical position, gradually release pressure (to avoid loss of air from calibration vessel), and open vent. Bring water level exactly to zero mark by bleeding water through the petcock in top of conical cover. After closing vent, apply pressure until water level has dropped an amount equivalent to about 0.1 to 0.2 percent of air more than the value of the calibration reading, K, as determined in X1.7. To relieve local restraints, lightly tap sides of bowl and, when water level is exactly at value of calibration reading, K, read the pressure P, as indicated by gauge, and record to nearest 0.1 lbf/in^2 (0.7 kPa). Gradually release pressure and open vent to determine whether water level returns to zero mark when sides of bowl are tapped lightly, failure to do so indicates loss of air from calibration vessel or loss of water due to a leak in assembly. If water level fails to return to within 0.05 percent air of zero mark and no leakage other than a few drops of water occurs, some air probably was lost from calibration vessel. In this case, repeat calibration procedure from the start. If leakage is more than a few drops of water, tighten the leaking joint before repeating calibration procedure. Check indicated pressure reading promptly by bringing water level exactly to zero mark, closing vent, and applying the pressure, P, just determined. Tap gauge lightly with a finger. When gauge indicates the exact pressure, P, the water column should read the value of the calibration reading, K, that was used in the initial pressure application within about 0.05 percent of air.

Caution: The apparatus assembly must not be moved from the vertical position until pressure has been applied, which will force water about one-third of the way up into calibration vessel. Any loss of air from vessel will nullify the calibration.

X1.9 Figure 10 shows a typical worksheet for determining expansion factor D, calibration reading K, and operating pressure P.

APPENDIX

X2. CALIBRATION OF TYPE B APPARATUS
(Mandatory Information)

X2.1 The symbols used in this appendix are of the generic type; more explicit use of the symbols, complete with subscripts, is shown on the worksheets, figure 8 through 11.

X2.2 Calibration tests shall be performed in accordance with the following methods as applicable to the meter type being used.

X2.3 *Calibration of Calibration Vessel.*-Determine accurately the mass of water, w, required to fill calibration vessel, using a scale accurate to 0.1 percent of mass of vessel filled with water.

X2.4 *Calibration of Measuring Bowl.*-Determine mass of water, W, required to fill measuring bowl, using a scale accurate to 0.1 percent of mass of bowl filled with water. Slide a glass plate carefully over flange of bowl in a manner to ensure that bowl is completely filled with water. A thin film of cup grease smeared on flange of bowl will make a watertight joint between glass plate and top of bowl.

X2.5 *Effective Volume of Calibration Vessel.*-The constant R represents effective volume of calibration vessel expressed as a percentage of volume of measuring bowl. The depth of measuring bowl and atmospheric pressure do not affect the effective volume of vessel for type B meters. Calculate R as follows:

$$R = \left(\frac{w}{W}\right)(100) \qquad (1)$$

where:

R = effective volume of calibration vessel expressed as a percentage of volume of measuring bowl,
w = mass of water required to fill calibration vessel, in pound mass (kilograms); and
W = mass of water required to fill measuring bowl, in pound mass (kilograms).

X2.5.1 Figures 8 and 9 show typical calculation forms for determining volume of calibration vessel and air-meter bowl.

X2.6 *Determination of Allowance for Expansion Factor.*-The allowance for the expansion factor, D, is included in the difference between the initial pressure indicated on pressure gauge and zero-percent mark on air-content scale on gauge. This allowance shall be checked by filling apparatus with water and pumping air into air chamber until gauge hand is stabilized at indicated initial pressure line, and then releasing air to measuring bowl (note X2.1). During this operation, ensure that all entrapped air has been removed. If initial pressure line is correctly positioned, gauge should read zero percent. The initial pressure line shall be adjusted if two or more determinations show the same variation from zero percent. The test shall be repeated to check the adjusted initial pressure line.

NOTE X2.1.-This determination may be accomplished in conjunction with calibration test described in section X2.8.

X2.7 *Calibration Reading.*-The calibration reading, K, is the final meter reading to be obtained when meter is operated at correct calibration pressure. For the type B meter, the calibration reading is the same as the effective volume of the calibration vessel:

$$K = R \qquad (2)$$

where:

K = calibration reading, in percent; and
R = as previously defined.

X2.8 *Calibration Test to Check Air Content Graduations on Pressure Gauge.*-Fill measuring bowl with water as described in X2.4. Screw the short piece of tubing or pipe furnished with apparatus into threaded petcock hole on underside of cover assembly, and assemble apparatus. Close air valve between air chamber and measuring bowl, and open the two petcocks on holes through cover assembly. Add water through the petcock on cover assembly having the extension below until all air is expelled from second petcock. Pump air into air chamber until pressure reaches indicated initial pressure line. Allow a few seconds for compressed air to cool to normal temperature. Stabilize gauge hand at initial pressure line by pumping or bleeding off air as necessary while lightly tapping gauge. Close petcock not provided with tube or pipe extension on underside of cover. Remove water from assembly to calibration vessel controlling the flow, depending on particular meter design, by opening petcock provided with tube or pipe extension and cracking air valve between air chamber and measuring bowl or by opening air valve and using petcock to control flow. Perform calibration at an air content which is within normal range of use. If calibration vessel has a capacity within normal range of use (sec. X2.3), remove exactly that amount of water. With some meters, the calibration vessel is quite small, which makes it necessary to remove its capacity several times to obtain an air content within normal range of use. In this instance, carefully collect water in an auxiliary container and determine amount removed by determining mass to nearest 0.1 percent. Calculate the correct volume, R, using equation (1). Release air from apparatus at petcock not used for filling calibration vessel and, if apparatus uses an auxiliary tube for filling vessel, open petcock to which tube is connected to drain tube back into measuring bowl (note X2.2). At this point, measuring bowl contains the percentage of air determined by calibration test of calibration vessel. Pump air into air chamber until pressure reaches initial pressure line marked on pressure gauge, close both petcocks in cover assembly, and then open valve between air chamber and measuring bowl. The indicated air content on pressure gauge dial should correspond to percentage of air determined to be in measuring bowl. If two or more determinations show the same variation from the correct air content, the dial hand shall be reset to correct air content and test repeated until gauge reading corresponds to calibrated air content within 0.1 percent. If dial hand was reset to obtain correct air content, recheck initial pressure mark as noted in section X2.6. If a new initial pressure reading is required, repeat calibration to check accuracy of graduation on pressure gauge, as previously described. If difficulty is encountered in obtaining consistent readings, check for leaks, for presence of water inside air chamber (fig. 4), or for presence of air bubbles clinging to inside surfaces of meter from the use of cool aerated water. For this latter case, use deaerated water which can be obtained by cooling hot water to room temperature.

NOTE X2.2.–If calibration vessel is an integral part of cover assembly, petcock used for filling vessel should be closed immediately after filling vessel and not opened until test is completed.

X2.9 Figure 10 shows a typical worksheet for determining the expansion factor *D*, calibration reading *K*, and operating pressure *P*.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4232-92

PROCEDURE FOR

BLEEDING OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4232; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 232-71 (Reapproved 1977).

1. Scope

1.1 This designation covers the procedure for determination of the relative quantity of mixing water that will bleed from a sample of freshly mixed concrete. Two methods, which differ primarily in the degree of vibration to which the concrete sample is subjected, are included as follows:

1.1.1 *Method A.*–For a sample consolidated by tamping only, and tested without further disturbance.

1.1.2 *Method B.*–For a sample consolidated by vibration, and tested with additional intermittent periods of vibration.

1.2 Samples of concrete from the same batch are not expected to yield same test results when tested by each method. When various concretes are to be compared, all tests should be conducted using the same method, and the sample masses, if batches are of similar density, should not differ by more than 2 lbm (0.9 kg).

2. Applicable Documents

2.1 *USBR Procedures*:

4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete.
4172 Sampling Freshly Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standards*:

C 232 Standard Test Method for Bleeding of Concrete[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]

METHOD A - SAMPLE CONSOLIDATED BY TAMPING

3. Apparatus

3.1 *Container.*–A cylindrical container of about 0.5 ft^3 (0.014 m^3) capacity, with an inside diameter of 10±1/4 inches (254±6.4 mm) and an inside height of 11±1/4 inches (279±6.4 mm). Container shall be made of a metal having a thickness of No. 10 to No. 12 U.S. gauge (3.6 to 2.8 mm), and shall be externally reinforced around the top with No. 10 to No. 12 U.S. gauge metal band, 1-1/2 inches (38 mm) wide. Inside of container shall be smooth, and free from corrosion, coatings, or lubricants. A steel cover shall be provided for container. Container and cover shall conform with design shown on figure 1.

3.2 *Scale.*–A scale with sufficient capacity to determine mass within an accuracy of 0.5 percent.

3.3 *Pipet.*–A pipet or similar instrument for removing free water from surface of test specimen.

3.4 *Glass Graduate.*–A 100-cm^3 capacity glass graduate for collecting and measuring quantity of water withdrawn.

3.5 *Tamping Rod.*–A round, straight, steel rod, 5/8 inch (16 mm) in diameter and about 24 inches (610 mm) in length, with tamping end rounded to a 5/8-inch-diameter hemispherical tip.

3.6 *Metal Beaker* (Optional).–A 1000-cm^3 metal beaker for collecting decanted supernatant water and sludge (note 1).

3.7 *Balance* (Optional).–A balance sensitive to 1 gram for determining mass of decanted water and sludge (note 1).

3.8 *Hotplate* (Optional).–A small, electric hotplate or other source of heat for evaporating decanted water (note 1).

NOTE 1.–The optional items (secs. 3.6, 3.7, and 3.8) are required if procedure of measuring amount of bleeding water recovered is one involving mass determination, evaporation, and redetermining mass.

4. Precautions

4.1 This method may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Test Specimen

5.1 For concrete made in laboratory, prepare concrete as described in USBR 4192. For concrete made in field, sample concrete as described in USBR 4172.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

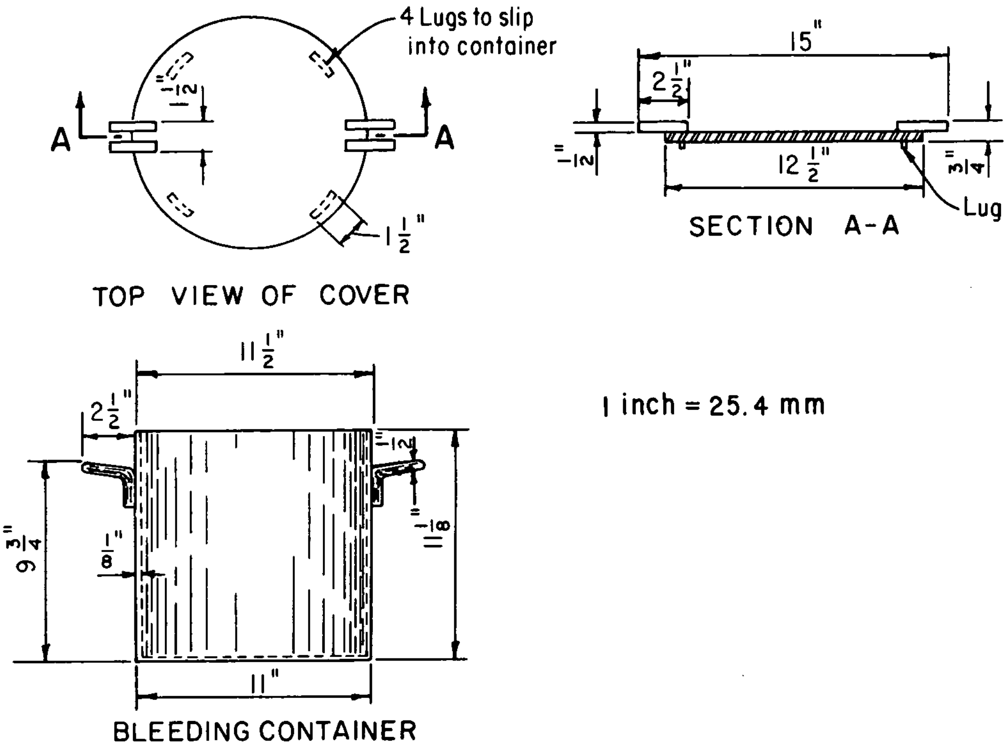

Figure 1. – Container and cover.

5.2 The apparatus described in this method may be used with samples of concrete containing any size aggregate graded up to and including a nominal maximum size of 1-1/2 inches (37.5 mm). Concrete containing aggregate larger than 1-1/2 inches shall be wet sieved over a 1-1/2-inch sieve and test performed on portion of sample that passes this sieve.

5.3 Fill container with concrete in accordance with section 7 of USBR 4138, except that container shall be filled to a height of 10±1/8 inches (254±3.2 mm). Level top surface of concrete to a reasonably smooth surface by a minimum amount of troweling.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

7. Procedure

7.1 During test, maintain ambient temperature between 65 and 75 °F (18.3 and 23.9 °C). Immediately after troweling surface of specimen, record time and determine mass of container plus contents. Place specimen and container on a level platform or floor that is free from noticeable vibration, and cover container to prevent evaporation of bleed water. Keep cover in place throughout test, except when drawing off water. Remove with a pipet or similar instrument the water that has accumulated on surface at 10-minute intervals during first 40 minutes and at 30-minute intervals thereafter until cessation of bleeding. To facilitate collection of bleeding water, tilt specimen carefully by placing a block about 2 inches (50 mm) thick under one side of container 2 minutes prior to each time water is withdrawn. After water is removed, return container to a level position without jarring. After each withdrawal, transfer water to a 100-cm^3 graduate. Record accumulated quantity of water after each transfer. When only the total volume of bleeding is to be determined, the periodic removal procedure may be omitted and entire amount may be removed in a single operation. To determine mass of bleeding water and to exclude material present other than the water, carefully decant contents of cylinder into a metal beaker. Determine and record mass of beaker plus contents. Dry beaker plus contents to a constant mass and record final mass. The difference between the two mass determinations is the mass of the bleeding water. The mass of the sludge may also be obtained, if desired, by subtracting mass of beaker.

8. Calculations

8.1 Calculate volume of bleeding water per unit area of surface as follows:

$$V = \frac{V_1}{A} \qquad (1)$$

where:

V = volume of bleeding water per unit area of surface in cubic feet (cubic centimeters),

V_1 = volume of bleeding water measured during selected time interval in cubic feet (cubic centimeters), and

A = surface area of concrete in square feet (square centimeters).

8.1.1 The comparative rate of bleeding can be determined as test progresses by comparing volume of bleeding water for each equal time interval.

8.2 Calculate the accumulated bleeding water, expressed as a percentage of free (above saturated-surface-dry) mixing water contained within test specimen, as follows:

$$C = \left(\frac{m}{M}\right)(S) \tag{2}$$

$$\text{Bleeding (percent)} = \frac{D}{C}(100) \tag{3}$$

where:

C = mass of water in test specimen in pound mass (grams),

M = total mass of batch in pound mass (kilograms),

m = free mass of water in batch in pound mass (kilograms),

S = mass of sample in pound mass (grams), and

D = mass of bleeding water in pound mass (grams) or total volume withdrawn from test specimen in cubic feet (cubic centimeters) multiplied by 62.4 lbm/ft^3 (1 g/cm^3).

8.3 Figure 3 shows a typical calculation form.

9. Report

9.1 Figure 3 also serves as a reporting form.

10. Precision and Bias

10.1 Data are not currently available to evaluate precision of method A directly; however, the precision for method A is at least as good as that for method B. Therefore, the values given in section 17 for method B may be used as maximum precision limits for method A.

10.2 The bias for method A has not been established.

METHOD B - SAMPLE CONSOLIDATED BY VIBRATION

11. Apparatus

11.1 *Vibrating Platform.*-A platform shall be provided upon which the filled container shall be mounted. Platform shall be equipped with a suitable device so that intermittent periods of vibration of reproducible duration, frequency, and amplitude will be imparted to specimen container as prescribed by section 12. Suitable vibration will be provided by a 1/8-hp (93-W) electric motor bolted to platform, with a small eccentric having a mass of about 110 grams attached to shaft of motor by a setscrew. The eccentric shall be fabricated from cold-rolled stock in accordance with details and dimensions shown on figure 2. The hole through the eccentric shall be 34/64 inch (13.5 mm) or an appropriate size to accommodate motor shaft. The platform shall be supported on rubber supports resting on a concrete slab. The concrete slab should be separated from the floor by a layer of cork (fig. 2).

11.2 *Timer.*-A timing device to regulate periods of vibration of platform and specimen shall be provided in accordance with section 12.

11.3 The remainder of the apparatus is identical with that given in sections 3.1 through 3.8.

12. Vibrating Cycle

12.1 The vibrating cycle shall be power on for 3 seconds, power off for 30 seconds. However, due to coasting of motor after power is turned off, period of perceptible vibration is about 7 seconds.

13. Test Specimen

13.1 Sample shall be prepared as described in section 5.1.

13.2 Sample shall be placed in container to a depth equal to about one-half the average diameter of container. Size of the test sample can best be regulated by mass; a sample with a mass of 45±1 lbm (20.4±0.5 kg) usually meets the requirements for the apparatus.

14. Procedure

14.1 *Consolidation of Test Specimen.*-Consolidate sample in container by vibrating only until desired degree of compaction has been achieved. Stop consolidating procedure immediately upon first appearance of free water segregating from concrete as indicated by development of a water sheen on its surface. For some unusually wet or plastic mixtures, no consolidating effort will be needed beyond that supplied by placing sample in container, handling container during operations of mass determination, and placing container on platform for test.

14.2 *Intermittent Vibration.*-Place cover on container and then place on vibrating platform. Clamp container to platform and the cover to container. Note and record time, and start motor. Continue intermittent vibration for 1 hour.

14.3 *Determination of Bleeding Water.*-The intermittent periods of vibration do not permit determination of bleeding water at a number of different time intervals, only a final total amount of bleeding water. Determine total volume of bleeding water in accordance with applicable portions of section 7.

15. Calculations

15.1 Calculate percentage of bleeding water as described in section 8. Figure 3 shows a typical calculation form.

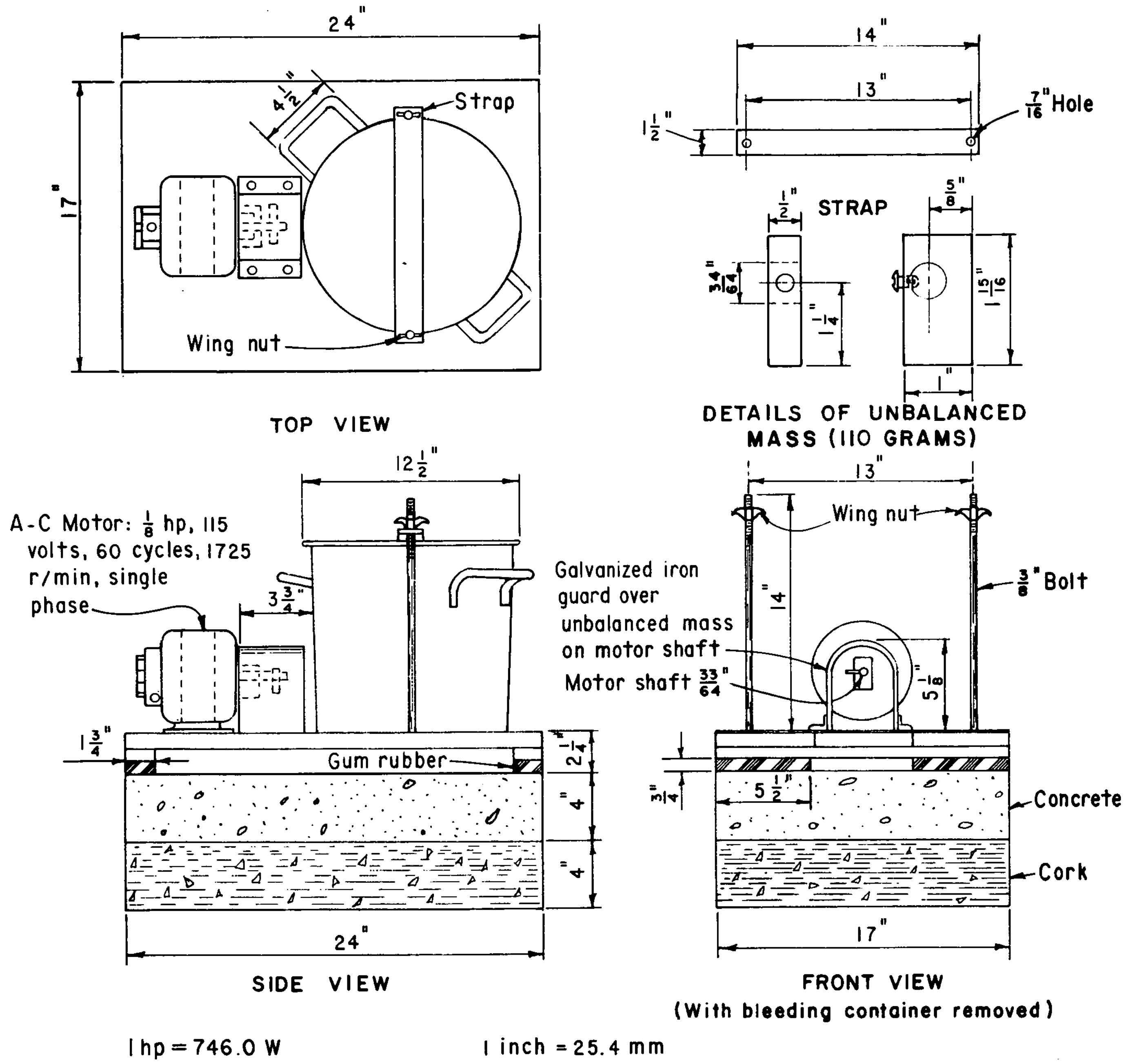

Figure 2. – Details of vibrating platform apparatus.

16. Report

16.1 Figure 3 also serves as a reporting form.

17. Precision and Bias

17.1 The single operator-day-multibatch standard deviation has been found to be 0.71 percent for a bleeding range from 0 to 10 percent, 1.06 percent from 10 to 20 percent, and 1.77 percent for more than 20 percent. Therefore, results of two properly conducted tests by same operator on same day on different batches of same mixture should not differ by more than 2.0 percent for bleeding range from 0 to 10 percent, 3.0 percent from 10 to 20 percent, and 5.0 percent for more than 20 percent.

NOTE 2.–Values of precision shown in section 17.1 are the 1S and D2S limits as described in ASTM C 670.

17.2 The bias for method B has not been established.

Spec. or Solic. No. DC-7557	Structure —	Tested by B. WYATT Date 5-17-84
Project CENTRAL ARIZONA	Item — Location —	Computed by B. WYATT Date 5-17-84
Feature REACH 1-B SALT-GILA AQUEDUCT	Station 342+00 Offset — Depth — to —	Checked by G. STEPHENS Date 5-17-84

BLEEDING OF CONCRETE

CONCRETE MATERIALS

Type and Source of Portland Cement: TYPE II LA, ARIZONA PORTLAND, RILLITO, AZ

Class and Source of Pozzolan: CLASS F, WESTERN ASH, CLARKSDALE, AZ

AEA: PROTEX Other Admixtures: PROTEX PDA-25

MIX PROPORTIONS

Water, lbm	Cement, lbm	Pozzolan, lbm	Sand, lbm	Coarse Aggregate			AEA, ounces	WRA, ounces	Density, lbm/yd^3
				No. 4 to 3/4 inch, lbm	3/4 to 1-1/2 inches, lbm	1-1/2 to 3 inches, lbm			
234	434	109	1,198	809	988	—	9	23	3,772

M (Mass of Batch): 3,772 lbm, m (Mass of Water in Batch): 234 lbm, S (Mass of Sample): 79.91 lbm

Container: Diameter 11.0 inches, Height 11.0 inches, A (Area of Exposed Concrete) ($\pi D^2/4$) 0.66 ft^2

Mass of Beaker: 0.227 lbm, Ambient Temperature: 70 °F

	Method A, minutes						Method B
	10	20	30	40	70	100	1 hour
Mass of beaker, bleed water, and accumulated sludge, lbm	0.273	0.271	0.269	0.267	0.265	0.265	0.353
Mass of beaker and accumulated sludge (water evaporated), lbm	0.238	0.247	0.254	0.258	0.260	0.262	0.262
Mass of beaker, lbm	0.227	0.227	0.227	0.227	0.227	0.227	0.227
Mass of sludge, lbm	0.011	0.020	0.027	0.031	0.033	0.035	0.035
D, Mass of bleed water, lbm	0.035	0.024	0.015	0.009	0.005	0.003	0.091
V_1, Volume of bleed water, in^3	0.969	0.665	0.415	0.249	0.138	0.083	2.520
V, Volume of bleed water per unit area of surface: $V = V_1/A$, in^3	0.0102	0.0070	0.0044	0.0026	0.0015	0.0009	0.0265
C, Mass of water in test specimen, $C = (m/M)(S) =$ 4.96 lbm							
Bleeding (percent) $= (D/C)(100)$	0.71	0.48	0.30	0.18	0.10	0.06	1.84

Figure 3a. - Sample data and calculation form (inch-pound units).

Spec. or Solic. No. DC-7557	Structure —	Tested by B. WYATT Date 5-17-84
Project CENTRAL ARIZONA	Item — Location —	Computed by B. WYATT Date 5-17-84
Feature REACH 1-B SALT-GILA AQUEDUCT	Station 342+00 Offset — Depth — to —	Checked by G. STEPHENS Date 5-17-84

BLEEDING OF CONCRETE

CONCRETE MATERIALS

Type and Source of Portland Cement: TYPE II LA, ARIZONA PORTLAND, RILLITO, AZ
Class and Source of Pozzolan: CLASS F, WESTERN ASH, CLARKSDALE, AZ
AEA: PROTEX Other Admixtures: PROTEX PDA-25

MIX PROPORTIONS

Water, kg	Cement, kg	Pozzolan, kg	Sand, kg	Coarse Aggregate			AEA, mL	WRA, mL	Density, kg/m^3
				4.75 to 19.0 mm, kg	19.0 to 37.5 mm, kg	37.5 to 75 mm, kg			
106	197	49	544	367	448	—	266	673	1711

M (Mass of Batch): 1711 kg, m (Mass of Water in Batch): 106 kg, S (Mass of Sample): 36 200 grams
Container: Diameter 279 mm, Height 279 mm, A (Area of Exposed Concrete) ($\pi D^2/4$) 613.1 cm^2
Mass of Beaker: 103 grams, Ambient Temperature: 21 °C

	Method A, minutes						Method B
	10	20	30	40	70	100	1 hour
Mass of beaker, bleed water, and accumulated sludge, grams	124	123	122	121	120	120	160
Mass of beaker and accumulated sludge (water evaporated), grams	108	112	115	117	118	119	119
Mass of beaker, grams	103	103	103	103	103	103	103
Mass of sludge, grams	5	9	12	14	15	16	16
D, Mass of bleed water, grams	16	11	7	4	2	1	41
V_1, Volume of bleed water, cm^3	16	11	7	4	2	1	41
V, Volume of bleed water per unit area of surface: $V = V_1/A$, cm^3	0.0261	0.0179	0.114	0.0065	0.0033	0.0016	0.0669
C, Mass of water in test specimen, $C = (m/M)(S) =$ 2243 grams							
Bleeding (percent) $= (D/C)(100)$	0.71	0.49	0.31	0.18	0.09	0.04	1.83

Figure 3b. - Sample data and calculation form (SI-metric).

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4233-92

PROCEDURE FOR

TESTING AIR-ENTRAINING ADMIXTURES FOR CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4233; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 233-82.

1. Scope

1.1 This designation covers procedures for testing of materials proposed for use as air-entraining admixtures to be added to concrete mixtures in the field. These tests are based on arbitrary stipulations permitting highly standardized testing in the laboratory and are not intended to simulate actual job conditions.

2. Applicable Documents

2.1 *USBR Procedures*:
4039 Compressive Strength of Cylindrical Concrete Specimens
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4185 Air Content of Hydraulic Cement Mortar
4192 Making and Curing Concrete Test Specimens in Laboratory
4211 Selecting Proportions for Concrete Mixtures
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4232 Bleeding of Concrete
4403 Time-of-Setting of Concrete Mixtures by Penetration Resistance
4666 Resistance of Concrete to Rapid Freezing and Thawing

2.2 *ASTM Standards*:
C 150 Specification for Portland Cement[1,2]
C 157 Test Method for Length Change of Hardened Cement Mortar and Concrete[1]
C 233 Standard Method of Testing Air-Entraining Admixtures for Concrete[2]
C 260 Specification for Air-Entraining Admixtures for Concrete[2]
D 1193 Specification for Reagent Water[3]
D 1429 Test Methods for Specific Gravity of Water and Brine[3]
E 70 Test Method for pH of Aqueous Solutions with the Glass Electrode[4]
E 100 Specification for ASTM Hydrometers[5]

3. Materials

3.1 *Cement*.–The cement used in any series of tests shall be either the cement proposed for specific work in accordance with section 3.4, Type I or II cement conforming to ASTM C 150, or a blend of two or more cements in equal parts. Each cement of the blend shall conform to requirements of either Type I or II cement conforming to ASTM C 150. If a blend of cements is used, the blend shall also be a combination which produces an air content less than 10 percent when tested in accordance with USBR 4185.

NOTE 1.–It is recommended that whenever practicable, tests be made in accordance with section 3.4 using the cement and pozzolanic or chemical admixtures, if any, proposed for the specific work.

3.2 *Aggregates*.–Except when tests are made in accordance with 3.4, using aggregates proposed for specific work, the fine and coarse aggregates used in any series of tests shall come from single lots of well-graded, sound materials that conform to the requirements of 3.2.1, 3.2.2, and 3.2.3.

3.2.1 *Aggregate Gradation*.–The specific work requirements of section 3.4 may dictate aggregate gradings for fine and coarse aggregate. If no specific work requirements exist, aggregates should conform to requirements shown in sections 3.2.2 and 3.2.3.

3.2.2 *Fine Aggregate Grading*:

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[1] *Annual Book of ASTM Standards*, vol. 04.01
[2] *Annual Book of ASTM Standards*, vol. 04.02
[3] *Annual Book of ASTM Standards*, vol. 11.01.
[4] *Annual Book of ASTM Standards*, vol. 15.05.
[5] *Annual Book of ASTM Standards*, vol. 14.01.

Sieve size	*Percentage retained (individual)*
No. 4 (4.75 mm)	0 to 5
No. 8 (2.36 mm)	5 to 15
No. 16 (1.18 mm)	10 to 25*
No. 30 (600 µm)	10 to 30
No. 50 (300 µm)	15 to 35
No. 100 (150 µm)	12 to 20
Pan	3

* If individual percentage retained on No. 16 sieve is 20 percent or less, maximum limit for percentage retained on No. 8 sieve may be increased to 20 percent.

3.2.3 *Coarse Aggregate Grading.*-The maximum size aggregate shall be 1-1/2 inches (37.5 mm). The coarse aggregate shall be separated into two size fractions, No. 4 to 3/4 inch (4.75 to 19.0 mm) and 3/4 to 1-1/2 inches. These two fractions shall be combined in equal masses. For the No. 4 to 3/4-inch fraction, a minimum of 50 percent should be retained on the 3/8-inch (9.5-mm) sieve. For the 3/4- to 1-1/2-inch fraction, a minimum of 25 percent should be retained on the 1-1/4-inch (31.5-mm) sieve.

3.3 *Reference Admixture.*-For this procedure, unless otherwise requested by purchaser, the reference admixture used in the concrete mixture specified in section 4 shall be "neutralized Vinsol resin."[6]

3.4 *Specific Use Test Materials.*-When it is desired to test an air-entraining admixture for use in specific work, cement and aggregates should be representative of those proposed for use in the work, and concrete mixtures should be designed to have the cement content specified for use in the work (note 1). If maximum size of coarse aggregate is greater than 1-1/2 inches, the freshly mixed concrete shall be screened over a 1-1/2-inch sieve prior to fabricating test specimens in accordance with wet sieving procedure described in USBR 4172.

3.5 *Preparation and Determination of Mass.*-All materials shall be prepared and all mass determinations shall be made as prescribed in sections 3, 4, and 7 of USBR 4192.

4. Concrete Mixtures

4.1 *Proportions.*-Using USBR 4211, all concrete shall be proportioned to conform to requirements of sections 4.1.1, 4.1.2, 4.1.3, and 4.1.4.

4.1.1 Cement content shall be 517±4.7 lbm/yd^3 (307±2.8 kg/m^3), except when tests are being made for specific uses (sec. 3.4).

4.1.2 Initial trial mixture shall contain the percentage of sand shown in USBR 4211 for the maximum size of aggregate and for the fineness modulus of sand being used.

4.1.3 Air content used in computation of proportions for all concrete shall be 5.0 percent except where admixture under test is for use in specific work (sec. 3.4), in which case the air content used in selecting proportions shall be the median of the range to be permitted in the work. If lightweight aggregates are to be used in specific work, the density of concrete used in selecting proportions shall be the median of the range permitted in the work.

4.1.4 Water and sand content shall be adjusted to obtain a slump of 2-1/2±1/2 inches (63.5±12.7 mm). Workability of concrete mixture shall be suitable for consolidation by hand rodding, and mixture shall have minimum water content possible. These conditions shall be achieved by final adjustments in the proportion of fine aggregate to total aggregate, or both, while maintaining yield and slump in required ranges.

4.2 *Conditions.*-Concrete mixtures shall be prepared with both the air-entraining admixture under test and with the reference admixture. Admixtures shall be added in amounts necessary to produce air content selected in accordance with 4.1.3 within a tolerance of ±0.5 percent of concrete volume.

5. Precautions

5.1 No particular hazards exist in performing the tests required under this procedure to justify special safety precautions.

5.2 Specific precautions in selection of materials, preparation of mix, preparation of specimens, and methods of curing and testing are covered throughout this test procedure.

6. Calibration and Standardization

6.1 Calibration of testing equipment is covered under the individual test procedures referenced in section 2.

6.2 Standardization of materials is covered in sections 3 and 4. Standardization of solutions for check tests for uniformity are covered in section 12.

7. Mixing

7.1 Machine mix concrete as prescribed in USBR 4192.

8. Tests and Properties of Freshly Mixed Concrete

8.1 The minimum number of tests shall be as shown in table 1. Test samples of freshly mixed concrete from at least three separate batches for each condition of concrete shall be prepared in accordance with the following USBR designations:

- *Slump.*-See USBR 4143.
- *Air Content.*-See USBR 4231. When lightweight aggregates are used under the provisions of section 3.4, use USBR 4173.
- *Bleeding.*-See USBR 4232.
- *Time-of-Setting.*-See USBR 4403, except that temperature of each ingredient of concrete mixtures,

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[6] Vinsol resin is manufactured by Hercules Inc., Wilmington, Delaware. Neutralization may be accomplished by treating 100 parts Vinsol resin with 9 to 15 parts of sodium hydroxide by mass. In an aqueous solution, the ratio of water to resinate shall not exceed 12:1 by mass.

just prior to mixing, and temperature at which time-of-setting specimens are stored during test period shall be 73.4±3 °F (23.0±1.7 °C).

9. Preparation of Test Specimens

9.1 Specimens for the test of hardened concrete, representing each test and age of test and each condition of concrete being compared, shall be made from at least three separate batches. The minimum number of specimens shall be as shown in table 1. On a given day, at least one specimen shall be made for each test and age of test from each condition of concrete except that at least two specimens for the freezing and thawing test shall be made from each condition of concrete. The preparation of all specimens shall be completed in 3 days of mixing.

9.2 *Manifestly Faulty Specimens*-Each group of specimens representing a given test or a given age of test, including tests of freshly mixed concrete, shall be examined visually before or during test, or both, whichever is appropriate. Discard any specimen found to be manifestly faulty by such examination. Visually examine all specimens representing a given test at a given age after testing, and should any specimen be found to be manifestly faulty, disregard test results. Should more than one specimen representing a given test at a given age be found manifestly faulty, either before or after testing, entire test shall be disregarded and repeated. The test result reported shall be the average of the individual test results of specimens tested or, in the event that one specimen or one result has been discarded, it shall be the average of the test results of remaining specimens.

10. Test Specimens of Hardened Concrete

10.1 *Number of Specimens.*-Make six or more test specimens for the freezing and thawing test, and three or more test specimens for each of the other types of test and age of test as specified in table 1 for each condition of concrete to be compared.

10.2 *Types of Specimens.*-Prepare specimens made from concrete with the air-entraining admixture under test and with the reference admixture in accordance with sections 10.2.1, 10.2.2, and 10.2.3.

10.2.1 *Compressive Strength.*-Make and cure test specimens in accordance with USBR 4192.

10.2.2 *Resistance to Freezing and Thawing.*-Test specimens shall consist of cylinders made and cured in accordance with the applicable requirement of USBR 4192. The cylinders shall be 3 by 6 inches (76 by 152 mm), with the +3/4-inch (+19.0-mm) material removed by wet screening. Make one set of specimens from the concrete mixture containing the air-entraining admixture under test and from the reference concrete mixture; the air content of each mixture being as specified in section 4.2.

10.2.3 *Length Change.*-Make and cure test specimens in accordance with ASTM C 157. The moist-curing period, including time in molds, shall be 14 days.

11. Tests on Hardened Concrete

11.1 Test specimens of hardened concrete in accordance with sections 11.1.1, 11.1.2, and 11.1.3.

11.1.1 *Compressive Strength.*-See USBR 4039. Test specimens at 3, 7, and 28 days; 6 months; and 1 year (note 2). Calculate compressive strength of concrete containing admixture under test as a percentage of compressive strength of reference concrete by dividing average compressive strength of specimens made from concrete containing admixture under test at a given age of test by average compressive strength of specimens made from reference concrete at same age of test, and multiply quotient by 100.

NOTE 2.-When tests are conducted with materials representative of those proposed for use in specific work in accordance with section 3.4, and if results of tests are required in a period of time that will not permit curing of specimens to the ages of 6 months and 1 year, the tests at those ages may be waived.

Table 1. - Types and minimum number of specimens and tests.

Test	Number of types of specimens[1]	Number of test ages	Number of conditions of concrete[2]	Minimum number of specimens
Slump	1	1	2	[3]
Air content	1	1	2	[3]
Bleeding	1	1	2	6
Time-of-setting	1	[4]	2	6
Compressive strength	1	5	2	30
Freezing and thawing	1	1	2	[5]12
Length change	1	1	2	6

[1] See sections 8 and 10.2.
[2] See section 4.2.
[3] Determined on each batch of concrete mixed.
[4] See section 8.1.
[5] Specimens for duplicate tests from each batch.

11.1.2 *Resistance to Freezing and Thawing.*-See USBR 4666. The six specimens for freeze-thaw testing shall be cured before being placed under test. Three cylinders shall be cured 28 days at 100-percent relative humidity at 73.4±3 °F (23±1.7 °C). The other three cylinders shall be cured 14 days at 100-percent relative humidity at 73.4±3°F, and followed by 76 additional days of curing at 50-percent relative humidity at 73.4±3 °F.

11.1.3 *Length Change.*-See ASTM C 157. The drying period shall be 14 days.

NOTE 3.-Applicable only when specifically required by purchaser for use in structures where length change may be of critical importance.

12. Check Tests for Uniformity

12.1 The check tests listed in ASTM C 260 covering "Optional Uniformity Requirements" shall be determined as described in sections 12.1.1, 12.1.2, and 12.1.3.

12.1.1 *pH.*-The pH of liquid, air-entraining admixtures shall be determined in accordance with ASTM E 70. Nonliquid admixtures should be prepared in solution concentration when required for use as a preliminary to determining pH (note 4). The temperature of check test sample shall be within ±2 °F (±1 °C) of that for the acceptance sample and preferably in the range from 70 to 80 °F (21 to 27 °C). The sample taken should be sufficient to fill container so as to minimize carbonation.

NOTE 4.-Unless there is a reason to do otherwise, dissolve material in water in proportions specified for job use as shown on package or in other manufacturer's instructions.

12.1.2 *Specific Gravity.*-The specific gravity of liquid, air-entraining admixtures shall be determined in accordance with ASTM D 1429, sections 6 to 10, or by a hydrometer meeting the requirements of ASTM E 100, series 111H-120H. Nonliquid admixtures should be prepared in solution concentration when required for use as a preliminary to determining specific gravity (note 4). The temperature of check test sample shall be within ±2 °F (±1 °C) of that for the acceptance sample and preferably in the range from 70 to 80 °F (21 to 27 °C); the same test method shall be used for the determination. The reagent water should meet the requirements of ASTM D 1193.

12.1.3 *Air Content of Mortar.*-Using the same amounts of successive lots of air-entraining admixtures with the same cement, determine the air contents of mortars in accordance with USBR 4185. The air-entraining admixtures shall be combined with mixing water prior to start of mixing procedure. The determinations for both reference test sample and acceptance sample should be made on same day. Any changes in air-entraining capacity of acceptance sample as successive check tests are made should be noted.

13. Conditioning

13.1 Conditioning of materials is covered under sections 3, 4, and 7 through 12.

14. Procedure

14.1 The procedure of testing is covered under sections 3, 4, and 7 through 12.

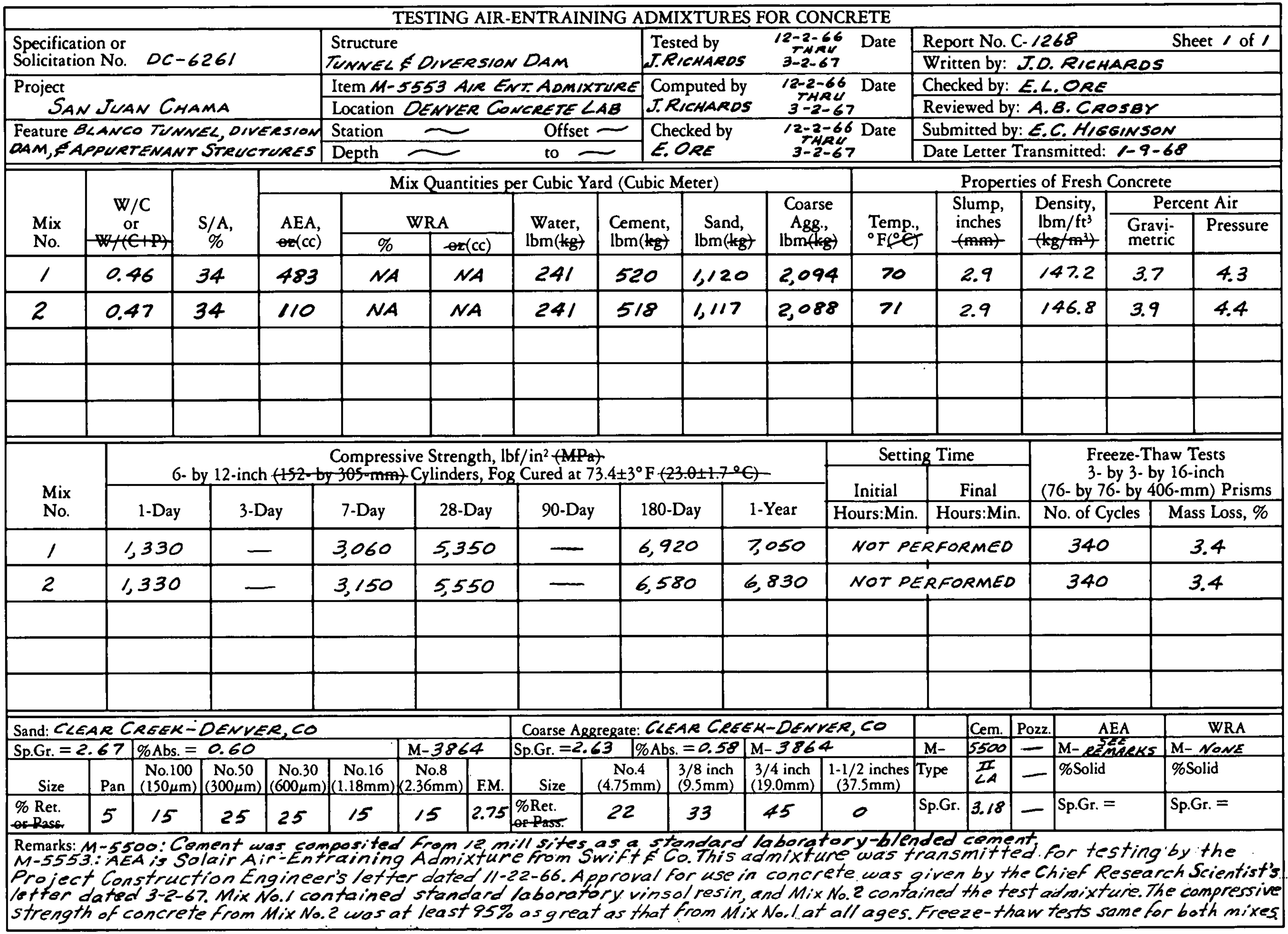
15. Calculations

15.1 Calculations involved in the referenced procedures of section 2 are covered in each respective procedure.

16. Report

16.1 Figure 1 shows a typical reporting form, the report shall include:

- Results of tests specified in this procedure as compared with requirements of ASTM C 260.
- Brand name, manufacturer's name and lot number, character of material, and quantity represented by sample of admixture under test.
- Brand name, manufacturer's name, and other data on reference admixture.
- Brand name, manufacturer's name, type, and test data on the portland cement portion of the cements used.
- Description of and test data on the fine and coarse aggregates used.
- Detailed data on concrete mixtures used, including amounts and proportions of admixtures used, actual cement factors, water-cement ratios, ratios of fine to total aggregate, consistency, and air content.
- In the event that, in accordance with provisions of note 2 or 3, some of the tests have been waived, the circumstances under which such action was taken shall be stated.



TESTING AIR-ENTRAINING ADMIXTURES FOR CONCRETE

Specification or Solicitation No. DC-6261	Structure TUNNEL & DIVERSION DAM	Tested by J. RICHARDS — Date 12-2-66 THRU 3-2-67	Report No. C-1268 Sheet 1 of 1 Written by: J.D. RICHARDS
Project SAN JUAN CHAMA	Item M-5553 AIR ENT. ADMIXTURE Location DENVER CONCRETE LAB	Computed by J. RICHARDS — Date 12-2-66 THRU 3-2-67	Checked by: E.L. ORE Reviewed by: A.B. CROSBY
Feature BLANCO TUNNEL, DIVERSION DAM, & APPURTENANT STRUCTURES	Station ~ Offset ~ Depth ~ to ~	Checked by E. ORE — Date 12-2-66 THRU 3-2-67	Submitted by: E.C. HIGGINSON Date Letter Transmitted: 1-9-68

Mix No.	W/C or ~~W/(C+P)~~	S/A, %	Mix Quantities per Cubic Yard (Cubic Meter) AEA, ~~oz~~(cc)	WRA %	WRA ~~oz~~(cc)	Water, lbm(~~kg~~)	Cement, lbm(~~kg~~)	Sand, lbm(~~kg~~)	Coarse Agg., lbm(~~kg~~)	Properties of Fresh Concrete Temp., °F(~~°C~~)	Slump, inches ~~(mm)~~	Density, lbm/ft^3 ~~(kg/m^3)~~	Percent Air Gravimetric	Percent Air Pressure
1	0.46	34	483	NA	NA	241	520	1,120	2,094	70	2.9	147.2	3.7	4.3
2	0.47	34	110	NA	NA	241	518	1,117	2,088	71	2.9	146.8	3.9	4.4

Mix No.	Compressive Strength, lbf/in^2 ~~(MPa)~~ 6- by 12-inch ~~(152- by 305-mm)~~ Cylinders, Fog Cured at 73.4±3° F ~~(23.0±1.7 °C)~~ 1-Day	3-Day	7-Day	28-Day	90-Day	180-Day	1-Year	Setting Time Initial Hours:Min.	Setting Time Final Hours:Min.	Freeze-Thaw Tests 3- by 3- by 16-inch (76- by 76- by 406-mm) Prisms No. of Cycles	Mass Loss, %
1	1,330	—	3,060	5,350	—	6,920	7,050	NOT PERFORMED		340	3.4
2	1,330	—	3,150	5,550	—	6,580	6,830	NOT PERFORMED		340	3.4

Sand: CLEAR CREEK–DENVER, CO								Coarse Aggregate: CLEAR CREEK–DENVER, CO						Cem.	Pozz.	AEA	WRA
Sp.Gr. = 2.67	%Abs. = 0.60					M-3864		Sp.Gr. = 2.63	%Abs. = 0.58	M-3864			M-	5500	—	M- SEE REMARKS	M- NONE
Size	Pan	No.100 (150 µm)	No.50 (300 µm)	No.30 (600 µm)	No.16 (1.18mm)	No.8 (2.36mm)	F.M.	Size	No.4 (4.75mm)	3/8 inch (9.5mm)	3/4 inch (19.0mm)	1-1/2 inches (37.5mm)	Type	II LA	—	%Solid	%Solid
% Ret. ~~or Pass~~	5	15	25	25	15	15	2.75	%Ret. ~~or Pass~~	22	33	45	0	Sp.Gr.	3.18	—	Sp.Gr. =	Sp.Gr. =

Remarks: M-5500: Cement was composited from 12 mill sites as a standard laboratory-blended cement. M-5553: AEA is Solair Air-Entraining Admixture from Swift & Co. This admixture was transmitted for testing by the Project Construction Engineer's letter dated 11-22-66. Approval for use in concrete was given by the Chief Research Scientist's letter dated 3-2-67. Mix No.1 contained standard laboratory vinsol resin, and Mix No. 2 contained the test admixture. The compressive strength of concrete from Mix No. 2 was at least 95% as great as that from Mix No. 1 at all ages. Freeze-thaw tests same for both mixes.

Figure 1. – Typical reporting form for mix quantities, properties of fresh concrete, compressive strength, time-of-setting, and freeze-thaw with air-entraining admixtures.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4266-92

PROCEDURE FOR

TIME-OF-SETTING OF HYDRAULIC CEMENT BY GILLMORE NEEDLES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4266; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation C 266-77.

1. Scope

1.1 This designation covers the procedure for determination of time-of-setting of hydraulic cement by Gillmore needles.

NOTE 1.–For the procedure for determining time-of-setting by the Vicat needle, see USBR 4191.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
4183 Sampling and Acceptance of Hydraulic Cement
4187 Normal Consistency of Hydraulic Cement
4191 Time-of-Setting of Hydraulic Cement by Vicat Needle
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:
C 266 Standard Test Method for Time-of-Setting of Hydraulic Cement by Gillmore Needles[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,2]

2.3 *National Institute of Standards and Technology*[3]:
Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

3. Apparatus

3.1 *Scales*.–For scales currently in use, the permissible variation at a load of 1000 grams shall be ±1 gram; permissible variation on new scales shall be one-half this value.

3.2 *Glass Graduates*.–Graduates shall be of 200- or 250-mL capacity, and conform to requirements of ASTM C 490.

3.3 *Gillmore Needles*.–Shall conform to requirements of table 1. The needle tips shall be cylindrical for about 3/16 inch (4.8 mm). The needle ends shall be plane, at right angles to axis of rod, and shall be maintained in a clean condition. Preferably, needles should be mounted as shown on figure 1.

Table 1. - Tolerances for Gillmore needles.

	Tolerance
Initial needle:	
Mass	0.25 ±0.001 lbm (113.4 ±0.5 g)
Diameter	0.083 ±0.002 inch (2.11 ±0.05 mm)
Final needle:	
Mass	1.000 ±0.001 lbm (453.6 ±0.5 g)
Diameter	0.042 ±0.002 inch (1.07 ±0.05 mm)

4. Precautions

4.1 This test method may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

4.2 Further precautions on use of apparatus, and effects that water percentage, water temperature, air temperature, humidity, and amount of kneading paste receives will have on end results is discussed under section 7.3.

5. Calibration and Standardization

5.1 Calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly.

5.2 Scales shall be calibrated to conform to section 3.1 in accordance with USBR 1012.

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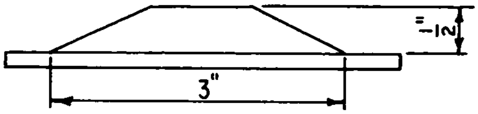
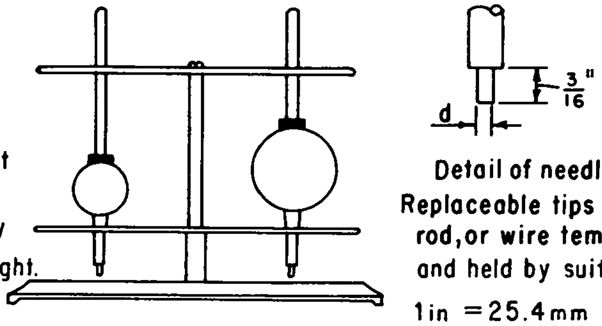
[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] Annual Book of ASTM Standards, vol. 04.02.

[3] Formerly National Bureau of Standards.



(a) Pat with top surface flattened for time of setting by Gillmore Method



NOTES: Cross arms must be designed to prevent their rotation about the vertical shaft. Lower arm preferably adjustable for height.

Detail of needle tips.
Replaceable tips may be made of stock drill rod, or wire tempered after shaping, and held by suitable chuck or other fastener.
1 in = 25.4 mm

(b) Gillmore Needles

Figure 1. - Gillmore apparatus and test specimen.

5.3 Glass graduates shall be accepted upon certification by manufacturer to conform to ASTM C 490.

5.4 The Gillmore needles shall be calibrated to conform to requirements of section 3.3 by using scales conforming to section 5.2 and linear measurement devices in accordance with USBR 1000.

6. Conditioning

6.1 *Temperature and Humidity*:

6.1.1 The temperature of air in vicinity of mixing slab, dry cement, and Gillmore needles shall be maintained between 68 and 81.5 °F (20 and 27.5 °C). The temperature of mixing water and of moist closet or moist room shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

6.1.2 The relative humidity of laboratory shall be not less than 50 percent. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 90 percent.

6.2 *Preparation of Cement Paste*.–Mix 650 grams of cement with percentage of mixing water required for normal consistency (USBR 4187) following the procedure described in USBR 4305. Distilled water is preferable and shall be used for all referee or cooperative tests.

7. Procedure

7.1 *Molding Test Specimen*.–From cement paste prepared as described in section 6.2, make a pat about 3 inches (76 mm) in diameter and 1/2-inch (13 mm) in thickness at center, with a flat top and tapering to a thin edge (fig. 1). Place pat on a flat, clean, glass plate about 4 inches (102 mm) square. In molding the pat, flatten cement paste initially on glass plate and then form pat by drawing trowel from outer edge toward center; then flatten top. Place pat in moist closet or moist room and allow to remain there except when determinations of time-of-setting are being made. A time-of-set specimen and an autoclave bar may be made from same batch.

7.2 *Time-of-Setting Determination*.–When determining time-of-setting, hold needles in a vertical position and apply lightly to surface of pat. Consider cement to have acquired its initial set when pat will bear, without appreciable indentation, the initial Gillmore needle. Consider cement to have acquired its final set when pat will bear, without appreciable indentation, the final Gillmore needle.

7.3 *Precautions*.–The time-of-setting is affected not only by percentage and temperature of water used and amount of kneading paste received, but also by temperature and humidity of air. Therefore, the determination of time-of-setting is only approximate.

8. Calculations

8.1 A typical calculation form is shown on figure 2.

9. Report

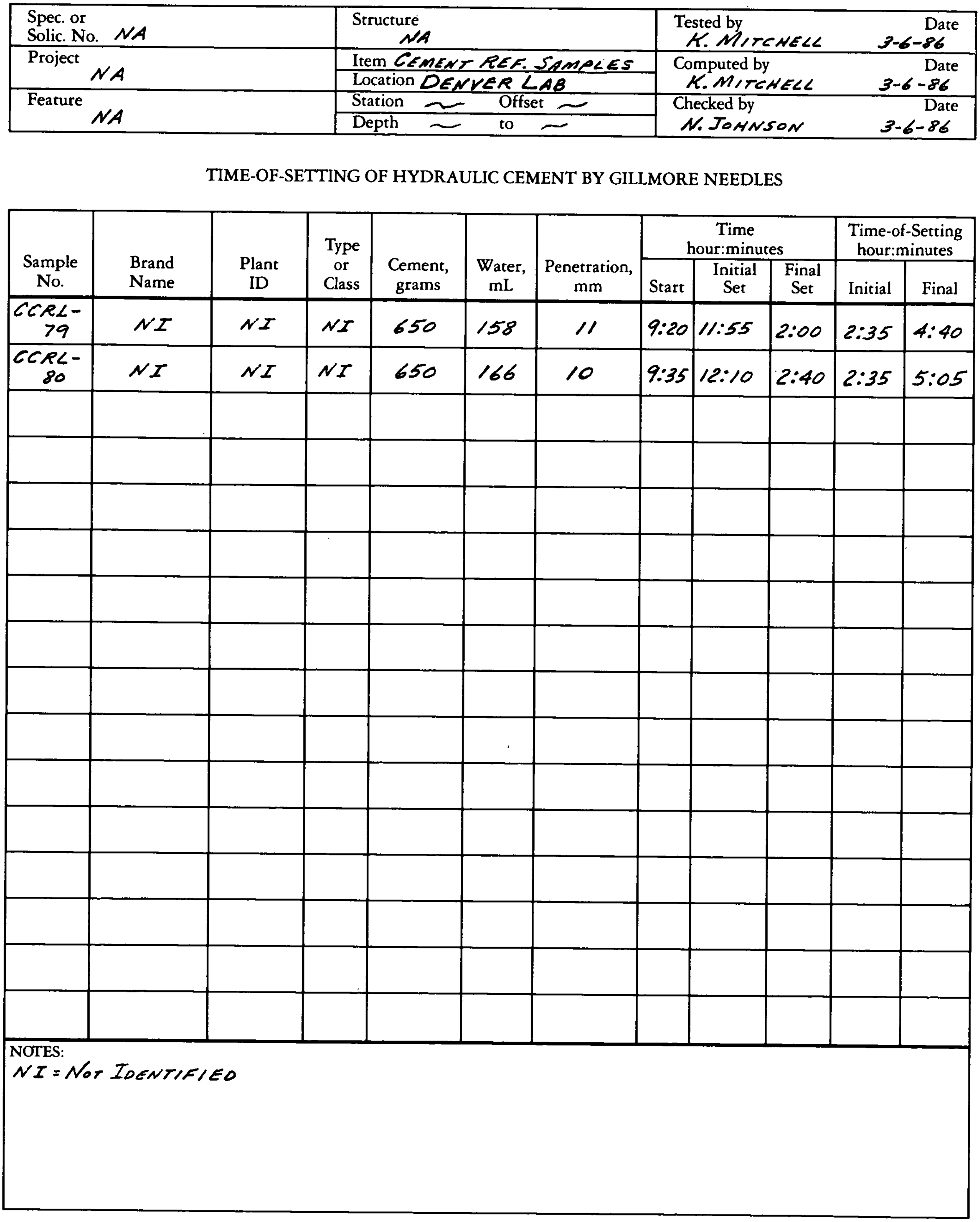
9.1 A suggested reporting form is shown on figure 5 of USBR 4183.

10. Precision and Bias

10.1 No precision data are available at this time, statements on precision and bias will be included in a later revision of this procedure.

11. References

11.1 For additional information on details of cement test methods, reference may be made to the "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.



Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 3-6-86
Project NA	Item CEMENT REF. SAMPLES Location DENVER LAB	Computed by K. MITCHELL Date 3-6-86
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by N. JOHNSON Date 3-6-86

TIME-OF-SETTING OF HYDRAULIC CEMENT BY GILLMORE NEEDLES

Sample No.	Brand Name	Plant ID	Type or Class	Cement, grams	Water, mL	Penetration, mm	Time hour:minutes			Time-of-Setting hour:minutes	
							Start	Initial Set	Final Set	Initial	Final
CCRL-79	NI	NI	NI	650	158	11	9:20	11:55	2:00	2:35	4:40
CCRL-80	NI	NI	NI	650	166	10	9:35	12:10	2:40	2:35	5:05

NOTES:
NI = NOT IDENTIFIED

Figure 2. – Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4295-92

PROCEDURE FOR

PETROGRAPHIC EXAMINATION OF AGGREGATE FOR CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4295; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 295-79.

1. Scope

1.1 This designation outlines procedures for the petrographic examination of samples representative of materials proposed for use as aggregates in concrete, and is based on methods of reference [1].[1] The specific procedures employed in the examination of any sample will depend to a large extent on purpose of examination and nature of sample. In most cases, examination will require use of optical microscopy. Complete petrographic examinations for particular purposes or to investigate particular problems may require examination of aggregates or selected constituents using additional procedures such as X-ray diffraction analysis, differential thermal analysis, or infrared spectroscopy. In some instances, such procedures are less time consuming and more definitive than microscopical methods. Petrographic examinations are made to:

- Determine physical and chemical properties of material that may be observed by petrographic methods, and that have a bearing on performance of material in its intended use.
- Describe and classify constituents of sample.
- Determine relative amounts of constituents of sample, which is essential for proper evaluation of sample when constituents differ significantly in properties that have a bearing on performance of material in its intended use.

1.2 Identification of the constituents of a sample is usually a necessary step towards recognition of the properties that may be expected to influence behavior of material in its intended use, but identification is only part of an examination. The value of any petrographic examination depends to a large extent on how representative the examined samples are, completeness and accuracy of information provided to petrographer concerning source and proposed use of material, and petrographer's ability to correlate these data with findings of examination.

1.3 This procedure does not attempt to outline the techniques of petrographic work because it is assumed the procedure will be used by personnel qualified by education and experience to employ such techniques for the recognition of characteristic properties of rocks and minerals and to describe and classify constituents of an aggregate sample. The objectives of this procedure are to outline the extent to which such techniques should be used, selection of properties that should be looked for, and manner in which such techniques may best be employed in the examination of samples of aggregates for concrete. These objectives will have been attained if engineers responsible for the application of the results of petrographic examinations to the evaluation of aggregate materials for use in concrete construction have reasonable assurance that such results, wherever and whenever obtained, may confidently be compared.

1.4 The rock and mineral names given in ASTM C 294 should be used when appropriate in reports prepared according to this procedure.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
4075 Sampling Aggregates
4114 Chemical Analysis of Hydraulic Cement
4117 Materials Finer than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size
4903 Flat and Elongated Particles in Coarse and Fine Aggregate

2.2 *ASTM Standards*:
C 294 Standard Descriptive Nomenclature of Constituents of Natural Mineral Aggregates[2]
C 295 Standard Practice for Petrographic Examination of Aggregates for Concrete[2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]

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[1] Numbers in brackets refer to entries in References, section 19.

[2] *Annual Book of ASTM Standards*, vol. 04.02.

3. Planning

3.1 It is assumed that the examination will be made by personnel qualified by education and experience to operate equipment used and to record and interpret results obtained. In some cases, the petrographer will have had experience adequate to provide detailed interpretation of materials' performance with respect to engineering and other consequences of observations. In other cases, interpretation will be made in part by engineers, scientists, or others qualified to relate observations to questions to be answered.

4. Significance and Use

4.1 Petrographic examination of aggregate considered for use in hydraulic cement concrete is only one aspect of the evaluation; the examination is also used for many other purposes, some of which are discussed in the subsequent sections.

4.2 Petrographic examinations provide identifications of types and varieties of rocks present in potential aggregates. The identification of every rock and mineral present in an aggregate source is only part of the examination. The examination should also establish whether the aggregate contains chemically unstable minerals such as soluble sulfates, unstable sulfides that may form sulfuric acid, radioactive materials in significant amounts, or volumetrically unstable materials such as smectites (the montmorillonite-saponite group of minerals) or swelling clays. These are aggregate ingredients that could be dangerous to personnel handling them and also dangerous to the concrete.

4.3 Petrographic examinations should discriminate the portion of each coarse aggregate that is weathered and the extent of that weathering, whether it is severe, moderate, or slight, and should distinguish the proportion of each rock type in each degree of weathering. If concrete in which the aggregate may be used will be exposed to freezing and thawing in a critically saturated condition, finely porous and highly weathered rocks should be discriminated because they will be especially susceptible to damage by these conditions. Such damage would cause aggregate portion of concrete to fail, which would ultimately destroy the concrete because such aggregates cannot be protected by adequately air-entrained sound mortar. Finely porous aggregates near the concrete surface are also likely to form popouts, which are blemishes on pavements and walls.

4.4 Petrographic examinations may also be used to determine proportions of cubic, spherical, ellipsoidal, pyramidal, tabular, flat, and elongated particles in an aggregate sample. Flat, elongated, and thin chip-like particles in coarse aggregate increase amount of mortar needed to form a workable concrete mixture. By increasing amount of cement paste required, the amount of cement needed increases, which raises the cost, or the amount of water needed increases, which will lower the quality of the paste, or both. Fine aggregates with significant portions of flat, elongated, or thin chip-like particles in manufactured fine aggregates also make harsh mortars and require increases in cementitious materials, or water, or both.

NOTE 1.–For methods to determine the proportion of flat and/or elongated particles in coarse and fine aggregates in concrete, see USBR 4903.

4.5 Petrographic examinations shall identify and call attention to potentially alkali-silica reactive and alkali-carbonate reactive ingredients. The examination shall determine such ingredients quantitatively, and recommend additional tests to confirm or refute the presence, in significant amounts, of aggregate ingredients capable of reaction in the concrete with potassium hydroxide and sodium hydroxide usually derived from cement constituents. Alkali-silica reactive constituents found in aggregates include opal, cristobalite, tridymite, siliceous and some intermediate volcanic glass, chert, glassy to cryptocrystalline acid igneous rocks, synthetic siliceous glasses; some argillites, phyllites, and metamorphic graywackes; also rocks containing highly metamorphic quartz such as graywackes, phyllites, schists, gneisses, gneissic granites, vein quartz, quartzite, and sandstone. Criteria are available in mineralogic literature for identifying these minerals by optical properties and/or X-ray diffraction, and in petrographic and petrologic literature for identifying the rocks by mineral composition and texture in thin section, sometimes assisted by X-ray diffraction in the mineral composition. Alkali-carbonate reactive rocks are usually calcareous dolomites or dolomitic limestones with clayey insoluble residues; however, some dolomites essentially free of clay and some very fine-grained limestones free of clay and with minor insoluble residue, mostly quartz, are also capable of some alkali-carbonate reactions.

4.6 Petrographic examinations may be directed specifically at the possible presence of contaminants in aggregates, such as synthetic glass, cinders, clinker or coal ash, magnesium and/or calcium oxide, soil, hydrocarbons, chemicals that may affect setting behavior of concrete or properties of aggregate, animal excrement, plants or rotten vegetation, and any other contaminant that may prove undesirable in the concrete.

5. Apparatus and Supplies

5.1 The apparatus and supplies listed in sections 5.1.1 and 5.1.2 comprise a selection that will permit the use of all of the procedures described in this test designation. All specific items listed have been used, in connection with the performance of petrographic examinations, by the procedures described herein; however, it is not intended to imply that other items cannot be substituted to serve similar functions. Whenever possible, the selection of particular items should be left to the judgment of the petrographer, based on experience and familiarity. The minimum equipment regarded as essential for a petrographic examination of aggregate samples are those items, or equivalent items that will serve the same purpose, that are denoted by (E) in the listings of sections 5.1.1 and 5.1.2.

5.1.1 *Apparatus and Supplies for Preparation of Specimens*:

- (E) *Rock-Cutting Saw.*-Preferably with a 14-inch (350-mm) or larger diamond blade, and automatic feed.
- (E) *Horizontal Grinding Wheel.*-Preferably 16 inches (400 mm) in diameter.
- *Polishing Wheel.*-Preferably 8 to 12 inches (200 to 300 mm) in diameter.
- (E) *Abrasives.*-Silicon carbide grit No. 100 (122 μm), No. 220 (63 μm), No. 320 (31 μm), No. 600 (16 μm), and No. 800 (12 μm); alumina M-305 (5 μm).
- *Geologist's Pick or Hammer.*
- (E) *Microscope Slides.*-Clear, noncorrosive, 1- by 1.75-inch (25- by 45-mm) size.
- (E) *Canada Balsam.*-Neutral, in xylene, or suitable low-viscosity epoxies, or Lakeside 70.
- (E) *Xylene.*
- (E) *Mounting Medium.*-Suitable for mounting rock slices for thin sections.
- (E) *Laboratory Oven.*
- (E) *Plate-Glass Squares.*-About 12 inches (300 mm) square for thin-section grinding.
- (E) *Sample Splitter with Pans.*
- (E) *Micro Cover Glasses.*-Noncorrosive, square, 1/2 to 3/4 inch (12 to 18 mm) or 1 inch (25 mm).
- *Plattner Mortar.*

5.1.2 *Apparatus and Supplies for Examination of Specimens*:

- (E) *Polarizing Microscope.*-With mechanical stage; low-, medium-, and high-power objectives, and objective-centering devices; eye-pieces of various powers; full- and quarter-wave compensators; quartz wedge.
- (E) *Microscope Lamps.*-Preferably with a sodium arc lamp.
- (E) *Stereoscopic Microscope.*-With objectives and oculars to give final magnifications from about 6X to about 60X.
- (E) *Magnet.*-Preferably Alnico, or an electromagnet.
- (E) *Needleholder and Points.*
- *Dropping Bottle.*-Capacity of 2 ounces (60 mL).
- *Petri Culture Dishes.*
- *Forceps.*-Smooth, straightpointed.
- (E) *Lens Paper.*
- (E) *Immersion Media.*- n = 1.410 to 1.785, in increments of 0.005.
- *Counter.*
- *Photomicrographic Camera and Accessories.*
- *Sieves.*-Shall meet requirements of ASTM E 11.
- *Balances or Scales.*-Shall meet requirements of USBR 4114.

5.2 The items listed under section 5.1.1 are, in most cases, those used to make thin sections. Semiautomatic thin-section machines are now available, and there are several thin-section makers who advertise in *Geotimes*, the *American Mineralogist*, and other geological journals. Laboratories may find it reasonable to buy a thin-section machine or use a commercial thin-section maker. Remotely located laboratories have more need to be able to make their own thin sections.

5.3 It is necessary that facilities be available to the petrographer to check index of refraction of immersion media. If accurate identification of materials is to be attempted; e.g., the differentiation of quartz and chalcedony or differentiation of basic from intermediate volcanic glass, the indexes of refraction of the media need to be known with accuracy. Media will not be stable for very long periods and are subject to considerable variation due to temperature change. In laboratories not provided with good temperature control, it is often necessary to recalibrate immersion media several times during the course of a single day when accurate identifications are required. The equipment needed for checking immersion media consists of an Abbe refractometer, which should be equipped with compensating prisms to read indexes for sodium light from white light, or it should be used with a sodium arc lamp.

5.4 A laboratory that undertakes any considerable amount of petrographic work should be provided with facilities to make photomicrographic records of such features that cannot adequately be described in words. Photomicrographs can be taken using standard microscope lamps for illumination; however, it is recommended that whenever possible a zirconium arc lamp be provided for this purpose. For illustrations of typical apparatus, reference may be made to the paper by Mather and Mather [1]. Manufacturers of microscopes equipped with cameras and photomacrographic equipment may also be consulted.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Sampling

7.1 Samples for petrographic examination should be taken by or under the direct supervision of a geologist familiar with the requirements for random sampling of aggregates for concrete and, in general, following requirements of USBR 4075. The exact location from which sample was taken, geology of site, and other pertinent data should be submitted with sample. The amount of material actually studied in the examination will be determined by the nature of the examination to be made and the nature of the material to be examined, as discussed in sections 7.1.1 through 7.1.4.

7.1.1 Undeveloped quarries should be sampled by means of cores drilled through the entire depth expected to be productive of sound material. Drilling such cores should be in a direction that is essentially normal to dominant structural feature of rock. Massive material may be sampled by "NX," 2-1/8-inch (54-mm) diameter cores.

Thinly bedded or complex material should be represented by cores not less than 4 inches (102 mm) in diameter. There should be an adequate number of cores to cover limits of deposit proposed for work under consideration. The entire footage of recovered core should be included in sample, and accurate data given as to elevations, depths, and core losses.

7.1.2 Operating quarries and operating sand and gravel deposits, where stockpiles of material produced are available, should be represented by not less than 100 pounds (45 kg) or 300 pieces, whichever is larger, of each size of material to be examined. Samples from stockpiles should be composed of representative portions of larger samples collected with due consideration given to segregation in the piles.

7.1.3 Exposed faces of nonproducing quarries, where stockpiles of processed material are not available, should be represented by not less than 4 pounds (2 kg) from each distinctive stratum or bed, with no piece weighing less than 1 pound (0.5 kg), or by a drilled core as described in 7.1.1.

7.1.4 Undeveloped sand and gravel deposits should be sampled by test pits excavated to anticipated depth of future economic production. Samples should consist of not less than the quantities of material indicated in table 1, selected so as to be representative of deposits.

NATURAL GRAVEL AND SAND

8. Selection of Samples for Examination

8.1 Samples of gravel and natural sand for petrographic examination should be dry sieved in accordance with USBR 4136 to provide samples of each sieve size. For sands, an additional portion should then be tested according to USBR 4117, with wash water being saved and removed by drying to provide a sample of material passing the No. 200 (75-µm) sieve. Results of sieve analysis of each sample made according to USBR 4136 should be provided to petrographer for use in calculating results of petrographic examination. Each sieve fraction should be examined separately, starting with largest size. Rocks are more easily recognized in larger pieces; the breakdown of a heterogeneous type rock present in the larger sizes may have provided particles of several apparently different types using smaller sizes. Some important and easily confused types may be recognizable using the stereoscopic microscope if they are first recognized and separated in larger sizes, but may require examination using the petrographic microscope if they are first encountered in smaller sizes.

8.2 The number of particles of each sieve fraction to be examined will be fixed by required precision of determination of the less abundant constituents. Assuming that field and laboratory sampling procedures are accurate and reliable, the number of particles examined, identified, and counted in each sieve fraction will depend on required accuracy of the estimate of constituents present in small quantities. The numbers given in this procedure are minimal; they are based on experience and statistical considerations [2,3]. It is believed that at least 300 particles of each sieve fraction should be identified and counted to obtain reliable results. Precise determinations of small quantities of an important constituent will require more than 300 particles. If sample of a sieve fraction contains many more particles than need to be identified, sample shall be reduced in accordance with one of the procedures of USBR 4702.

9. Calibration and Standardization

9.1 Calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

9.2 Oven shall be calibrated in accordance with USBR 1020.

9.3 The balances or scales shall meet requirements of USBR 4114, and shall be calibrated in accordance with USBR 1012.

10. Conditioning

10.1 Conditioning required is covered under section 11.

11. Procedure

11.1 *Examination of Natural Gravel*:

11.1.1 *Coatings*.–The pebbles shall be examined to establish whether exterior coatings are present. If present, it should be determined whether coatings consist of

Table 1. – Minimum sizes for samples from undeveloped sand and gravel deposits.

Sieve size	Minimum for sample		
	lbm	kg	No. pieces
> 6 inches (>150 mm)	–	–	*
3 to 6 inches (75 to 150 mm)	–	–	300*
1-1/2 to 3 inches (37.5 to 75 mm)	400	180	–
3/4 to 1-1/2 inches (19.0 to 37.5 mm)	200	90	–
No. 4 to 3/4 inch (4.75 to 19.0 mm)	100	45	–
Finer than No. 4 (4.75 mm)**	50	23	–

* Not less than one piece from each apparent type of rock.
** Fine aggregate.

materials likely to be deleterious in concrete, such as opal, gypsum, easily soluble salts, and organic matter. It should also be determined how firmly coatings are bonded to pebbles. The coated particles shall be counted and the proportion calculated as a particle percentage of the whole sample.

11.1.2 *Particle Shape.*–Pebbles shall be examined to determine proportions of angular, subangular, subrounded, rounded, and flat and/or elongated particles. The primary particle shape shall be noted, and the flat and/or elongated particles counted and the proportions calculated as particle percentages of each sieve size examined.

11.1.3 *Rock Types.*–The sieve fraction should be sorted into different rock types by visual examination. If all or most of the groups present are types easily identifiable by examination of a natural or broken surface or by scratch and acid tests, no further identification may be needed. Fine-grained rocks that cannot be identified megascopically or that may consist of or contain constituents known to be deleterious in concrete should be examined with the stereoscopic microscope. If they still cannot be identified, they should be examined with the petrographic microscope. The amount of work done in identifying fine-grained rocks should be adapted to the data needed about the particular sample. Careful examination of one size of a sample, or study of data from a previous examination of samples from same source, will usually reveal amount of additional detailed microscopical work required to obtain adequate data. In some cases, petrographic methods other than microscopy, such as X-ray diffraction, may be required or may more quickly serve to identify fine-grained rock materials.

11.1.4 *Condition.*–The separated groups of each rock type should be examined to determine if further separation by physical condition is necessary. If all particles of a rock type are in comparable condition, that fact should be noted. More frequently, particles in several different degrees of weathering will be found in a group, and should be sorted into categories based on condition and on the expectation of comparable behavior in concrete. These categories are: (*a*) fresh, dense, (*b*) moderately weathered, (*c*) very weathered; or (*a*) satisfactory, (*b*) fair, (*c*) poor; or (*a*) dense, (*b*) porous (or porous and friable). It usually is not practicable to recognize more than three conditions per rock type, and one or two may be sufficient. An important constituent present in larger quantities may sometimes require separation into four groups by condition. A conspicuous example is chert, when it is the major constituent of a gravel sample. It may be present as dense, unfractured chert; as vuggy chert; as porous chert; and as dense but highly fractured chert. The determination of which of these four conditions characterizes a particle may be expected to have an important influence on the prediction of behavior of the particle in concrete.

11.1.5 *Record*:

11.1.5.1 Notes should be taken during the examination describing each rock type. The relevant features may include:

- Particle shape.
- Particle surface.
- Grain size.
- Texture and structure, including observations of pore space, packing of grains, and cementation of grains.
- Color.
- Mineral composition.
- Significant heterogeneities.
- General physical condition of rock type in sample.
- Presence of constituents known to cause deleterious chemical reaction in concrete.

11.1.5.2 Particle counts should be recorded so that tables can be made for inclusion in the report. When examination has been completed, notes should contain enough information to permit preparation of tables and descriptions. Tables should be prepared showing composition and condition of sample by sieve fractions, and the weighted average composition based on grading of sample as received and on distribution of constituents by sieve fractions. Descriptions of constituent groups should be prepared containing relevant features listed in section 11.1.5.1.

11.1.5.3 A tabulation should be prepared listing the rock types (noting the alkali-reactive types), rock descriptions, physical qualities, and percentages by particle count for the 3/8- to 3/4-inch (9.5- to 19.0-mm) and 3/4- to 1-1/2-inch (19.0- to 37.5-mm) size fractions. Figure 1 shows a typical tabulation of this type of data. The physical and chemical quality can then be determined and reported in tabular form along with the particle shapes and coatings, see figure 2. The No. 4 (4.75-mm) size fraction is visually examined and lithologically, physically, and chemically compared with the 3/8- to 3/4-inch size material. Differences and results are noted on figure 2.

11.2 *Examination of Natural Sand.*–The procedure for examination of natural sand is similar to that for natural gravel, with modifications necessitated by differences in particle size.

11.2.1 *Sizes Coarser Than No. 30* (600μm).–Each sieve fraction present that is coarser than the No. 30 (600-μm) sieve should be reduced in accordance with one of the procedures of USBR 4702 until a split containing at least 300 particles is obtained. The reduced sample of each sieve fraction should be examined, and its constituents identified and counted, using the stereoscopic microscope. It is convenient to spread out the sample in a flat-bottom glass dish, such as a Petri dish, and manipulate grains with forceps and dissecting needle. The identification of grains in coarser sand sizes is often easier when grains are just submerged in water. The submergence lessens reflection from outer surfaces and may show diagnostic features that cannot be seen when grains are dry. There are exceptions to this generalization. Where identification is difficult, the examination includes examination of natural surface (dry and wet), of a broken surface (dry and wet), and scratch and acid tests. The petrographer should resort to the petrographic microscope only after all of these steps

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PETROGRAPHIC EXAMINATION OF COARSE AGGREGATE

Rock types	Description of rock types	Physical quality	Percentage by particle count	
			3/4 to 1-1/2 inches (19.0 to 37.5 mm)	3/8 to 3/4 inch (9.5 to 19.0 mm)
Quartzite and sandstone	Hard; dense; white, yellow, or red; fine-grained; structureless; slightly absorptive, weathered, and fractured; includes quartzose, feldspathic-quartzose, and calcareous sandstones.	Satisfactory	34.5	29.5
	Firm; moderately absorptive, weathered, fractured, and friable.	Fair	6.5	3.0
	Firm to soft; highly absorptive, weathered, fractured, and friable; sandstone fragments easily disaggregate into individual grains.	Poor	1.0	0.5
Limestone	Hard; dense; light gray, yellow, or brown; fine-grained; structureless; slightly absorptive, weathered, and fractured; includes silty, fossiliferous, and argillaceous limestones.	Satisfactory	29.0	24.5
	Hard to firm; moderately absorptive, weathered, and fractured.	Fair	4.0	5.0
	Firm to soft; highly absorptive, weathered, and fractured; may cause popouts in concrete.	Poor	0.5	0.5
Gneiss	Hard; dense; green, pink, red, or gray; fine grained; schistose to gneissic; slightly absorptive, weathered, and fractured; includes granite and diorite gneisses as well as minor schist and miscellaneous metamorphic rocks.	Satisfactory	10.5	14.0
	Hard to firm; moderately absorptive, weathered, and fractured.	Fair	1.0	2.0
Chert[1]	Hard; dense; brown, yellow, or gray; cryptocrystalline to chalcedonic; structureless; slightly weathered and fractured; includes minor cherty limestone.	Satisfactory	7.0	11.5
	Hard to firm; slightly absorptive; moderately weathered and fractured.	Fair	0.5	1.0
	Soft, highly absorptive and weathered; may cause popouts in concrete.	Poor	–	0.5
Granite	Hard; dense; pink, white, and/or yellow; fine to medium grained; structureless; slightly absorptive, weathered, and fractured; includes minor feldspar grains and monzonite.	Satisfactory	4.0	6.0
	Hard to firm; slightly friable; moderately absorptive, weathered, and fractured.	Fair	1.0	0.5
Basalt	Hard; dense; dark gray; aphanitic; structureless; slightly absorptive, weathered, fractured, and vesicular.	Satisfactory	0.5	1.0
	Hard to firm; moderately absorptive, weathered, fractured, and vesicular.	Fair	–	0.5

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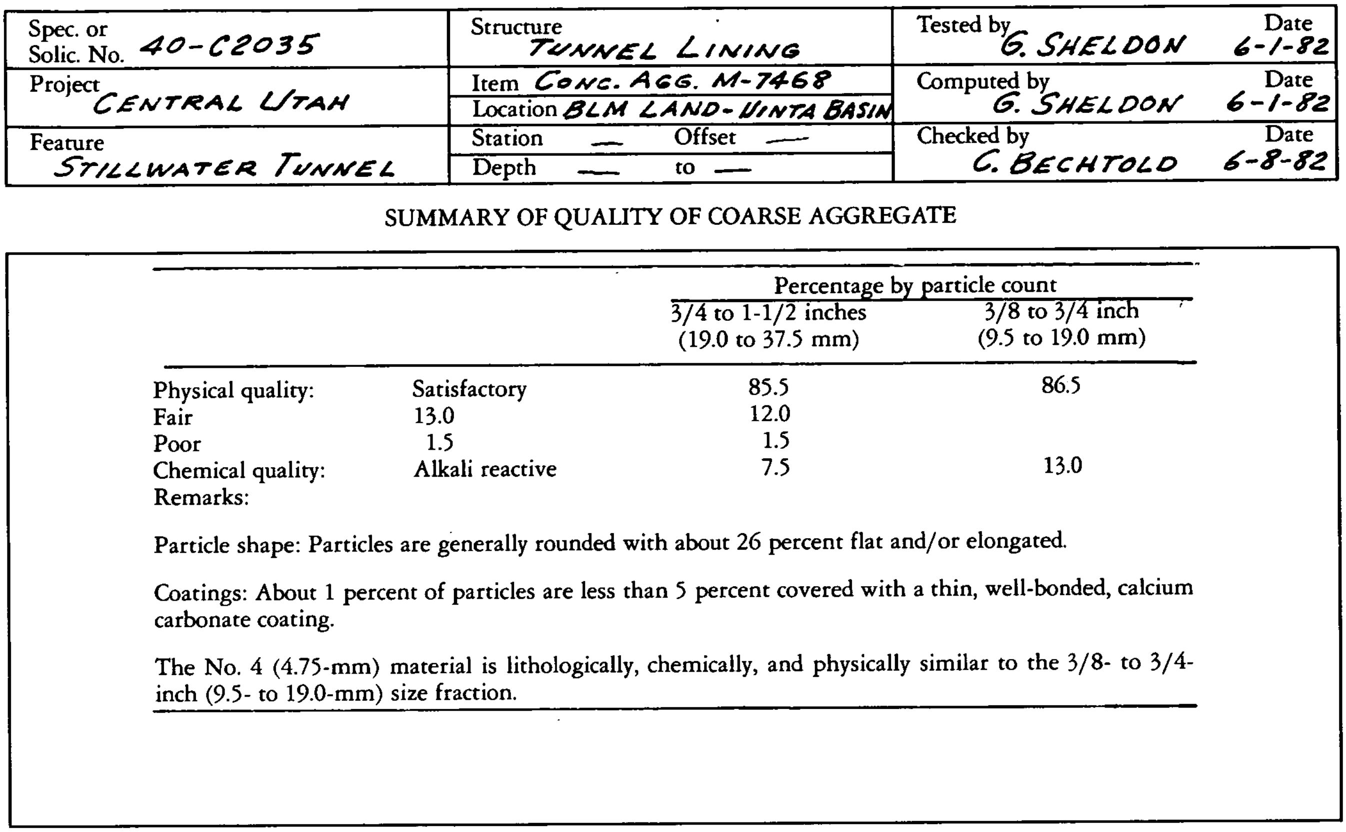
[1] Alkali-reactive rock type.

Figure 1. – Typical data sheet for coarse aggregate.



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SUMMARY OF QUALITY OF COARSE AGGREGATE

		Percentage by particle count	
		3/4 to 1-1/2 inches (19.0 to 37.5 mm)	3/8 to 3/4 inch (9.5 to 19.0 mm)
Physical quality:	Satisfactory	85.5	86.5
Fair	13.0	12.0	
Poor	1.5	1.5	
Chemical quality:	Alkali reactive	7.5	13.0

Remarks:

Particle shape: Particles are generally rounded with about 26 percent flat and/or elongated.

Coatings: About 1 percent of particles are less than 5 percent covered with a thin, well-bonded, calcium carbonate coating.

The No. 4 (4.75-mm) material is lithologically, chemically, and physically similar to the 3/8- to 3/4-inch (9.5- to 19.0-mm) size fraction.

Figure 2. – Typical data sheet on the quality of coarse aggregate.

have been taken and the grain is still unidentified. Grains that cannot be identified using the stereoscopic microscope, or that are suspected of consisting of or containing substances known to react deleteriously in concrete, should be set aside to be examined with the petrographic microscope. If the question of reaction with alkalies (sodium and potassium) of portland cement paste is important in the examination of a sample, certain additions to the procedure are indicated. If coarser sand sizes contain fine-grained, possibly glassy, igneous rocks, several typical particles of each variety of such rocks should be selected for a more thorough examination. The petrographer should determine the presence or absence of glass by crushing typical grains and examining them in immersion media using the petrographic microscope. In difficult or especially important cases, it may be necessary to break suspected grains and to make immersion mounts of part of the grain and a thin section of another part. Where sand contains chert and the potential reactivity of the chert is an important consideration, a number of chert particles from fractions retained on the No. 30 (600-μm) sieve should be set aside for determination of index of refraction.

11.2.1.1 The shape of the particles and the percentage by particle count of unsound and alkali-reactive particles in each size fraction shall be determined. The percentages by particle count of coated and flat and/or elongated particles are determined only in the No. 8 (2.36-mm) size fraction unless excessive, in which case they are counted in all fractions.

11.2.1.2 After examination is completed, rock and mineral types and percentages by particle count are reported in tabular form along with the particle shape and percentages of physically unsound, alkali-reactive, coated, and flat and/or elongated particles, see figure 3.

11.2.2 *Sizes Finer Than No. 30* (600-μm).–The sieve fractions finer than the No. 30 (600-μm) sieve should each be reduced in a sample splitter or by quartering to about 4 or 5 grams. This amount will usually be less than a level teaspoonful. In some gradations, fractions retained on the No. 100 (150-μm) and No. 200 (75-μm) sieves may be present in such small amounts that reduction is unnecessary. If not, these splits should be further reduced on a miniature sample splitter or by coning and quartering with a spatula on a clean sheet of paper. A representative portion of each reduced split should be mounted in immersion oil on a clean glass slide and covered with a clean cover glass. No entirely satisfactory method of reducing a split to about 300 grains is known. The reduced split can be sampled by spreading it in a thin layer on glass or clean paper, dragging end of a dissecting needle moistened in immersion oil through sample, and transferring grains that adhere to needle to a drop of immersion oil on a clean slide. If this is done carefully, a fairly representative sample will be obtained. If dissecting

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PETROGRAPHIC EXAMINATION OF COARSE SAND

Rock and mineral types	Percentage by particle count		
	No. 8 (2.36 mm)	No. 16 (1.18 mm)	No. 30 (600 μm)
Quartzite, sandstone, and quartz grains (includes quartzose, feldspathic-quartzose, and calcareous sandstones)	27	34	51.0
Limestone (includes silty, fossiliferous, and argillaceous limestones)	25	20	6.0
Gneiss (includes granite and diorite gneisses as well as schist and miscellaneous metamorphic rocks)	9	5	5.0
Chert (includes minor cherty limestone)	22	17	9.0
Granite	7	4	3.0
Basalt	1	2	0.5
Feldspar grains	9	18	25.0
Mica	-	-	0.5
Percent unsound	3	3	2.0
Percent alkali reactive	22	17	9.0
Percent flat and/or elongated	6	ND	ND
Percent well-bonded, calcium carbonate coated	Trace	ND	ND

Remarks:

Coarse sands are generally subrounded to angular in shape.

Fine sands are subrounded to generally angular in shape and consist of decreasing amounts of rock types found in coarse sand and increasing amounts of monomineralic grains of quartz, feldspar, calcite, mica, amphibole, zircon, epidote, iron oxide, magnetite, clay, and a few miscellaneous detrital minerals. Fine sands also contain about 1 percent physically unsound material and 5 percent potentially alkali-reactive chert particles.

The silt-size material removed by washing, about 6 percent by mass, consists of same material found in fine sand sizes with additional clay.

Qualitative chemical tests indicate presence of trace amounts of water-soluble chloride and sulfate ions.

ND denotes not determined.

Figure 3. – Typical data sheet for coarse sand.

needle is made of magnetized steel, a concentration of magnetic minerals may result. It is usually necessary to make several mounts of the No. 50 (300-μm) and No. 100 (150-μm) sieve fractions to obtain at least 300 grains of each. The index of the immersion oil should be selected to make identification of important constituents as easy and as definite as possible. The use of an immersion oil with an index of or just below the lower index of quartz (1.544) is recommended. The slide should be mounted on a petrographic microscope equipped with a mechanical stage. Several traverses should be made, and each grain that passes under the cross hair should be identified and counted. Care should be taken to move the slide on the north-south adjustment between traverses so that no grain will be counted twice. Each sieve fraction passing the No. 30 (600-μm) and retained on the No. 200 (75-μm) sieve should be examined in this way. Ordinarily, material passing the No. 200 sieve is mounted on a slide, examined by petrographic microscope, and its composition estimated. If an unusually large amount of this size is present, or if it contains constituents that may be expected to have an important effect on suitability of aggregate for intended use, it should be counted.

11.2.2.1 Present policy for examination of sieve fractions finer than No. 30 (600 μm) varies somewhat from that described in section 11.2.2. The No. 50 (300-μm) and No. 100 (150-μm) size fractions are split, and 200 particles are obtained for stereomicroscopic examination. The particle shape is noted, physically unsound and alkali-reactive particles are counted, and then the percentages by particle count are determined. The minus No. 100 material is examined in immersion oils under the petrographic microscope to determine rock and mineral types present. Figure 3 shows typical recorded data.

11.2.2.2 Sand is qualitatively analyzed for soluble chloride and sulfate ions. The sand is washed, and the water chemically tested using a few drops of silver nitrate to detect chloride ions and barium chloride to detect sulfate ions. This information is also recorded, see figure 3.

DRILLED CORE, LEDGE ROCK, CRUSHED STONE, AND MANUFACTURED SAND

12. Examination of Drilled Core

12.1 Each core should be examined, and a log prepared showing:

- Footage of core recovered
- Core loss and location
- Location and spacing of fractures and parting planes
- Lithologic type
- Alternation of types
- Physical condition and variations in condition
- Toughness, hardness, and coherence
- Obvious porosity
- Grain size and texture (including variations of both)
- Type of breakage
- Presence of constituents capable of deleterious reaction in concrete

12.2 If size of core permits, the probability that rock will make aggregate of required maximum size should be considered. If surface of core being examined is wetted, it is usually easier to recognize significant features and changes in lithology. Most of the information usually required can be obtained by careful visual examination, scratch and acid tests, and hitting the core with a hammer. In the case of fine-grained rocks, it may be necessary to examine parts of the core using stereoscopic microscope, or prepare thin sections of selected portions. Some considerations and procedures are more applicable to particular rock types than to others. Ordinarily, layered rocks considered for concrete aggregate will be limestone; occasionally metamorphic rocks such as phyllite, gneiss, or schist. One of the most important questions arising in the examination of limestone is that of the presence, type, and distribution of argillaceous impurities. Limestones that contain intercalated thin beds of soft shale may make suitable sources of aggregate if shale is so distributed that it does not prevent manufacture of required maximum size, and if shale can be eliminated or reduced in processing. Where argillaceous impurities are present, it should be determined whether they actually consist of clay minerals or of other minerals in clay sizes. If they do consist of clay minerals, it should be established whether the minerals include members of the smectite or montmorillonite group (swelling clays) [4]. X-ray diffraction analysis is especially valuable in identification and quantitative determination of clay minerals. In the examination of fine-grained igneous rocks, particular attention should be directed to the nature of ground mass. This examination should include determination of presence or absence of opal, chalcedony, natural glass, and clay minerals of the smectite or montmorillonite groups. If any of these groups are found, estimate the amount of each. If natural glass is found, type should be determined.

13. Examination of Ledge Rock

13.1 The procedure used in this examination should be the same as for core samples to the extent that spacing of samples and size of individual pieces allow. If sample consists of a relatively large quantity of broken stone produced by blasting, it is desirable to inspect whole sample, estimate relative abundance of rock types or varieties present, and sample each type before further processing. Subsequent procedure should be the same as given in section 14 for crushed stone.

14. Examination of Crushed Stone

14.1 The procedure for examination of crushed stone should be similar to that for core, except that necessary quantitative data should be obtained by particle counts of the separated sieve fractions obtained as described in sections 8, 11.1, and 11.2.

15. Examination of Manufactured Sand

15.1 The examination of manufactured sand is similar to that for natural sand, with particular emphasis on amount and extent of fracturing and amount and nature of rock dust developed by milling operations. If a sample of rock from which sand was produced is available, examination of the rock will provide useful information.

CALCULATIONS AND REPORT

16. Calculations

16.1 Calculate composition of each sieve fraction of a heterogeneous sample and weighted average composition of whole sample as described in the subsequent sections.

16.1.1 Express composition of each sieve fraction by summing total number of particles of that fraction counted, and then calculating each constituent in each condition as a percentage of total amount (as number of particles in percent, in each sieve fraction). It is convenient to calculate and record percentages to tenths at this stage. An example of these calculations is given in the top portion of figure 4.

16.1.2 Obtain mass percent of sieve fraction in whole sample (individual percentages retained on consecutive sieves) from grading of sample as determined by USBR 4136.

16.1.3 By multiplying percentage of constituent in sieve fraction (sec. 16.1.1) by percentage of sieve fraction in whole sample (sec. 16.1.2), calculate percentage in whole sample of that constituent in that size (weighted percentage of constituents in sieve fraction, fig. 4). It is convenient to calculate and record these percentages to tenths.

16.1.4 By adding weighted percentages of each constituent in each sieve fraction, obtain weighted percentage of each constituent in whole sample (see weighted composition of sample on fig. 4).

16.1.5 Construct a table to show composition of each sieve fraction and weighted composition of whole sample; record values to nearest whole number. Report constituents amounting to 0.5 percent or less of a sieve fraction or of whole sample as traces. Figure 5 is an example constructed from data obtained on figure 4. As a convention, total in each sieve fraction and total in whole sample shall each be 100 percent without the traces. Difficulties in abiding by this convention can usually be avoided by grouping minor constituents of minimum engineering importance. It is preferable to tabulate constituents known to react deleteriously in concrete so that their distribution will be apparent from inspection of table, even though amount in whole sample or in any fraction is very small. For other methods of presenting results of petrographic analysis, see tables 1 through 4 in reference [5].

16.2 Present policy is not to calculate weighted averages, but to use only particle count percentages as determined in section 16.1.1.

17. Report

17.1 The report of the petrographic examination should summarize essential data needed to identify sample as to source and proposed use, and should include a description of essential data on composition and properties of material as revealed by examination. Report should also record test procedures employed and describe nature and features of each important constituent of sample, accompanied by such tables and photographs as may be required. Findings and conclusions should be expressed in terms likely to be intelligible to those who must make decisions as to suitability of material for use as concrete aggregate.

17.2 When sample has been found to possess properties or constituents that are known to have specific unfavorable effects in concrete, those findings should be described qualitatively and, to extent practicable, quantitatively. The unfavorable effects that may be expected to ensue in the concrete should be mentioned. When appropriate, it should be stated that a given sample was not found to contain any undesirable features. When such is the case it may also be appropriate, especially if report of petrographic examination is not accompanied by reports of results of physical and chemical tests for which numerical limits may be applicable, to add that material appears acceptable for use provided applicable acceptance tests are made and results are within appropriate limits. However, the report should not contain conclusions other than those based upon the findings of the examination unless additional data to support such conclusions are included in or with the petrographic report and petrographer has been authorized to analyze other relevant nonpetrographic data.

17.3 The petrographic report should include recommendations regarding any additional petrographic, chemical, physical, or geological investigations that may be required to evaluate adverse properties that are indicated by the petrographic examination. Supplementary petrographic investigations might include qualitative or quantitative analysis of aggregate or of selected portions thereof by X-ray diffraction, differential thermal methods, or other procedures that are directed to identification and description of constituents of aggregate.

17.4 The report should include a conclusion on the physical and chemical quality of both gravel and sand, which may differ from one another; percentage of flat and/or elongated particles; type and percentage of coatings; presence or absence of soluble ions; and any appropriate recommendations.

17.5 Report should have a summary of both gravel and sand including particle shape, percentage of coated particles (if appropriate), rock and mineral types, and percentages of physically unsound and alkali-reactive portions.

17.6 The report should contain data summarizing the petrographic examination of coarse aggregate (see fig. 1), quality of coarse aggregate (see fig. 2), and petrographic examination of coarse sand (see fig. 3).

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RESULTS OF PARTICLE COUNTS

Individual percentge retained on sieve	Composition of fractions retained on sieves							
	3/4 inch (19.0 mm) 17.4		1/2 inch (12.5 mm) 32.6		3/8 inch (9.5 mm) 29.5		No. 4 (4.75 mm) 20.5	
Constituents	Number of particles	Percent	Number of particles	Percent	Number of particles	Percent	Number of particles	Percent
A_1	250	50.0	200	40.0	150	30.0	50	10.0
A_2	50	10.0	100	20.0	125	25.0	100	20.0
A_3	10	2.0	50	10.0	75	15.0	100	20.0
B_1	107	21.4	70	14.0	62	12.4	32	6.4
B_2	76	15.2	53	10.6	19	3.8	87	17.4
B_3	-	-	20	4.0	43	8.6	96	19.2
C_1	5	1.0	5	1.0	20	4.0	20	4.0
C_2	2	0.4	2	0.4	6	1.2	10	2.0
C_3	-	-	-	-	-	-	5	1.0
Totals	*500	100	*500	100	*500	100	*500	100

	Weighted percentages of constituents in each sieve fraction				Weighted composition of sample
	3/4 inch (19.0 mm)	1/2 inch (12.5 mm)	3/8 inch (9.5 mm)	No.4 (4.75 mm)	
A_1	8.7	13.0	8.9	2.1	32.7
A_2	1.7	6.5	7.4	4.1	19.7
A_3	0.4	3.3	4.4	4.1	12.2 Total of A = 64.6
B_1	3.7	4.6	3.7	1.3	13.3
B_2	2.6	3.5	1.1	3.6	10.8
B_3	-	1.3	2.5	3.9	7.7 Total of B = 31.8
C_1	0.2	0.3	1.2	0.8	2.5
C_2	0.1	0.1	0.3	0.4	0.9
C_3	-	-	-	0.2	0.2 Total of C = 3.6
Total in sieve fraction	17.4	32.6	29.5	20.5	
Total in sample, condition 1					48.5
Total in sample, condition 2					31.4
Total in sample, condition 3					20.1

Note: This tabulation indicates a convenient method of setting up a worksheet for recording results and calculations. Results developed here are entered in the form indicated on figure 5, which should be included in petrographic report. The letters A, B, and C refer to various constituents found, subscript numbers 1, 2, and 3 refer to various conditions in which each constituent has been found, such as relative degree of weathering.

* The requirement that each fraction include at least 300 particles has been met; selection of 500 particles per fraction for the sample is to illustrate calculation; it is not intended to suggest that a predetermined number of particles per fraction should be selected.

Figure 4. - Typical calculation form for particle counts.

Spec. or Solic. No. 40-C2035	Structure TUNNEL LINING	Tested by G. SHELDON Date 6-1-82
Project CENTRAL UTAH	Item CONC. AGG. M-7468 Location BLM LAND-UINTA BASIN	Computed by G. SHELDON Date 6-1-82
Feature STILLWATER TUNNEL	Station — Offset — Depth — to —	Checked by C. BECHTOLD Date 6-8-82

COMPOSITION AND CONDITION OF AGGREGATE SAMPLE

Constituents	Amount, as number of particles, in percent[1]							
	In fractions retained on sieves[2]				In whole sample[3]			
	3/4 inch (19.0 mm)	1/2 inch (12.5 mm)	3/8 inch (9.5 mm)	No. 4 (4.75 mm)	Condition 1	Condition 2	Condition 3	Totals
A	62	70	70	50	33	20	12	65
B	37	29	25	43	13	11	8	32
C	1	1	5	7	2	1	Tr	3
Totals	100	100	100	100	-	-	-	100
Weighted average, condition 1				48	-	-	-	
Weighted average, condition 2				-	32	-	-	
Weighted average, condition 3				-	-	20	-	

[1] This tabulation was constructed from data shown on figure 4.

[2] Based on count of 500 particles in each sieve fraction. (The number of particles of each sieve fraction counted should be shown in report, and may conveniently be done as a footnote on the report.)

[3] Based on grading of sample as received and on distribution of constituents by sieve fractions shown. (If petrographic report is part of a complete investigation of sample, including a report of grading, grading need not be shown. If petrographic report is to be submitted alone, grading of sample should be included.)

Figure 5. - Typical example constructed from data on figure 4.

17.7 A narrative summation of the petrographic analysis along with the above referenced figures is included on the reporting form illustrated by figure 3 in USBR 4075.

18. Precision and Bias

18.1 Precision and bias statements are not appropriate for this type of procedure.

19. References

[1] Mather, Katharine and Bryant, "Method of Petrographic Examination of Aggregates for Concrete," *Proceedings*, American Society for Testing Materials, ASTEA, vol. 50, pp. 1288-1312, 1950.

[2] Simpson, G. G., and A. Rowe, *Quantitative Zoology*, pp. 182-185, McGraw-Hill Co., Inc., New York, NY, 1939.

[3] Dryden, A. L., Jr., "Accuracy in Percentage Representation of Heavy Mineral Frequencies," *Proceedings*, U.S. National Academy Sciences, No. 5, vol. 17, pp. 233-238, May 1931.

[4] Loughlin, G. F., "Usefulness of Petrology in the Selection of Limestone," *Rock Products*, vol. 31, No. 6, pp. 50-59, Mar. 17, 1928.

[5] Mielenz, R. C., "Petrographic Examination of Concrete Aggregates," cp. 33, *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, STP 169B, p. 197.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4305-92

PROCEDURE FOR

MECHANICAL MIXING OF HYDRAULIC CEMENT PASTES AND MORTARS OF PLASTIC CONSISTENCY

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4305; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 305-82.

1. Scope

1.1 This designation covers the procedure for the mechanical mixing of hydraulic cement pastes and mortars of plastic consistency.

2. Applicable Documents

2.1 *ASTM Standards*:

C 305 Standard Method for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency[1]

Manual of Cement Testing[2]

3. Significance and Use

3.1 This procedure is intended for use in the mechanical mixing of pastes and mortars for the testing of hydraulic cements.

4. Apparatus

4.1 *Mixer*.–The mixer shall be an electrically driven mechanical mixer of the epicyclic type, which imparts both a planetary and revolving motion to mixer paddle. Mixer shall have a minimum of two speeds controlled by definite mechanical means; rheostat speed adjustment is not acceptable. The first (slow) speed shall revolve paddle at a rate of 140±5 r/min, with a planetary motion of about 62 r/min. The second (medium) speed shall revolve paddle at 285±10 r/min, with a planetary motion of about 125 r/min. The electric motor shall be at least 1/6 hp (124 W or 124 J/s) (note 1). The mixer shall be equipped with a clearance adjustment bracket (fig. 1) which shall be used to maintain a clearance between lower end of paddle and bottom of bowl of not greater than 2.5 mm and not less than 0.8 mm when bowl is in mixing position (note 2). The 0.8-mm clearance value is based on the approximate diameter of a grain of No. 20 to No. 30 (850- to 600-μm) Ottawa sand.

NOTE 1.–The Model N-50 Mixer, less the clearance adjustment bracket, manufactured by Hobart Corp., Troy, Ohio, is considered to conform to these requirements.

NOTE 2.–When bracket is in proper position beneath motor housing, the lugs are to the front and facing upward and heads of adjustment screws are to rear and facing downward in the path of the sliding frame that holds bowl. It is intended that the bracket be fastened at the front housing connection by inserting replacement screws of an appropriate size upward through opening in each lug and into existing threaded holes in bottom of motor housing. The original stops for the sliding frame are to be filed down if they prevent frame from coming in contact with adjustment screws.

4.2 *Paddle*.–The paddle shall be readily removable, made of stainless steel, and shall conform to basic design shown on figure 2. Dimensions of paddle shall be such that, when in mixing position, paddle outline conforms to the contour of bowl used with mixer; and clearance between corresponding points on edge of paddle and side of bowl in the position of closest approach shall be about 4 mm but not less than 0.8 mm.

4.3 *Mixing Bowl*.–The removable mixing bowl shall have a nominal capacity of 1-1/4 gal (4.73 L), be of general shape and comply with limiting dimensions shown on figure 3, and made of stainless steel. Bowl shall be so equipped that it will be positively held in mixing apparatus in a fixed position during mixing procedure. A cover lid made of a nonabsorbing material that is not chemically attacked by cement shall be provided for the bowl.

4.4 *Scraper*.–The scraper shall consist of a semirigid rubber blade attached to a handle about 6 inches (150 mm) long. The blade shall be about 3 inches (75 mm) long, 2 inches (50 mm) wide, and tapered to a thin edge about 1/16 inch (2 mm) thick.

NOTE 3.–A kitchen tool known as a plate and bowl scraper conforms to these requirements.

4.5 *Supplementary Apparatus*.–The balances, standard unit masses, glass graduates, and any other supplementary

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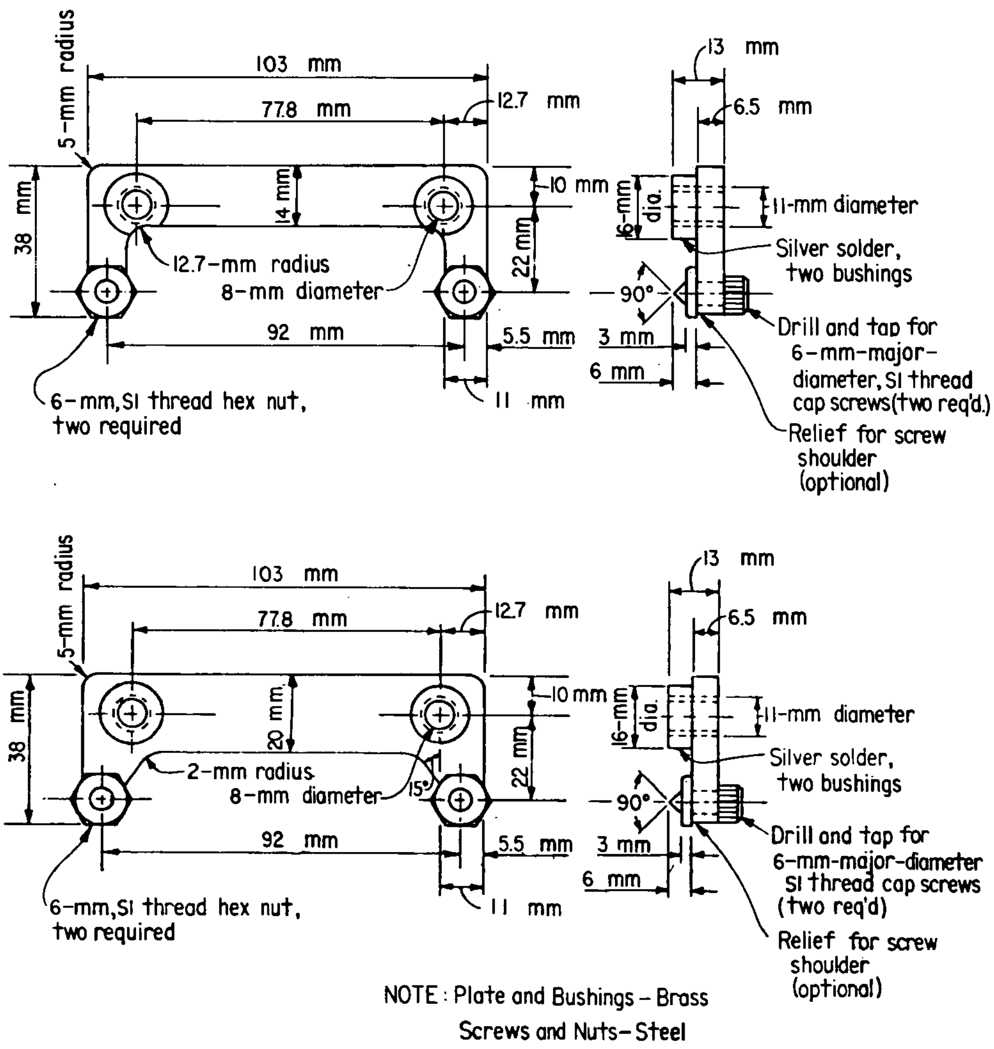
[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] For additional useful information on details of cement test methods, reference may be made to the "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.



NOTE: Plate and Bushings - Brass
Screws and Nuts - Steel

Figure 1. - Clearance adjustment brackets.

apparatus used in measuring and preparing the mortar materials prior to mixing shall conform to the respective requirements for such apparatus as specified in the procedure for the particular test for which mortar is being prepared.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Materials, Proportioning, and Consistency

6.1 The materials and their proportions and quantities shall conform to the requirements of the particular procedure for which the paste or mortar is being prepared.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular standard directly or by reference.

8. Conditioning

8.1 The temperature of mixing room shall be maintained between 68 and 81.5 °F (20 and 27.5 °C), and temperature of dry materials, paddle, and bowl shall be within this same range at time of test. Temperature of mixing water shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

8.2 The relative humidity of the mixing room shall be not less than 50 percent.

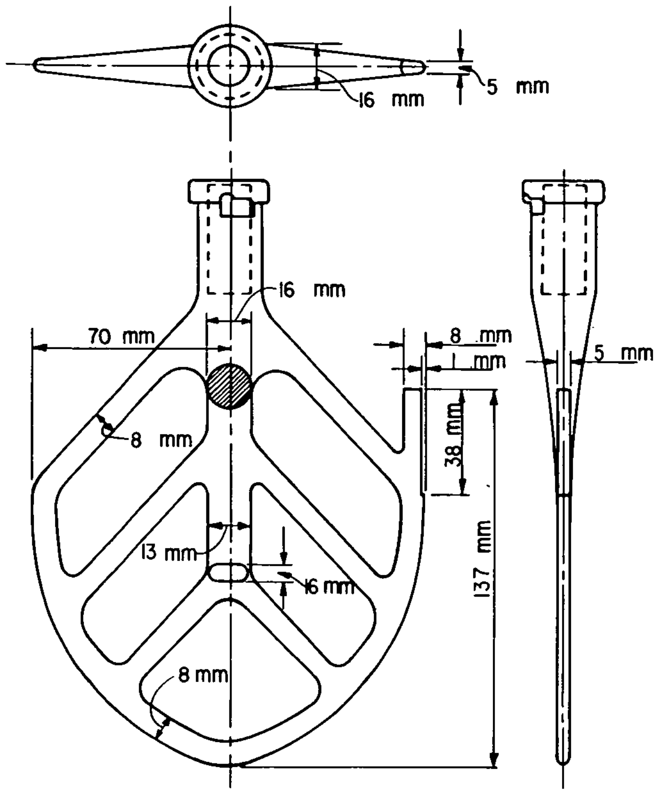


Figure 2. - Paddle.

9. Method for Mixing Pastes

9.1 Place dry paddle and dry bowl in mixing position in mixer. Then, put materials for a batch into bowl and mix in following manner:

(1) Put all mixing water in bowl.

(2) Add cement to water and allow 30 seconds for absorption of water.

(3) Start the mixer and mix at slow speed (140±5 r/min) for 30 seconds.

(4) Stop mixer for 15 seconds and, during this interval, scrape down into batch any paste that may have collected on sides of bowl.

(5) Start mixer at medium speed (285±10 r/min) and mix for 1 minute.

10. Method for Mixing Mortars

10.1 Place dry paddle and dry bowl in mixing position in mixer. Then, put materials for a batch into bowl and mix in following manner:

(1) Put all mixing water in bowl.

(2) Add cement to water, start mixer, and mix at slow speed (140±5 r/min) for 30 seconds.

(3) Add entire quantity of sand slowly over a 30-second period while continuing mixing at slow speed.

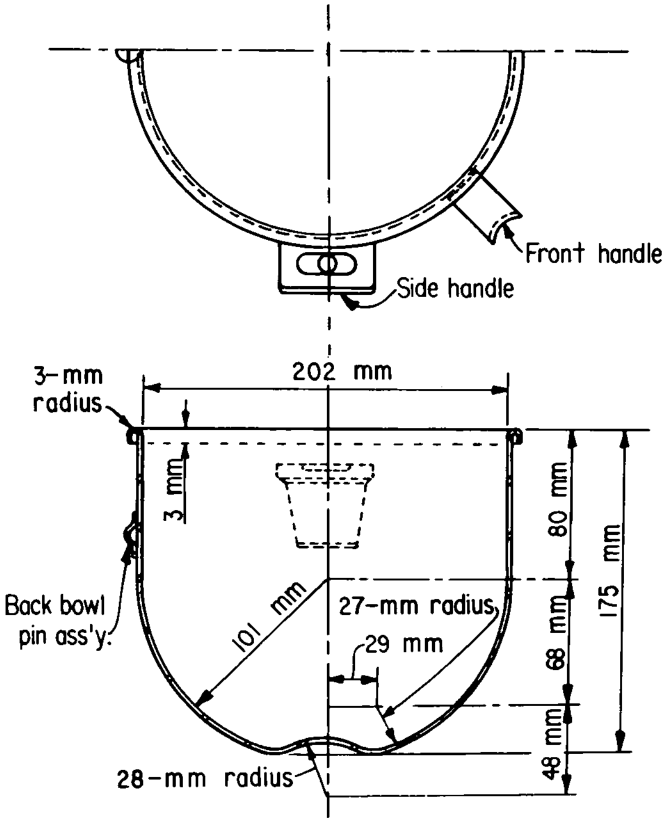


Figure 3. - Mixing bowl.

(4) Stop the mixer, change to medium speed (285±10 r/min), and mix for 30 seconds.

(5) Stop mixer and let mortar stand for 90 seconds. During first 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on sides of bowl. Cover bowl with lid for balance of standing interval.

(6) Complete method by mixing for 1 minute at medium speed.

10.2 In any case requiring a remixing interval, any mortar adhering to sides of bowl shall be quickly scraped down into batch with scraper prior to remixing.

NOTE 4.-*Caution*: Clearances between paddle and bowl specified in this procedure are suitable when using standard mortar made with Ottawa sand. To permit mixer to operate freely and to avoid serious damage to paddle and bowl when coarser aggregates are used, it may be necessary to adjust clearance bracket to provide greater clearances than those specified in section 4.1.

11. Calculations

11.1 No calculations are involved in this procedure.

12. Report

12.1 No report is required for this procedure.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4311-92

PROCEDURE FOR

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4311; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 311-85.

1. Scope

1.1 This designation covers procedures for sampling and testing fly ash and raw or calcined pozzolans for use as a mineral admixture in portland cement concrete.

1.2 The procedures appear in the following order:

	Section
Sampling	6
CHEMICAL ANALYSIS	
Moisture content	9
Loss on ignition	10
Silicon dioxide	11
Aluminum oxide and iron oxide	12
Calcium oxide	13
Magnesium oxide	14
Sulfur trioxide	15
Available alkalies	16
PHYSICAL TESTS	
Density	18
Fineness	19
Increase of drying shrinkage of mortar bars	20
Soundness	21
Limits on amount of air-entraining admixture in concrete	22
Air entrainment of mortar	23
Pozzolanic activity index with portland cement	24
Water requirement	25
Pozzolanic activity index with lime	26
Reactivity with cement alkalies	27

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens
4114 Chemical Analysis of Hydraulic Cement
4151 Autoclave Expansion of Portland Cement
4185 Air Content of Hydraulic Cement Mortar
4188 Density of Hydraulic Cementitious Materials
4233 Testing Air-Entraining Admixtures for Concrete
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
4430 Fineness of Hydraulic Cement by No. 325 (45-μm) Sieve
4441 Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete Due to Alkali-Aggregate Reaction

2.2 *ASTM Standards*:

C 150 Standard Specification for Portland Cement[1,2]
C 157 Standard Test Method for Length Change of Hardened Cement Mortar and Concrete[1,2]
C 260 Standard Specification for Air-Entraining Admixtures for Concrete[2]
C 311 Standard Methods of Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete[2]
E 200 Standard Methods for Preparation, Standardization, and Storage of Standard Solutions for Chemical Analysis[3]
E 617 Standard Specification for Laboratory Weights and Precision Mass Standards[4]
E 832 Standard Specification for Laboratory Filter Papers (Redesignation, formerly D 1100)[4,5]

3. Apparatus and Materials

3.1 *Balance*.–The analytical balance used in the chemical determinations shall have a capacity of not more than 200 grams. The balance may be of conventional design, either with or without "quick" mass-determining devices, or it may be a constant-load, direct-reading type. Balance

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vol. 15.05.
[4] *Annual Book of ASTM Standards*, vol. 14.02.
[5] *Annual Book of ASTM Standards*, vol. 15.09.

shall be capable of reproducing results within 0.0002 gram with an accuracy of ±0.0002 gram. Direct-reading balances shall have a sensitivity not exceeding 0.0001 gram (note 1). Conventional two-pan balances shall have a maximum sensibility reciprocal of 0.0003 gram. Any rapid weighing device that may be provided, such as a chain, damped motion, or heavy riders, shall not increase the basic inaccuracy by more than 0.0001 gram at any reading and with any load within rated capacity of balance.

NOTE 1.-The sensitivity of a direct-reading balance is the mass required to change reading one graduation. The sensibility reciprocal for a conventional balance is defined as the change in mass required on either pan to change the position of equilibrium one division on the pointer scale at capacity or at any lesser load.

3.2 *Standard Masses.*-Standard masses used for analysis shall conform to type I or II, grade S or O, and class 1, 2, or 3 as described in ASTM E 617. They shall be checked at least annually, or when questioned, and adjusted at least to within the allowable tolerances for class 3 standard masses (note 2). For this purpose, each laboratory shall maintain, or have available for use, a reference set of standard masses from 50 grams to 10 milligrams, which shall conform at least to class 3 requirements and be calibrated at intervals not exceeding 5 years by NIST (National Institute of Standards and Technology).[6] After initial calibration, recalibration by NIST may be waived provided it can be shown by documented data obtained within time interval specified that a mass comparison between summations of smaller standard masses and a single larger standard mass nominally equal to that summation establishes that allowable tolerances have not been exceeded. All new sets of standard masses shall begin at 1-gram size, be made of stainless steel or other corrosion-resisting alloy not requiring protective coating, and shall meet density requirements for grade S or O.

NOTE 2.-Scientific supply houses do not presently list standard masses as meeting ASTM E 617; however, they do meet NIST or OIML (International Organization of Legal Meterology) standards. This situation is in a state of flux because of the trend toward internationalization; hopefully, this problem will soon be resolved. The NIST classes S and S-1 and OIML class F-1 masses meet the requirements of this procedure.

3.3 *Glassware and Laboratory Containers.*-Standard volumetric flasks, burets, and pipets should be of precision grade or better. Standard-taper, interchangeable, ground-glass joints are recommended for all volumetric glassware and distilling apparatus, when available. Wherever applicable, use of special types of glassware, such as colored glass, for the protection of solutions against light is recommended. Alkali-resistant glass and high-silica glass, which have exceptional resistance to thermal shock, are recommended. Polyethylene containers are recommended for all aqueous solutions of alkalies and for standard solutions where presence of dissolved silica or alkali from the glass would be objectionable. Such containers shall be made of high-density polyethylene having a wall thickness of at least 0.04 inch (1 mm).

3.4 *Desiccators.*-Desiccators shall be provided with a good desiccant such as magnesium perchlorate, activated alumina, or sulfuric acid. Anhydrous calcium sulfate may also be used provided it has been treated with a color-change indicator to show when it has lost its effectiveness. Calcium chloride is not a satisfactory desiccant for this type of analysis.

3.5 *Filter Paper.*-Filter paper shall conform to the requirements of ASTM E 832, type II, quantitative. When coarse-textured paper is required, class E paper shall be used; when medium-textured paper is required, class F shall be used; and when retentive paper is required, class G shall be used.

3.6 *Crucibles.*-Platinum crucibles for ordinary chemical analysis should preferably be made of pure unalloyed platinum and be of 15- to 30-mL capacity. Where alloyed platinum is used for greater stiffness or to obviate sticking of crucible and lid, alloyed platinum should not decrease in mass by more than 0.2 milligram when heated at 2192 °F (1200 °C) for 1 hour.

3.7 *Muffle Furnace.*-The muffle furnace shall be capable of operation at temperatures required and shall have an indicating pyrometer accurate within ±77 °F (±25.0 °C), as corrected, if necessary, by calibration. More than one furnace may be used provided each is used within its proper operating temperature range.

4. Purity of Reagents

4.1 *Purity of Reagents.*-Reagent grade chemicals or equivalent, as specified in ASTM E 200, shall be used in all tests.

4.2 *Purity of Water.*-Unless otherwise indicated, references to water in sections 11 through 16 shall be understood to mean distilled water or water of equal purity.

4.3 *Concentrations of Reagents.*-Concentrations of reagents used in these procedures shall conform to section 4 of USBR 4114.

5. Precautions

5.1 These test procedures may involve hazardous materials, operations, and equipment, and do not claim to address all safety problems associated with their use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling, Test Specimens, and Test Units

6.1 *Size and Number of Samples*:

6.1.1 Samples for purpose of tests shall have a mass of at least 4 lbm (1.8 kg) each when they are to be composited. Individual test samples, on which all specified tests are to be made, shall have a mass of at least 8 lbm (3.6 kg).

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[6] Formerly National Bureau of Standards.

6.1.2 Test samples shall be either individual or composite samples, as may be specified, and one individual test sample shall represent not more than 400 tons (363 Mg).

6.1.3 The sampling shall be done by or under the direction of a responsible representative of purchaser.

6.2 *Sampling.*–The mineral admixture may be sampled by any one of the methods described in sections 6.2.1, 6.2.2, 6.2.3, or 6.2.4.

6.2.1 *From Conveyor Delivering to Bulk Storage.*–Take one sample of 4 lbm (1.8 kg) or more from at least every 400 tons (363 Mg) passing over conveyor. This may be done by taking entire test sample in a single operation, known as the "grab method," or by combining several portions taken at regular intervals, the "composite method." When obtaining a composite sample, combine approximately equal masses of mineral admixture taken at regular intervals. Automatic samplers may be used in obtaining samples.

6.2.2 *From Bulk Storage at Points of Discharge.*–Draw sufficient mineral admixture from discharge openings to obtain samples representative of admixture. This is determined by appearance at openings of indicators placed on surface of admixture directly above openings before drawing out the admixture. Take one 4-lbm (1.8-kg) sample for at least every 400 tons (363 Mg) by either the grab or composite method described in 6.2.1.

6.2.3 *From Bulk Storage Using Sampling Tubes.*–When methods of 6.2.1 and 6.2.2 cannot be applied and when depth of mineral admixture to be sampled does not exceed 10 feet (3 m), obtain samples using sampling tubes inserted vertically to full depth of admixture. Obtain these samples from points well distributed over area of storage.

6.2.4 For samples taken from cars and trucks, where mineral admixture is being shipped from one source, combine samples from multiple cars or trucks to form a test sample representing not more than 400 tons (363 Mg). When bulk shipments are sampled, take representative samples from well-distributed points.

6.3 *Preparation of Sample.*–Prepare composite samples for tests, as required in section 6.4 by arranging all test samples in groups, with each group representing number of tons required by test for which composite sample is intended. From each test sample in a group, take equal proportions sufficient in amount to form a composite sample large enough to permit making the required physical or chemical determinations. Mix composite sample thus prepared thoroughly before using.

6.4 *Number of Tests*:

6.4.1 Each sample representing 400 tons (363 Mg), or the sample representing the quantity sampled but less than 400 tons, shall be tested for:

- Fineness, No. 325 (45-μm) sieve analysis
- Moisture content
- Density
- Loss on ignition
- Soundness
- Lime-pozzolan test, 7-day

6.4.2 All other physical tests and chemical determinations shall be made on composite samples representing every 2000 tons (1815 Mg). The composite sample for this purpose is prepared by combining equal parts of five consecutive samples, each representing 400 tons (363 Mg).

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

7.2 The calibration and standardization of other miscellaneous equipment or apparatus used in performing these tests, such as ovens, are to be calibrated in accordance with USBR 1020.

7.3 Muffle furnaces to comply with sections 3.7 and 10 must be checked with certified thermometers.

7.4 Balances used to determine the mass in all tests must be calibrated in accordance with USBR 1012.

8. Conditioning

8.1 Conditioning of materials for the individual tests is covered under the procedure for each test.

CHEMICAL ANALYSIS

9. Moisture Content

9.1 *Summary of Procedure.*–This procedure is based on drying a sample as received to a constant mass in an oven at 221 °F (105 °C). The loss in mass is calculated as moisture.

9.2 *Procedure.*–Dry sample, with mass determined as received, to a constant mass in an oven at 221 to 230 °F (105 to 110 °C).

9.3 *Calculation.*–A typical calculation form is shown on figure 1. Calculate percentage of moisture to nearest 0.01, as follows:

$$\text{Moisture content (percent)} = \frac{D-A}{D}(100) \qquad (1)$$

where:

D = mass of sample at time of sampling, in grams; and
A = mass of oven-dried sample in air, in grams.

NOTE 3.–Be aware that this moisture content is based on the as-sampled condition, not on the oven-dry basis.

10. Loss on Ignition

10.1 *Summary of Procedure.*–In this procedure, a previously dried sample is ignited in a muffle furnace at 1382 °F (750 °C) to a constant mass. The loss in mass between 221 and 1382 °F (105 and 750 °C) is calculated as ignition loss.

10.2 *Procedure*.-Determine the LOI (loss on ignition) in accordance with section 16 of USBR 4114, except that material remaining from determination of moisture content shall be ignited to a constant mass in an uncovered porcelain, not platinum, crucible at 1382±90 °F (750±50 °C).

10.3 *Calculation*.-A typical calculation form is shown on figure 2. Calculate percentage of loss on ignition to nearest 0.01, as follows:

$$\text{LOI (percent)} = \frac{A - G}{A}(100) \qquad (2)$$

where:

G = mass after ignition loss, and
A = as defined in equation (1).

11. Silicon Dioxide

11.1 *Summary of Procedure*.-This procedure is based on the sodium carbonate fusion followed by double evaporation to dryness of the HCl (hydrochloric acid) solution of fusion product to convert SiO_2 (silicon dioxide) to insoluble form. The solution is filtered, insoluble siliceous residue ignited, and mass determined. The SiO_2 is volatilized by HF (hydrofluoric acid) and loss of mass is reported as pure SiO_2.

11.2 *Procedure*:

11.2.1 Determine mass of a sample of ignited material equivalent to 0.5 gram of moisture-free sample before ignition as follows:

$$\text{Mass of ignited sample (grams)} = \frac{0.5\,(100 - \text{percent LOI})}{100}$$

11.2.2 Thoroughly mix sample with 4 to 6 grams of Na_2CO_3 (sodium carbonate) by grinding in an agate mortar. Place a thin layer of Na_2CO_3 on bottom of a platinum crucible of 20- to 30-mL capacity, add sample Na_2CO_3 mixture, and cover mixture with a thin layer of Na_2CO_3. Place covered crucible over a moderately low flame and increase flame gradually to a maximum, about 2012 °F (1100 °C). Maintain this temperature until mass is quiescent (about 45 minutes). Remove burner, lay aside cover of crucible, grasp crucible with tongs, and slowly rotate crucible so that molten contents spread over sides and solidify as a thin shell on the interior. Set crucible and cover aside, and cool.

11.2.3 Place crucible upright in 250-mL beaker, add 30 to 40 mL of concentrated HCl, and cover beaker immediately with a watchglass. After chemical action has subsided slightly, add 5 to 10 mL of water. When action has again subsided, place beaker on a steam bath and repeat additions of 5 to 10 mL of water at 3- to 5-minute intervals as long as each addition causes noticeable further solution of fused cake, or until a total volume of 75 mL of water has been added. With a glass rod, turn crucible on its side and, if necessary, add sufficient water to just cover crucible. Digest until disintegration is complete, then lift crucible and cover from beaker, thoroughly rinsing each with hot water directly into beaker. If any gritty particles are present, fusion is incomplete and must be repeated using a new sample and a larger amount of Na_2CO_3.

11.2.4 Decant liquid through a rapid filter paper into a 600-mL Pyrex beaker. Wash down sides of 250-mL beaker with hot diluted HCl (1:99) and break up larger particles of siliceous material with flattened end of a glass rod. Decant as before, permitting only finely divided material to pass on to filter paper. Repeat above steps until all siliceous material has been quantitatively transferred to filter paper. Wash filter paper and residue several times with small portions of the hot HCl and finally with hot water until free of chlorides; retain the residue.

11.2.5 Evaporate filtrate to dryness on a steam bath and bake residue in oven for 1 hour at 221 to 230 °F (105 to 110 °C). Cool and wet the dried residue thoroughly with 10 mL of concentrated HCl, add 90 mL of hot water, heat to incipient boiling, and digest with intermittent stirring until all soluble salts are in solution. Filter immediately through a medium texture paper and wash residue thoroughly with the hot HCl (1:99), then with hot water until free of chlorides. Retain filtrate and washings for determination of ammonium hydroxide group, section 12.1.

11.2.6 Transfer filter papers and residues from both filtrations to a platinum crucible with known mass. Dry and ignite, slowly at first, until carbon of paper is completely consumed without flaming, and finally at 2012 to 2192 °F (1100 to 1200 °C) for at least 1 hour. Cool in a desiccator and determine mass. Treat SiO_2 thus obtained, which will contain small amounts of impurities, in the crucible with 0.5 to 1.0 mL of water, 2 drops of H_2SO_4 (1:1), about 10 mL of HF, and evaporate cautiously to dryness. Finally, heat the small residue at 1922 to 2012 °F (1050 to 1100 °C) for 5 minutes, cool in desiccator, and determine mass. The difference between this mass and mass previously obtained represents the amount of SiO_2. Add 0.5 gram of $Na_2S_2O_7$ (sodium pyrosulfate) or $K_2S_2O_7$ (potassium pyrosulfate) to crucible and heat below red heat until small residue of impurities is dissolved in melt. Cool, dissolve fused mass in water, and add it to filtrate and washings retained for determination of ammonium hydroxide group (sec. 12.1).

11.2.7 *Blank Determination*.-Following same procedure and using same amounts of reagents, make a blank determination and correct results obtained in analysis accordingly.

11.3 *Calculation*.-A typical calculation form is shown on figure 3. Calculate percentage of SiO_2 to nearest 0.01 by multiplying mass in grams of SiO_2 by 100 divided by mass of sample used (0.5 g).

12. Aluminum Oxide and Iron Oxide

12.1 *Ammonium Hydroxide Group*:

12.1.1 *Summary of Procedure*.-The ammonium hydroxide group, designated by R_2O_3 and consisting of aluminum, iron, titanium, and phosphorus; are precipitated from filtrate, after SiO_2 removal, using ammonium hydroxide. With care, negligible manganese will be precipitated. The precipitate is ignited and mass determined as oxides.

12.1.2 *Procedure*:

12.1.2.1 Treat filtrate retained from silicon dioxide determination (sec. 11) for determination of ammonium hydroxide group, principally Al_2O_3 (aluminum oxide) and Fe_2O_3 (iron oxide), in accordance with sections 7 and 8 of USBR 4114. Retain the combined filtrate for determinations of CaO (calcium oxide) and MgO (magnesium oxide) if either or both of these are required and the referee methods of USBR 4114 are used.

12.1.2.2 Calculate combined percentage of SiO_2, Al_2O_3, and Fe_2O_3 by adding percentage of SiO_2 determined in section 11 to percentage of ammonium hydroxide group calculated in accordance with section 8 of USBR 4114. Report result to nearest 0.01. A typical calculation form is shown on figure 4.

13. Calcium Oxide

13.1 *Summary of Procedure.*-This procedure covers the gravimetric determination of CaO after removal of SiO_2 and ammonium hydroxide groups, and the double precipitation of calcium as the oxalate. The precipitate is converted to CaO by ignition, and then mass is determined.

13.2 *Procedure*:

13.2.1 Acidify combined filtrates obtained in the precipitation of aluminum plus ferric hydroxides (sec. 12) with HCl and evaporate them to a volume of about 100 mL. Add 40 mL of saturated bromine water to the hot solution and immediately add NH_4OH (ammonium hydroxide) until solution is distinctly alkaline. Boil solution 5 minutes or more, making certain that solution is at all times distinctly alkaline. Allow precipitate to settle, filter using medium texture paper, and wash with hot water. Discard precipitate. Acidify filtrate with HCl and boil until bromine is expelled. Add 5 mL of HCl, dilute to 200 mL, add a few drops of methyl-red indicator, and 30 mL of warm ammonium oxalate solution (50 g/L). Heat solution to 158 to 176 °F (70 to 80 °C), and add NH_4OH (1:1) dropwise while stirring until color changes from red to yellow (note 4). Allow solution to stand without further heating for 1 hour (not longer) with occasional stirring during first 30 minutes. Filter, using retentive paper, and wash moderately with cold, 0.1 percent ammonium oxalate solution. Retain filtrate and washings. Transfer precipitate and filter paper to beaker in which precipitation was effected. Dissolve oxalate in 50 mL of hot HCl (1:4) and macerate the filter paper. Dilute to 200 mL with water, add 20 mL of ammonium oxalate solution, heat solution to nearly boiling, and precipitate calcium oxalate again by neutralizing acid solution with ammonium hydroxide as previously described. Allow solution to stand for 1 or 2 hours (longer standing will now do no harm), filter, and wash as before. Combine filtrate with that already obtained, acidify with HCl, and retain for determination of MgO (sec. 14). Dry precipitate and paper in a covered platinum crucible of known mass, char paper without flaming, burn carbon at as low a temperature as possible, and finally heat with crucible tightly covered in an electric furnace or over a blast lamp at 2012 to 2192 °F (1100 to 1200 °C). Cool in a desiccator and determine mass as CaO. Repeat the ignition to constant mass.

NOTE 4.-This neutralization must be made slowly, otherwise precipitated calcium oxalate may have a tendency to run through filter paper. When a number of these determinations are being made simultaneously, the following technique will assist in ensuring slow neutralization: Add 2 or 3 drops of NH_4OH to first beaker while stirring, then 2 or 3 drops to the second, and so on, returning to first beaker to add 2 or 3 more drops, etc., until indicator color has changed in each beaker.

13.2.2 *Blank Determination.*-Make a blank determination following same procedure and using same amounts of reagents, and correct results obtained in analysis accordingly.

13.3 *Calculation.*-Calculate percentage of CaO to nearest 0.01 by multiplying mass in grams of CaO by 100 divided by mass of sample used (0.5 g). A typical calculation form is shown on figure 5.

14. Magnesium Oxide

14.1 *Summary of Procedure.*-In this procedure, magnesium is precipitated as magnesium ammonium phosphate from filtrate after removal of calcium. The precipitate is ignited and mass determined as $Mg_2P_2O_7$ (magnesium pyrophosphate). The MgO equivalent is then calculated.

14.2 *Reagents*:

14.2.1 *Ammonium Nitrate Wash Solution.*-Dissolve 100 grams of NH_4NO_3 (ammonium nitrate) in water, add 200 mL of NH_4OH, and dilute to 1 liter.

14.3 *Procedure*:

14.3.1 Acidify filtrates retained in determination of CaO (sec. 13) with HCl and concentrate to about 250 mL. Add to this solution about 10 mL of $(NH_4)_2HPO_4$ (ammonium phosphate) (250 g/L), and cool solution by placing in a beaker of ice water. After cooling, add NH_4OH drop by drop, while stirring constantly, until crystalline magnesium ammonium phosphate begins to form, and then in moderate excess (5 to 10 percent of volume of solution); continue stirring for several minutes. Set solution aside for at least 8 hours in a cool atmosphere, and then filter. Wash twice with an ammonium nitrate wash solution.

14.3.2 Transfer precipitate and filter paper to same beaker in which first precipitation was effected. Dissolve precipitate with hot HCl (1:4), and stir to thoroughly macerate filter paper. If necessary, add more of the hot HCl to dissolve precipitate. Dilute solution to about 100 mL, add 1 mL of $(NH_4)_2HPO_4$, and then add NH_4OH drop by drop, while stirring constantly, until precipitate is again formed as described and NH_4OH is in moderate excess. Cool, allow to stand for about 2 hours, filter, and wash with four 10-mL portions of the NH_4O_3 wash solution. Place in a platinum or porcelain crucible of known mass, slowly char paper, and carefully burn off resulting carbon. Ignite precipitate at 2012 to 2192 °F (1100 to 1200 °C) to constant mass, taking care to avoid melting pyrophosphate (note 5).

NOTE 5.-If crucible is glazed, temperature should not exceed 2057 °F (1125 °C) because glaze may partially fuse at about 2192 °F (1200 °C).

14.3.3 *Blank Determination.*-Make a blank determination following same procedure and using same amounts of reagents, and correct results obtained in analysis accordingly.

14.4 *Calculation.*-A typical calculation form is shown on figure 6. Calculate percentage of MgO to nearest 0.01, as follows:

$$\text{MgO (percent)} = 72.4\, M_1 \qquad (3)$$

where:

M_1 = grams of $Mg_2P_2O_7$, and
72.4 = molecular ratio of 2MgO to $Mg_2P_2O_7$ (0.362) divided by mass of sample used (0.5 g), and multiplied by 100.

15. Sulfur Trioxide

15.1 *Summary of Procedure.*-In this procedure, sulfate is precipitated from an acid solution of sample with $BaCl_2$ (barium chloride). The precipitate is ignited and mass determined as $BaSO_4$ (barium sulfate), and the SO_3 (sulfur trioxide) equivalent calculated.

15.2 *Procedure*:

15.2.1 To 1 gram of sample, add 25 mL of distilled water, heat mixture to about 160 °F (71 °C) and, while stirring vigorously, add 5 mL of HCl. Continue stirring for 15 minutes. Dilute solution to 50 mL and digest for 15 minutes without stirring at a temperature just below boiling. Filter and wash residue thoroughly with hot water using a rapid-filtering, acid-washed filter paper folded inside a fine-textured, acid-washed filter paper. Slightly acidify combined filtrate with HCl, dilute solution to 250 mL, and heat to boiling. From a pipet, add slowly, dropwise, 10 mL of hot $BaCl_2$ (100 g/L) and continue boiling until precipitate is well formed. Digest solution for 12 to 24 hours at a temperature just below boiling. Take care to keep volume of solution between 225 and 260 mL; add water for this purpose if necessary. Filter precipitate using a fine-textured filter paper, wash, place paper and contents in a platinum or porcelain crucible of known mass, and slowly char and consume paper without inflaming. Then, ignite at 1562±90 °F (850±50 °C), cool in a desiccator, and determine mass of $BaSO_4$.

15.2.2 *Blank Determination.*-Make a blank determination following same procedure and using same amounts of reagents, and correct results obtained in analysis accordingly.

15.3 *Calculation.*-A typical calculation form is shown on figure 7. Calculate percentage of SO_3 to nearest 0.01, as follows:

$$SO_3 \text{ (percent)} = 34.3\, M_2 \qquad (4)$$

where:

M_2 = grams of $BaSO_4$, and
34.3 = molecular mass ratio of SO_3 to $BaSO_4$ (0.343) multiplied by 100.

16. Available Alkalies

16.1 *Summary of Procedure.*-Measured amounts of sample, $Ca(OH)_2$ (calcium hydroxide), and water are combined, sealed, and allowed to react at 100.4 °F (38 °C) for 28 days. Mixture is then unsealed, ground, slurried, filtered, and washed. The neutralized filtrate is analyzed for sodium and potassium, which are then calculated and reported as equivalent Na_2O (sodium oxide).

16.2 *Procedure*:

16.2.1 Thoroughly mix by grinding together, in a mortar or mechanical blender, the sample and $Ca(OH)_2$ in a proportion of 2-1/2 parts sample to 1 part $Ca(OH)_2$ by mass. Add 7 grams of this mixture to 10 mL of water in a small plastic vial of about 25-mL capacity, stirring until mixture is uniform. Seal vial and store at 100.4±3.6 °F (38±2 °C).

16.2.2 Open vial at age of 28 days and transfer contents to a 250-mL casserole. Break up and grind the cake with a pestle, adding a small amount of water if necessary, so that a uniform slurry containing no lumps is obtained (note 6). Add sufficient water to make total volume 200 mL, and let stand 1 hour at room temperature with frequent stirring. Then, filter through a medium-textured filter paper into a 500-mL volumetric flask. Wash thoroughly 8 to 10 times with hot water.

NOTE 6.-At times, it may be necessary to break vial and peel off plastic from solid cake. In such cases, care should be exercised to avoid loss of material and to remove all solid material from fragments of vial. If cake is too hard to break up and grind in casserole, a mortar should be used.

16.2.3 Neutralize filtrate with dilute HCl (1:3) using 1 to 2 drops of phenolphthalein solution as indicator. Add exactly 5 mL of the dilute HCl in excess. Cool solution to room temperature and fill flask to mark with distilled water. Determine amount of Na_2O (sodium oxide) and K_2O (potassium oxide) in solution by using flame photometric or atomic absorption procedure described in section 17 of USBR 4114, except that standard solutions shall be made to contain 8 mL of $CaCl_2$ (calcium chloride) stock solution per liter of standard solution, (note 7). This solution, as prepared, shall be used in place of the solution of cement.

NOTE 7.-The standard solutions made with 8 mL of $CaCl_2$ stock solution contain the equivalent of 504 p/m (parts per million) of CaO (calcium oxide). Tests have shown that this amount closely approximates amount of calcium dissolved in test solution.

16.3 *Calculation.*-A typical calculation form is shown on figure 8. Calculate results as mass percent of original sample material, and report as the equivalent percentage of Na_2O:

$$\text{Equivalent } Na_2O \text{ (percent)} = Na_2O \text{ (percent)} + (0.658)\ (K_2O \text{ percent})$$

17. Report

17.1 Figure 13 shows a typical reporting form for the chemical analysis.

PHYSICAL TESTS

18. Density

18.1 *Procedure.*-Determine the density of sample in accordance with procedure described in USBR 4188, except use about 50 grams of fly ash or natural pozzolan instead of about 64 grams of cement as recommended in section 7.3 of USBR 4188.

18.2 *Calculations.*-A typical calculation form is shown on figure 2 of USBR 4188.

19. Fineness

19.1 *Procedure.*-Determine amount of sample retained when wet-sieved on a No. 325 (45-µm) sieve in accordance with USBR 4430, except use a representative sample of fly ash or natural pozzolan instead of hydraulic cement in the determination.

19.2 *Calculations.*-Typical calibration and calculation forms are illustrated by figures 2 and 3 of USBR 4430.

20. Increase of Drying Shrinkage of Mortar Bars

20.1 *Test Specimens.*-Prepare test specimens in accordance with procedures of ASTM C 157, except mold three mortar bars from both control mix and the test mix using table 1.

Table 1. - Mix proportions for increase of drying shrinkage of mortar bars.

	Control mix	Test mix
Portland cement, grams	500	500
Fly ash or natural pozzolan, grams	None	125
Graded Ottawa sand, grams	1375	1250
Water	Sufficient to produce a flow of 100 to 115 percent	

20.2 *Procedure.*-Cure and measure test specimens in accordance with ASTM C 157, except that moist-curing period (including time in molds) shall be 7 days, and measurement of length at the age of 24±1/2 hours shall be omitted. Immediately after measurement at end of 7-day period, store specimens in accordance with ASTM C 157. After 28 days of air storage, measure length of specimens in accordance with of ASTM C 157.

20.3 *Calculations*:

20.3.1 Calculate increase of drying shrinkage of mortar bars as follows:

$$S_i \text{ (percent)} = S_t - S_c \qquad (5)$$

where:

S_i = increase of drying shrinkage,
S_t = average drying shrinkage of test specimens calculated, and
S_c = average drying shrinkage of control specimens, calculated as follows:

$$S \text{ (percent)} = \frac{L_i - L_f}{L_i}\ (100) \qquad (6)$$

where:

S = drying shrinkage,
L_i = length of test of control specimen at time of initial reading, and
L_f = length of test of control specimen at follow-up or final reading.

20.3.2 Report results to nearest 0.001 percent. If average drying shrinkage of control specimens is larger than average drying shrinkage of test specimens, prefix a minus sign to the value reported for the increase of drying shrinkage of mortar bars. Typical calculation forms are shown on figures 9 and 10.

21. Soundness

21.1 *Procedure.*-Conduct the soundness test in accordance with USBR 4151, except that specimens shall be molded from a paste composed of 25 parts by mass of fly ash or natural pozzolan and 100 parts by mass of a portland cement conforming to ASTM C 150.

21.2 *Calculations.*-Typical calculation forms are shown on figures 4 and 5 of USBR 4151.

22. Limits on Amount of Air-Entraining Admixture in Concrete

22.1 *Procedure.*-Proceed in accordance with USBR 4233, except that a revolving, open-tub type mixer with revolving mixing paddles may be used. The following subsections describe the concrete mixtures.

22.1.1 The control mix is prepared as described in section 4.1 of USBR 4233, with the air-entraining admixture added in an amount necessary to produce 5.0±0.5 percent of air in the concrete.

22.1.2 The test mix shall have same proportions as control mix (sec. 22.1.1) except that it shall contain a quantity of the fly ash or natural pozzolan under test equivalent to 25 percent by mass of the cement instead of an equal mass of standard sand, and a sufficient amount of air-entraining admixture to produce 5.0±0.5 percent of air in the concrete. Adjust total water content of test mix to provide same consistency required for control mix. Determine air content as specified in USBR 4233.

22.1.3 If amount of air-entraining admixture, expressed as percent by mass of cement, found to be necessary in test mix of 22.1.2 is more than 2.0 times the amount of air-entraining admixture needed in control mix of 22.1.1, make tests in accordance with USBR 4233 to determine whether air-entraining admixture, when used in larger quantity required, meets requirements of ASTM C 260. For this purpose, test mix specified in 22.1.2, with 5.0±0.5 percent of air in concrete, shall be compared with a similar control mix containing no air-entraining admixture, except that for the freezing and thawing test, mixture specified in 22.1.2 shall be compared with mixture of 22.1.1.

22.2 *Calculations.*–A typical calculation form is shown on figure 1 of USBR 4233.

23. Air Entrainment of Mortar

23.1 *Procedure*:

23.1.1 Using portland cement conforming to requirements for type I or II of ASTM C 150, prepare a test mix in accordance with USBR 4185, and using table 2.

Table 2. – Mix proportions for air-entrainment of mortar.

	Test mix
Portland cement, grams	300
Fly ash or natural pozzolan, grams	75
Standard Ottawa sand, grams	1125
Water, milliliters	See footnote 1
Neutralized Vinsol resin solution,[2] milliliters	See footnote 3

[1] Sufficient to give a flow of 80 to 95 percent.
[2] Available from Hercules, Inc., 917 King St., Wilmington, DE, 19899.
[3] Sufficient to produce an air content of 18±3 percent, amount used shall be considered as part of mixing water.

23.1.2 Prepare two test mixes with sufficient neutralized Vinsol resin to produce an air content of 15 to 18 percent in first mix and 18 to 21 percent in second mix. Then, determine by interpolation the amount of Vinsol resin, expressed as mass percent of cement, required to produce an air content of 18 percent.

23.2 *Calculation.*–Calculate air content of test mixes as follows:

$$M_a = \frac{M}{400} \qquad (7)$$

$$M_c = \frac{300 + 1125 + 75 + (300)(P)(0.01)}{\frac{300}{3.15} + \frac{1125}{2.65} + \frac{75}{SP} + \frac{(300)(P)(0.01)}{1}}$$

$$V = 100\left(1 - \frac{M_a}{M_c}\right)$$

where:

M_a = actual mass per unit volume of mortar as determined by USBR 4185 in grams per milliliter,
M = mass of specified 400 mL of mortar (see section 11.4 of USBR 4185) in grams,
M_c = theoretical mass per unit volume, calculated on an air-free basis and using values for specific gravity and quantities of materials in mix, in grams per milliliter,
P = percentage of mixing water plus Vinsol resin solution based on mass of cement,
SP = specific gravity of fly ash or natural pozzolan used in mix, and
V = volume of air content of mortar in percent.

23.2.1 A typical calculation form is shown on figure 5 of USBR 4185.

24. Pozzolanic Activity Index With Portland Cement

24.1 *Specimens.*–Mold specimens from control and test mixes in accordance with USBR 4109. The portland cement used in control mix shall meet requirements of ASTM C 150, and shall be the type and brand (if available) of the cement to be used in the actual work. For the test mix, replace 35 percent of absolute volume of amount of cement used in control mix by an equal absolute volume of test sample. Make three-cube batches as follows:

Control Mix:
Portland cement, 250 grams
Graded Ottawa sand, 687.5 grams
Water, as required for flow of 100 to 115 percent, W_c (in milliliters).
Test Mix:
Portland cement, 162.5 grams
Grams of sample: 87.5 times specific gravity of sample divided by specific gravity of portland cement
Graded Ottawa sand, 687.5 grams
Water, as required for flow of 100 to 115 percent, W_t (in milliliters). See section 25 for calculation of W_c and W_t.

24.2 *Storage of Specimens.*–After molding, place specimens and molds (on base plates) in moist room or closet at 73.4±3 °F (23.0±1.7 °C) for 20 to 24 hours; protect surfaces of specimens from dripping water. Following this storage period, remove molds from moist room or closet and remove cubes from molds. Place cubes in close-fitting metal or glass containers (note 8), seal the containers airtight, and store at 100±3 °F (37.8±1.7 °C) for 27 days. Allow the specimens to cool to 73.4±3 °F (23.0±1.7 °C) before testing.

NOTE 8.–Use any metal container having a capacity of three cubes if it can be sealed airtight by soldering. Containers of light-tinned sheet metal with inside dimensions of 2-1/32 by 2-1/32 by 6-1/4 inches (52 by 52 by 160 mm) have been found to be satisfactory. Widemouth Mason jars of 1-quart (1-liter) capacity have also been found to be satisfactory provided care is taken to prevent breakage.

24.3 *Compressive Strength Test.*–Determine compressive strength of all specimens at an age of 28 days.

24.4 *Calculation.*–A typical calculation form is shown on figure 11. Calculate pozzolanic activity index with portland cement as follows:

Pozzolanic activity index with portland cement is:

$$\frac{X}{Y}(100) \tag{8}$$

where:

X = average compressive strength of test mix cubes, lbf/in^2 (MPa), and
Y = average compressive strength of control mix cubes, lbf/in^2 (MPa).

25. Water Requirement

25.1 *Calculation.*–A typical calculation form is shown on figure 11. Calculate water requirement for the values of W_c and W_t in section 24.1 as follows:

$$W_r = \frac{W_t}{W_c}(100) \tag{9}$$

where:

W_r = water requirement (percentage of control),
W_t = water required for flow of 100 to 115 percent in test mix, in milliliters, and
W_c = water required for flow of 100 to 115 percent in control mix, in milliliters.

26. Pozzolanic Activity Index With Lime

26.1 *Procedure*:

26.1.1 *Pozzolanic Activity Test.*–To determine the activity of fly ash or natural pozzolan constituent with hydrated lime, make specimens of standard mortar and test in compression as described in the subsequent sections.

26.1.2 *Standard Materials.*–The hydrated lime shall be chemical reagent grade calcium hydroxide (note 9) of such fineness that residue on a No. 325 (45-μm) sieve is not greater than 5 percent by mass as determined in accordance with USBR 4430. The sand shall be natural silica sand from Ottawa, Illinois, conforming to requirements of section 4, USBR 4109.

NOTE 9.–The calcium hydroxide should be protected from exposure to carbon dioxide. Material remaining in an opened container after a test should not be used for subsequent tests.

26.1.3 *Proportioning and Mixing.*–The mortar shall contain 1 part hydrated lime and 9 parts graded standard sand by mass, plus an amount of oven-dry mineral admixture equal to twice the mass of the lime multiplied by a factor obtained by dividing specific gravity of mineral admixture by specific gravity of lime. The amount of mixing water, measured in milliliters, shall be such as to produce a flow to 110±5 percent in accordance with procedure described in section 11.3 of USBR 4109. A sufficient quantity of mortar shall be made to mold at least three 2-inch (51-mm) cube specimens. The mineral admixture and lime shall be put together and shaken vigorously in a covered container for 2 minutes. Mortar shall be mixed in accordance with section 10 of USBR 4305, except that it shall be understood that when references are made to cement, those references are to the fly ash- or natural pozzolan-lime mixture for this case.

26.1.4 *Molding Specimens.*–Molds shall be in accordance with section 3.4 of USBR 4109. The molding of test specimens shall be in accordance with section 11.4.3 of USBR 4109; molding at least three specimens for each test mold. Immediately after specimens are molded, seal the molds by waxing a base plate to top of mold to prevent escape of moisture.

26.1.5 *Storage of Specimens.*–Store specimens in molds initially at 73.4±3 °F (23.0±1.7 °C) for 24±2 hours, and then at 131±3 °F (55.0±1.7 °C) for 6 days. Cool specimens to 73.4±3 °F 4±0.25 hours before testing.

26.1.6 *Testing.*–At 0.5 to 1 hour before testing, strip specimens carefully, and keep them damp after stripping. These specimens are not capped for compression testing as molds are built to the rigid requirements of USBR 4109. Determine compressive strength of specimens using a loading rate from 100 to 500 lbf/in^2 (690 to 3450 kPa) per minute. Report average compressive strength of specimens as the pozzolanic strength. Specimens that differ by more than 15 percent from average value of all test specimens made from same sample shall not be considered in determining compressive strength. If compressive strength of more than one specimen differs from average by more than 15 percent, repeat the test for pozzolanic strength. Figure 12 shows a typical recording form for compressive strength.

27. Reactivity With Cement Alkalies

27.1 *Procedure*:

27.1.1 *Reduction of Mortar Expansion.*–Determine reduction of mortar expansion in accordance with USBR 4441.

27.1.2 *Mortar Expansion.*–Determine mortar expansion in accordance with requirements of USBR 4441.

28. Report

28.1 Figure 13 shows a typical reporting form for the physical tests.

29. Precision and Bias

29.1 The precision limits for this procedure have not been established at this time.

29.2 There is no known bias for this procedure.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-22-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-22-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-22-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Crucible No.	Tare, grams	Tare plus Wet Sample, grams	D Wet Sample, grams	Tare plus Dried Sample, grams	A Dried Sample, grams	$D - A$ Mass Loss, grams	$\frac{D - A}{D}$ × 100 Moisture Content, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	2	9.5760	11.7125	2.1365	11.7110	2.1350	0.0015	0.07
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	3	10.7364	12.8673	2.1309	12.8650	2.1286	0.0023	0.11

NOTES:

Figure 1. - Sample calculation form for moisture content determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-22-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-22-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-22-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Porcelain Crucible No.	Tare, grams	Tare plus Dried Sample, grams	A Dried Sample, grams	Tare plus Ignited Sample, grams	G Ignited Sample, grams	$\frac{A-G}{A} \times 100$ Loss on Ignition, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	2	9.5760	11.7110	2.1350	11.7001	2.1241	0.51
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	3	10.7364	12.8650	2.1286	12.8488	2.1124	0.76

NOTES:

Figure 2. – Sample calculation form for loss on ignition determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Loss on Ignition, percent	Platinum Crucible No.	Tare, grams	(1) Mass of Ignited Sample, grams	(2) Tare plus Precipitate, grams	(3) Col. (2) After HF, grams	(4) Gross SiO_2, grams	(5) Blank Determination, grams	(6) Net SiO_2, grams	$\frac{\text{Col. (6)}}{0.5} \times 100$ SiO_2, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	0.51	25	21.2337	0.4974	21.4026	21.2400	0.1626	0.0001	0.1625	32.50
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	0.76	1	24.5976	0.4962	24.8730	24.6042	0.2688	0.0001	0.2687	53.74

NOTES:

Mass in col. (1) $= \frac{0.5\,(100 - \text{percent LOI})}{100}$

HF = hydrofluoric acid

Figure 3. – Sample calculation form for silicon dioxide content determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.[1]	Brand Name	Plant ID	Type or [✓ Class]	Platinum Crucible No.	Tare, grams	(1) Tare plus R_2O_3, grams	(2) Gross R_2O_3, grams	(3) Blank Determination, grams	(4) Net R_2O_3, grams	$\frac{\text{Col. (4)}}{0.5}$ × 100 R_2O_3, percent	R_2O_3 plus SiO_2, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	25	21.2337	21.3651	0.1314	0.0006	0.1308	26.16	58.66
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	1	24.5976	24.7613	0.1637	0.0006	0.1631	32.62	86.36

NOTES:

[1] 0.5000-gram sample

Figure 4. – Sample calculation form for ammonium hydroxide group determinations.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.[1]	Brand Name	Plant ID	Type or [✓ Class]	Platinum Crucible and Lid Nos.	Tare, grams	(1) Tare plus CaO, grams	(2) Gross CaO, grams	(3) Blank Determination grams	(4) Net CaO, grams	$\frac{(4)}{0.5}$ × 100 CaO, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	25-A	26.2321	26.3704	0.1383	0.0006	0.1377	27.54
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	1-Q	29.5973	29.6352	0.0379	0.0006	0.0373	7.46

NOTES:

[1] 0.5000-gram sample

Figure 5. - Sample calculation form for calcium oxide determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.[1]	Brand Name	Plant ID	Type or [✓ Class]	Porcelain Crucible No.	Tare, grams	Tare plus $Mg_2P_2O_7$, grams	Gross $Mg_2P_2O_7$, grams	Blank Determination, grams	M_1 Net $Mg_2P_2O_7$, grams	$72.4\ M_1 = MgO$, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	8	11.2312	11.3028	0.0716	0.0019	0.0697	5.05
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	4	10.5960	10.6233	0.0273	0.0019	0.0254	1.84

NOTES:

[1] 0.5000-gram sample

Figure 6. - Sample calculation form for magnesium oxide determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS	Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS	Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER	Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.[1]	Brand Name	Plant ID	Type or [✓ Class]	Procelain Crucible No.	Tare, grams	Tare plus $BaSO_4$, grams	Gross $BaSO_4$, grams	Blank Determination, grams	M_2 Net $BaSO_4$, grams	$34.3\ M_2 = SO_3$, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	15	10.5203	10.6144	0.0941	0.0004	0.0937	3.21
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	3	10.7355	10.7517	0.0162	0.0004	0.0158	0.54

NOTES:

[1] 1.0000-gram sample

Figure 7. - Sample calculation form for sulfur trioxide determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. ELLIS Date 8-23-83
Project NA	Item ~ Location ~	Computed by J. ELLIS Date 8-23-83
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by F. HELLER Date 8-23-83

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Sample No.[1]	Brand Name	Plant ID	Type or [✓ Class]	(1) Avail. Alkalie Reading, p/m	(2) Dilution Factor	(3)[2] Na$_2$O, percent	(4) Avail. Alkalie Reading, p/m	(5) Dilution Factor	(6)[3] K$_2$O, percent	(7) 0.658 K$_2$O, percent	(3) + (7) Equiv. Na$_2$O, percent
M-7572	COMANCHE POWER-PLANT	PUEBLO, COLO.	C	1.29	200	2.58	0.32	50	0.16	0.11	2.69
M-7573	CHEROKEE POWER-PLANT	DENVER, COLO.	F	0.36	50	0.18	0.36	50	0.18	0.12	0.30

NOTES:

[1] 5000-mg sample

[2] Col. (3) $= (1)(2)(100)\ \frac{500\text{ mL}}{1000}$ divided by sample mass in milligrams.

[3] Col. (6) $= (4)(5)(100)\ \frac{500\text{ mL}}{1000}$ divided by sample mass in milligrams.

Figure 8. - Sample calculation form for available alkalies determination.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. OWENS Date 12-8-81
Project NA	Item ~ Location DENVER LAB	Computed by J. OWENS Date 12-8-81
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 12-8-81

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Comparator No. 1 Effective Gauge Length, L = 10 inches ~~(mm)~~ Reference Bar Reading 0.2650

Sample: ☑ Mortar or ☐ Concrete, MSA = No.4 ~~inches (mm)~~, Lab Std. Cement No. M-7120, Brand Name IDEAL, Plant ID DEVIL'S SLIDE, UT, Type II LA

Consistency: ☐ Slump of ______ inches (mm), or ☑ Flow of 107 % Consolidation: ☐ Vibrated or ☑ Rodded

Curing: 7 DAYS IN LIME WATER AND 28 DAYS IN 50 PERCENT RELATIVE HUMIDITY ROOM

Test Bar Nos. 475, 476, & 477, Initial Reading Date 12-8-81 AT 7 DAYS

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Mix No.	Fabrication Date	Elapsed Time, days		Test Bar No. 475			Test Bar No. 476			Test Bar No. 477			S_c	±S
								R, Dial Reading		DR/L_i × 100, %	R, Dial Reading		DR/L_i × 100, %	R, Dial Reading		DR/L_i × 100, %	Avg. Shrinkage, %	Drying Shrinkage, %
						T_i	T_f	inches	mm		inches	mm		inches	mm			
M-7120	IDEAL	DEVIL'S SLIDE, UT	II LA	H2	12-1-81	7	35	L_i = 10.1490 L_f = 10.1421		— 0.068	10.1433 10.1364		— 0.068	10.1459 10.1391		— 0.067	— 0.068	— —

NOTES:
DR = Difference in dial readings (R) for elapsed time interval.

Figure 9. – Sample calculation form for determination of the increase of drying shrinkage of mortar bars using the control mix.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. OWENS Date 12-8-81
Project NA	Item ~ Location DENVER LAB	Computed by J. OWENS Date 12-8-81
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 12-8-81

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

Comparator No. 1 Effective Gauge Length, L = 10 inches ~~(mm)~~ Reference Bar Reading 0.2650
Sample: ☑ Mortar or ☐ Concrete, MSA = No. 4 ~~inches (mm)~~, Lab Std. Cement No. M-7120, Brand Name IDEAL, Plant ID DEVIL'S SLIDE, UT, Type II LA
Consistency: ☐ Slump of ______ inches (mm), or ☑ Flow of 108 % Consolidation: ☐ Vibrated or ☑ Rodded
Curing: 7 DAYS IN LIME WATER AND 28 DAYS IN 50 PERCENT RELATIVE HUMIDITY ROOM
Test Bar Nos. 478, 479, & 480, Initial Reading Date 12-8-81 AT 7 DAYS

Sample No.	Brand Name	Plant ID	Type or [✓ Class]	Mix No.	Fabrication Date	Elapsed Time, days		Test Bar No. 478			Test Bar No. 479			Test Bar No. 480			S_t	$\pm S$
								R, Dial Reading		DR/L_i × 100, %	R, Dial Reading		DR/L_i × 100, %	R, Dial Reading		DR/L_i × 100, %	Avg. Shrinkage, %	Drying Shrinkage, %
						T_i	T_f	inches	mm		inches	mm		inches	mm			
M-7430	PANHANDLE FLY ASH	CARLSBAD, NM	F	112	12-1-81	7	35	L_i = 10.1491 L_f = 10.1417		— 0.073	10.1407 10.1331		— 0.075	10.1490 10.1416		— 0.073	— 0.074	— +0.068

NOTES:
DR = Difference in dial readings (R) for elapsed time interval.

Figure 10. – Sample calculation form for determination of the increase of drying shrinkage of mortar bars using the test mix.

Spec. or Solic. No. NA	Structure RESEARCH LAB STANDARDS	Tested by J. OWENS Date 11-30-81
Project NA	Item ~ Location DENVER LAB	Computed by J. OWENS Date 11-30-81
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 11-30-81

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

MIX PROPORTIONS

Cement-Pozzolan Sample No.	Brand Name	Plant ID	Type or Class	Specific Gravity	Cement Mass, grams	Pozzolan Mass, grams	Ottawa Sand Mass, grams	W_c or W_t Water Mass, mL	Flow, percent	W_r Water Required, percent
M-7120	IDEAL	DEVIL'S SLIDE, UTAH	TYPE II LA	3.15	500	0	1375	Wc 242	107	—
M-7430	PANHANDLE FLY ASH INC.	CARLSBAD, NM	CLASS F	2.65	325	147	1375	Wt 220	108	90.9

COMPRESSIVE STRENGTH OF 2-INCH OR 50-mm CUBES

Specimen No.	Series	Age, days	Total Load		Compressive Strength		Difference from Average, percent	Compressive Strength Corrected Average		Pozzolanic Activity Index, percent
			lbf	N	lbf/in²	MPa		lbf/in²	MPa	
1	CONTROL	28		104 500		41.8	-0.4			
2	do	28		107 250		42.9	+2.2			
3	do	28		103 000		41.2	-1.8			
						AVG. 41.97			41.97	
10	TEST	28		105 750		42.3	+2.3			
11	do	28		103 000		41.2	-0.3			
12	do	28		101 250		40.5	-2.0			
						AVG. 41.33			41.33	98.5

NOTES:

Figure 11. – Water requirement and pozzolanic activity index with portland cement.

Spec. or Solic. No. NA	Structure RESEARCH	Tested by J. OWENS Date 11-30-81
Project NA	Item ~ Location DENVER LAB	Computed by J. OWENS Date 11-30-81
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 11-30-81

SAMPLING AND TESTING FLY ASH OR NATURAL POZZOLANS FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE

MIX PROPORTIONS

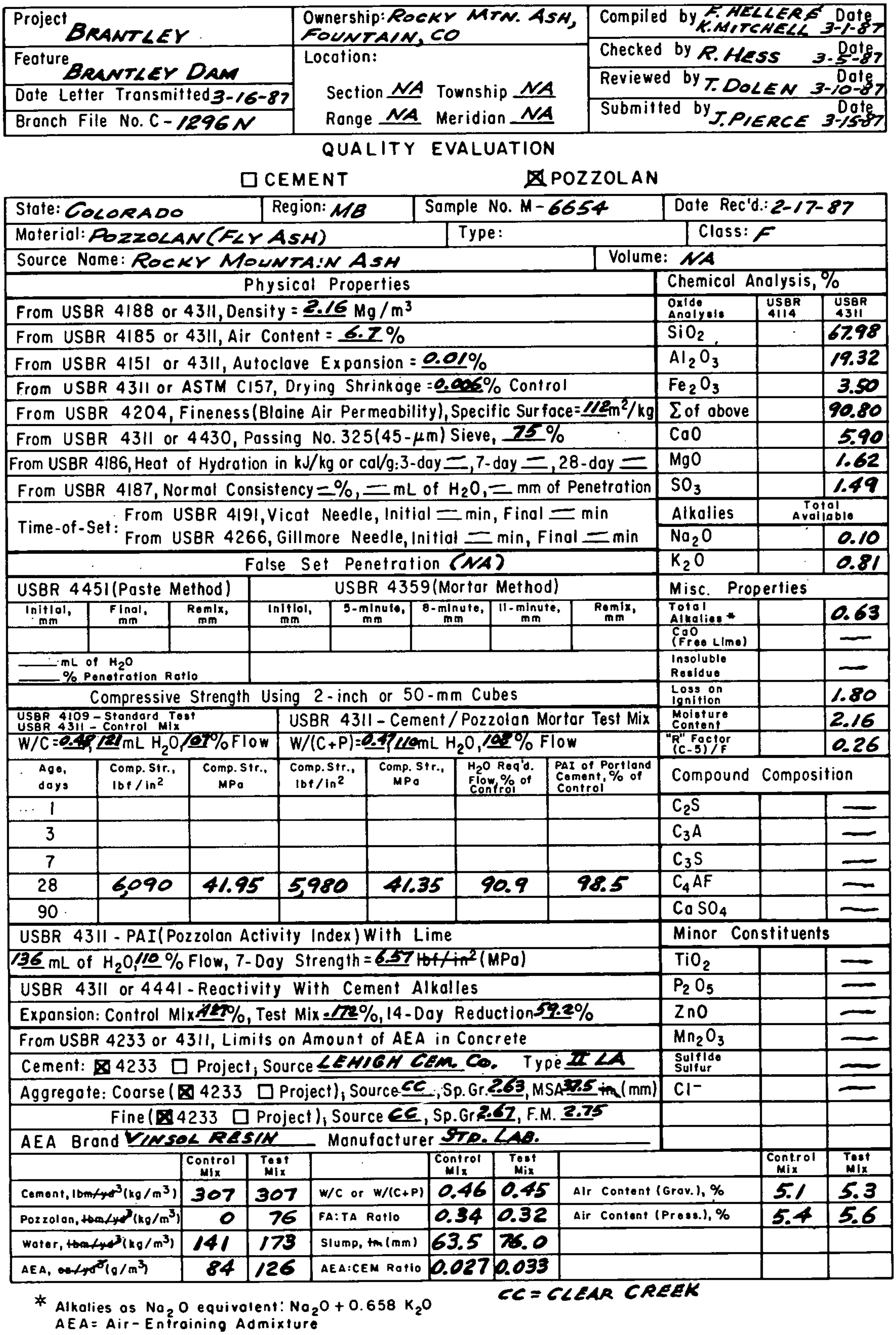
Pozzolan Sample No.	Brand Name	Plant ID	Class	Curing Temp. °F	Curing Temp. °C	Curing Time hours	Pozzolan Specific Gravity	Lime Specific Gravity	Pozzolan Mass, grams	Lime Mass, grams	Ottawa Sand Mass, grams	Water Mass, mL	Flow, %
M-7430	PANHANDLE FLY ASH INC.	CARLSBAD, NM	F		100	24	2.65	2.24	196	83	747	136	110

COMPRESSIVE STRENGTH OF 2- BY 4-INCH (51- BY 102-mm) CYLINDERS AND 2-INCH (50-mm) CUBES

Specimen No.	Cylinder Size inches	Cylinder Size mm	Cube Size inches	Cube Size mm	Series	Curing Temperature °F	Curing Temperature °C	Age, days	Total Load lbf	Total Load N	Compressive Strength lbf/in²	Compressive Strength MPa	Average Compressive Strength lbf/in²	Average Compressive Strength MPa
7				50	M-7430		54	7		16700		6.68		
8				50	do		54	7		16100		6.44		6.57
9				50	do		54	7		16450		6.58		

NOTES:

Figure 12. – Pozzolanic activity index with lime.



Project BRANTLEY	Ownership: ROCKY MTN. ASH, FOUNTAIN, CO	Compiled by F. HELLER & K. MITCHELL Date 3-1-87
Feature BRANTLEY DAM	Location:	Checked by R. HESS Date 3-5-87
Date Letter Transmitted 3-16-87	Section NA Township NA	Reviewed by T. DOLEN Date 3-10-87
Branch File No. C-1296N	Range NA Meridian NA	Submitted by J. PIERCE Date 3-15-87

QUALITY EVALUATION

☐ CEMENT ☒ POZZOLAN

State: COLORADO | Region: MB | Sample No. M-6654 | Date Rec'd.: 2-17-87

Material: POZZOLAN (FLY ASH) | Type: | Class: F

Source Name: ROCKY MOUNTAIN ASH | Volume: NA

Physical Properties

From USBR 4188 or 4311, Density = 2.16 Mg/m³

From USBR 4185 or 4311, Air Content = 6.7 %

From USBR 4151 or 4311, Autoclave Expansion = 0.01 %

From USBR 4311 or ASTM C157, Drying Shrinkage = 0.006 % Control

From USBR 4204, Fineness (Blaine Air Permeability), Specific Surface = 112 m²/kg

From USBR 4311 or 4430, Passing No. 325 (45-μm) Sieve, 75 %

From USBR 4186, Heat of Hydration in kJ/kg or cal/g: 3-day —, 7-day —, 28-day —

From USBR 4187, Normal Consistency — %, — mL of H_2O, — mm of Penetration

Time-of-Set: From USBR 4191, Vicat Needle, Initial — min, Final — min

From USBR 4266, Gillmore Needle, Initial — min, Final — min

False Set Penetration (NA)

USBR 4451 (Paste Method)			USBR 4359 (Mortar Method)				
Initial, mm	Final, mm	Remix, mm	Initial, mm	5-minute, mm	8-minute, mm	11-minute, mm	Remix, mm

_____ mL of H_2O
_____ % Penetration Ratio

Compressive Strength Using 2-inch or 50-mm Cubes

USBR 4109 – Standard Test
USBR 4311 – Control Mix
W/C = 0.48, 121 mL H_2O, 107 % Flow

USBR 4311 – Cement/Pozzolan Mortar Test Mix
W/(C+P) = 0.44, 110 mL H_2O, 102 % Flow

Age, days	Comp. Str., lbf/in²	Comp. Str., MPa	Comp. Str., lbf/in²	Comp. Str., MPa	H_2O Req'd. Flow, % of Control	PAI of Portland Cement, % of Control
1						
3						
7						
28	6,090	41.95	5,980	41.35	90.9	98.5
90						

USBR 4311 - PAI (Pozzolan Activity Index) With Lime

136 mL of H_2O, 110 % Flow, 7-Day Strength = 6.57 ~~lbf/in²~~ (MPa)

USBR 4311 or 4441 - Reactivity With Cement Alkalies

Expansion: Control Mix .421 %, Test Mix .172 %, 14-Day Reduction 59.2 %

From USBR 4233 or 4311, Limits on Amount of AEA in Concrete

Cement: ☒ 4233 ☐ Project; Source LEHIGH CEM. CO. Type II LA

Aggregate: Coarse (☒ 4233 ☐ Project); Source CC, Sp. Gr. 2.63, MSA 37.5 ~~in.~~ (mm)

Fine (☒ 4233 ☐ Project); Source CC, Sp. Gr. 2.67, F.M. 2.75

AEA Brand VINSOL RESIN Manufacturer STD. LAB.

	Control Mix	Test Mix		Control Mix	Test Mix		Control Mix	Test Mix
Cement, lbm~~/yd³~~ (kg/m³)	307	307	W/C or W/(C+P)	0.46	0.45	Air Content (Grav.), %	5.1	5.3
Pozzolan, ~~lbm/yd³~~ (kg/m³)	0	76	FA:TA Ratio	0.34	0.32	Air Content (Press.), %	5.4	5.6
Water, ~~lbm/yd³~~ (kg/m³)	141	173	Slump, ~~in.~~ (mm)	63.5	76.0			
AEA, ~~oz/yd³~~ (g/m³)	84	126	AEA:CEM Ratio	0.027	0.033			

Chemical Analysis, %

Oxide Analysis	USBR 4114	USBR 4311
SiO_2		67.98
Al_2O_3		19.32
Fe_2O_3		3.50
Σ of above		90.80
CaO		5.90
MgO		1.62
SO_3		1.49
Alkalies	Total	Available
Na_2O		0.10
K_2O		0.81
Misc. Properties		
Total Alkalies *		0.63
CaO (Free Lime)		—
Insoluble Residue		—
Loss on Ignition		1.80
Moisture Content		2.16
"R" Factor (C-5)/F		0.26
Compound Composition		
C_2S		—
C_3A		—
C_3S		—
C_4AF		—
$CaSO_4$		—
Minor Constituents		
TiO_2		—
P_2O_5		—
ZnO		—
Mn_2O_3		—
Sulfide Sulfur		—
Cl^-		—

CC = CLEAR CREEK

* Alkalies as Na_2O equivalent: $Na_2O + 0.658\ K_2O$
AEA = Air-Entraining Admixture

Figure 13. – Typical reporting form for properties of cementitious materials.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4341-92

PROCEDURE FOR

LENGTH CHANGE OF DRILLED OR SAWED SPECIMENS OF CEMENT MORTAR AND CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4341; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 341-84.

1. Scope

1.1 This designation covers the procedure for determination of the length changes of drilled or sawed specimens of cement mortar and concrete that are caused by other than externally applied forces and temperature changes. This procedure can be readily adapted, if desired, to studies of length change involving different schedules or environmental treatment.

1.1.1 The term "length change," as used in this procedure, is defined as "an increase or decrease in a linear dimension of a test specimen that has been caused by any factor other than externally applied forces and temperature changes".

2. Applicable Documents

2.1 *USBR Procedures*:
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4901 Drying Shrinkage of Hardened Concrete
4908 Length Change of Hardened Concrete Exposed to Alkali Sulfates

2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]
C 341 Standard Test Method for Length Change of Drilled or Sawed Specimens of Cement Mortar and Concrete[2]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[3]

3. Summary of Procedure

3.1 Specimens removed from existing structures by coring or sawing are stored in lime-saturated water or in a room of specified temperature and humidity; changes in a linear dimension are measured at specified intervals.

4. Significance and Use

4.1 Measurements of length change permit assessment of potential for volumetric expansion or contraction of drilled or sawed specimens of cement mortar or concrete due to various causes other than externally applied forces and temperature changes. This procedure is useful in evaluating movements in structures by measurements made on specimens taken from the structure.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 490.

6. Apparatus

6.1 Any of the following length-change devices may be used depending on dimensions of test specimen. These devices shall generally conform to requirements of ASTM C 490.

6.1.1 *Horizontal Comparator.*-This instrument consists of a rigid invar steel frame carrying a movable table on which specimen is supported at three points. Each end of the invar frame holds an upright invar post. One post is equipped with an adjustable head at the top, and the other post is fitted with a dial gauge, see figure 3 of USBR 4901. The head of the adjusting screw and stem of dial gauge contact a stainless-steel gauge point in each end of test specimen. A standard bar of 1/2-inch (12.7-mm) diameter invar steel, of varying lengths for the different-sized comparators and with mounts to position bar equidistant between measuring points of the instrument, is used to obtain a constant dial setting.

6.1.2 *Vertical Comparator.*-This instrument, one type of which is shown on figure 1, has been found satisfactory for use in measuring small prisms with lengths as small as 3 inches (76 mm). The terminals of this instrument are heat treated and polished.

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.

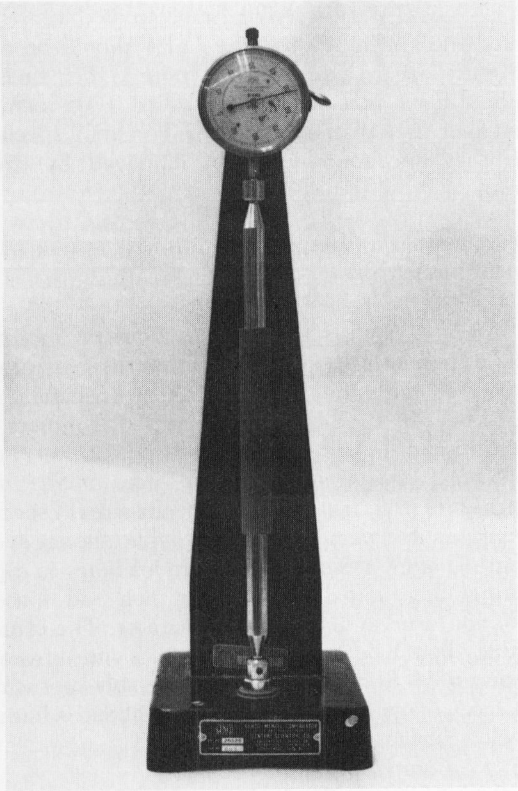

Figure 1. - A suitable verticle comparator for the measurement of length changes.

6.1.3 *Fulcrum Plate Strain Gauges.*-These gauges shall be designed to accomodate the size of specimen used and to provide or permit a positive means of contact with the gauge studs (note 1). The strain gauge shall provide a dial micrometer or other measuring device graduated to read in 0.0001-inch (0.0025-mm) increments. The design shall provide a means for checking measuring device against a reference bar.

NOTE 1.-Three strain gauges of the fulcrum plate type are illustrated on figure 2 in this procedure and figure 4 in USBR 4901. These gauges are essentially alloy steel frames that are held to permit a short longitudinal travel using a flat plate spring arrangement. The instrument is positioned by a set of pointed pins held in holes in the flathead gauge studs in the specimen. A dial is mounted between the movable frames for length-change readings.

6.1.4 *Inserts, Insert Screws, and Gauge Points or Studs.*-These items shall be AISI type 316 stainless steel or other corrosion-resistant metal of similar hardness. Gauge studs of invar or similar metal should be used when specimens are tested at substantially different temperatures. Figure 3 in this procedure and figure 2 in USBR 4908 show an assortment of these items.

6.1.4.1 *Gauge Studs in Ends of Specimens.*-When comparator is to be used to measure between gauge studs in ends of specimens, the gauge length for computing percentage length change shall be considered to be distance between innermost ends of gauge studs. Contact terminals of comparator shall be plane, polished, heat-treated surfaces as described in ASTM C 490.

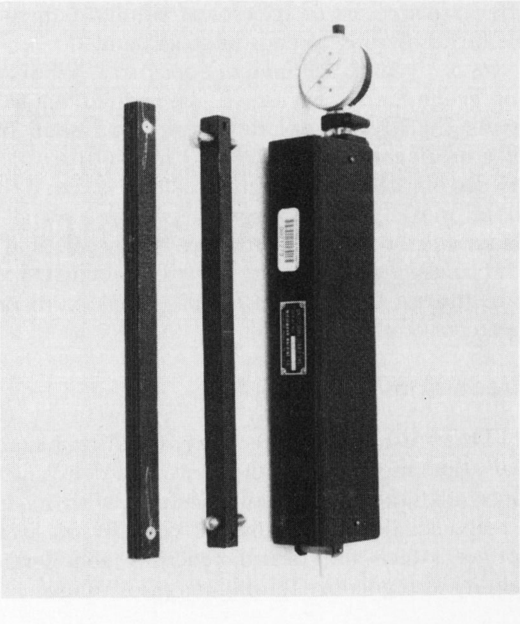

Figure 2. - A suitable extensometer for measurement of length change of specimens having gauge studs on sides.

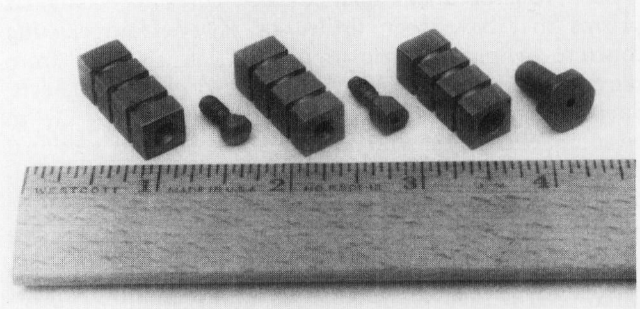

Figure 3. - Inserts and insert screws for various sizes of specimens. The screws permit adjustment of specimen to a standard length.

6.1.4.2 *Gauge Studs on Sides of Specimens.*-When comparator is to be used to measure between gauge studs on sides of specimens, contact terminals shall be conical, heat-treated surfaces as shown on figure 2. In this case, the gauge length shall be the distance between reference points, which are located in exposed ends of gauge studs (sec. 6.1.5).

6.1.5 *Gauge Studs.*-Gauge studs shall be AISI type 316 stainless steel or other corrosion-resistant metal of similar hardness.

6.1.5.1 *Studs for Ends of Specimens.*-Gauge studs that are to be located in ends of specimens shall have a rounded surface to provide point contact with terminals of comparator. The types of studs described in ASTM C 490 are suitable for insertion into drilled holes. Spherical studs having a diameter of 1/4 to 3/8 inch (6 to 10 mm), or studs that are sections of spheres of similar diameter, are suitable for cementing to ends of specimens.

6.1.5.2 *Studs for Sides of Specimens*.–The exposed ends of gauge studs that are to be located on sides of specimens shall have a plane surface, and shall have a diameter or diagonal of 3/8 to 1/2 inch (10 to 13 mm). For dry setting, the stud length shall be 1/2 to 5/8 inch (13 to 16 mm). Shorter lengths, including plane disks, may be satisfactory for studs that are to be cemented.

6.2 *Dial Gauges*.–Dial gauges shall be graduated to read either to nearest 0.0001 inch (0.0025 mm) or to nearest 0.001 percent of gauge length.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Sampling, Test Specimens, and Test Units

8.1 Samples shall be obtained in accordance with applicable provisions of USBR 4042.

8.2 Test specimens shall be either cores or rectangular prisms that have been drilled or sawed from existing concrete or mortar structures; and that are free from reinforcing steel, visible cracks, or other structural defects: Specimens may be of any size; however, if they are to be compared, they should not differ in their cross-sectional dimensions by more than 10 percent or in their length by more than 20 percent (note 2). It is desirable that gauge length be at least six times the maximum nominal size of the coarse aggregate but not less than 3 inches (76 mm), and that minimum cross-sectional dimension be at least three times the maximum nominal size of the coarse aggregate but not less than 2 inches (51 mm). When gauge studs are to be located on sides of specimen, the overall specimen length shall exceed gauge length by at least 2 inches.

NOTE 2.–Sizes of specimens for which comparators are normally available are:

- 1- by 1- by 10-inch (25- by 25- by 254-mm) bars
- 3- by 3- by 15-inch (76- by 76- by 381-mm) bars
- 4- by 4- by 30-inch (102- by 102- by 762-mm) bars
- 8- by 8- by 48-inch (203- by 203- by 1219-mm) bars
- 3- by 6-inch (76- by 152-mm) cores or cylinders
- 6- by 12-inch (152- by 305-mm) cores or cylinders
- 10- by 20-inch (254- by 508-mm) cores or cylinders
- 12- by 24-inch (305- by 610-mm) cylinders
- 18- by 36-inch (457- by 914-mm) cylinders
- 24- by 48-inch (610- by 1219-mm) cylinders
- 30- by 60-inch (762- by 1524-mm) cylinders
- 36- by 72-inch (914- by 1829-mm) cylinders

8.3 *Setting Gauge Studs*:

8.3.1 Gauge studs may be dry-set, cemented into drilled holes, or cemented directly to surface of specimen.

8.3.2 *Drilled Holes*.–For gauge studs that are to be cemented into drilled holes, the holes should be drilled only slightly larger than the studs (note 3). For studs that are to be dry-set, holes should be drilled 0.005 inch (0.13 mm) smaller than diameter of studs. For small specimens, ensure that specimens are not damaged by drilling operation.

NOTE 3.–Carbide-tipped masonry drills have been found most suitable for this purpose.

8.3.2.1 *For Gauge Studs in Ends of Specimen*.–Drill holes in ends of a specimen so that their longitudinal axes coincide with longitudinal axis of specimen. Hole depths should be such that gauge studs will project from 1/8 to 3/16 inch (3 to 5 mm) beyond ends of specimen.

8.3.2.2 *For Gauge Studs on Sides of Specimen*.–Drill two holes in each of the two opposite sides of specimen to compensate for warping and to provide a better average for length change. Position both pairs of holes in a plane containing longitudinal axis of specimen and space the holes to conform to length of comparator. The center of each hole should be at least 1 inch (25 mm) from end of specimen. Hole depths should preferably be such that top surfaces of gauge studs can be set about 0.1 inch (3 mm) below surface of specimen.

8.3.3 *Cementing Methods*:

8.3.3.1 *Studs Set in Holes*.–Position gauge studs in their previously drilled holes and at prescribed depths with their exposed ends parallel to surface of specimen for studs having plane end surfaces. The cementing material should be stable and effective in either a wet or dry environment and at temperatures up to 250 °F (121 °C). The following cementing materials have been found satisfactory:

8.3.3.1.1 *Epoxy Resin*.–Epoxy resins for this purpose should cure at room temperatures. Holes should be free of loose particles and visually dry to ensure good bond.

8.3.3.1.2 *Lead*.–Lead is satisfactory for specimens subjected to air storage but is not recommended for long periods of water storage (sec. 10.2.1).

8.3.3.1.3 *Portland Cement Paste*.–Use a thick paste of portland cement plus 2 percent calcium chloride by mass of cement. Moisten each hole with about 5 mL of water, and cement studs in place after water has been absorbed. Moist-cure the paste for about 24 hours.

8.3.3.1.4 *Other Cementing Media*.–Sulfur, rose metal, and plaster of paris have also proven satisfactory.

8.3.3.2 *Studs Cemented to Surface*.–An epoxy resin that sets at room temperature and does not soften at a temperature of 250 °F (121 °C) is the most satisfactory material for cementing studs to surface of specimen. To ensure good bond, it is essential that surface be clean. Acid etching, followed by flushing with water and drying, is a satisfactory preparation of surface for bonding. The exposed end surface of each stud having a plane end surface should be parallel to surface of specimen.

8.3.4 *Dry-Setting Method*.–Drive gauge studs into their previously drilled holes to their prescribed depths being careful not to deform exposed ends of studs during driving operation.

8.3.5 *Reference Points on Gauge Studs.*-Establish a reference point on each gauge stud that is located on side of specimen by drilling a hole, about 0.04 inch (1 mm) in diameter, with a No. 56 American Standard twist drill into end of stud to a depth sufficient to provide clearance between bottom of hole and point of comparator, see figure 2. A template will aid in spacing holes at proper gauge length, which should be as close to mean gauge length of comparator as practicable. Remove burred edges from reference point holes.

9. Calibration and Standardization

9.1 Each measuring device shall be checked against a reference bar at regular intervals as described in ASTM C 490.

10. Conditioning

10.1 *For Measurement.*-Prior to initial measurement for length, condition specimens by immersion in lime-saturated water. Maintain temperature of this water at 73.4±3.0 °F (23.0±1.7 °C), except that during last hour of immersion prior to making measurements, maintain temperature at 73.4±1.0 °F (23.0±0.6 °C). When measuring, remove specimens from water one at a time, wipe with a damp cloth, and immediately measure for length. Make length measurements at 7-day intervals, and continue conditioning until change in length over a 7-day period is less than 0.001 percent. Use the length measurement that determines that this criterion has been met as the basis for calculating length change occurring during the air- or water-storage period.

10.2 *Subsequent Storage.*-After measurement at end of conditioning period, store specimens as described in either 10.2.1 or 10.2.2, unless another condition of storage is specified.

10.2.1 *Water Storage.*-Immerse specimens in lime-saturated water at 73.4±3.0 °F (23.0±1.7 °C). For at least 30 minutes prior to measuring the specimens, maintain the temperature at 73.4±1.0 °F (23.0±0.6 °C). Make length measurements on each specimen after 1, 2, 4, 8, 16, 32, and 64 weeks, unless otherwise specified.

10.2.2 *Air Storage.*-Store specimens in circulating air maintained at 73.4±2.0 °F (23.0±1.1 °C) and at a relative humidity of 50±4 percent, unless some other condition of storage is specified. Unless otherwise specified, measure specimens for length at weekly intervals and continue them in air storage until their change in length over a 7-day period is less than 0.001 percent. Preferably, make the measurements in a room maintained at the same temperature and humidity levels prescribed for storage.

11. Procedure

11.1 *Determination of Gauge Length.*-Determine gauge length of each specimen to an accuracy of 1 percent. For specimens with side-mounted gauge studs, determine gauge length by direct measurement between reference points with a suitable scale. For specimens with end-mounted studs, determine gauge length by first measuring distance between ends of studs with suitable calipers, and then subtracting the lengths of the two studs.

11.2 *Subsequent Readings*:

11.2.1 *Vertical Comparator.*-When using the vertical comparator, specimen should be brought to comparator with the dial feeler point retracted. The lower gauge point of specimen should be brought to rest squarely on lower instrument pin; specimen is then held in position while dial feeler point is released to contact upper gauge point. Before a reading is taken, specimen shall be rotated to ensure correct seating.

11.2.2 *Horizontal Comparator.*-Operation of the horizontal comparator is similar to that of the vertical comparator, with specimen being carefully placed on instrument supports and gauge points placed against neutral instrument pin before gauge feeler pin is released to contact gauge point in other end of specimen.

11.2.3 *Fulcrum Strain Gauge.*-The strain gauge should be clasped firmly with one end of gauge in either hand. The fourth and index fingers of other hand should then be brought in contact with specimen and instrument pins brought to specimen carefully by closing the fingers until instrument pins are in contact with gauge points. The instrument pins should be perpendicular to specimen to ensure correct readings and to prevent breakage of feeler pins.

12. Calculations

12.1 Figure 6 in USBR 4901 shows a standard data form used in the length-change computations for 8- by 8- by 48-inch (203- by 203- by 1219-mm) bars and for 18-inch (457-mm) diameter by 36-inch (914-mm) length cores or cylinders. Figure 5 in USBR 4901 is a sample data form devised to illustrate the computations involved for a 4- by 4- by 30-inch (102- by 102- by 762-mm) bar; this form is explained as follows:

Column	
1	Date of measurement
2	Age in days from time of casting or start of test
3	Time in days for conditioning and storing
4	Room temperature, T, at time of measurement
5	ΔT, which is 73.4 °F - T (23.0 °C - T)
6	Standard bar base reading
7	Standard bar reading corrected to 73.4 °F (23.0 °C)
8	Actual dial reading of specimen No. 1
9	Actual dial reading of specimen No. 2
10	Average dial reading of specimens 1 and 2
11	Thermal correction to reading, which is equal to thermal coefficient times ΔT times *GL* (gauge length)

12 Dial reading corrected for deviation from 73.4 °F (23.0 °C)
13 ΔL, total drying shrinkage to date
14 ΔL_t, unit length change, or $\Delta T/GL$, in inch per inch per °F [(mm/mm)/°C] $\times 10^{-6}$
15 ΔL_t in percent = ΔL_t (100)
16 Percentage of length change between readings

13. Report

13.1 The length change of hardened concrete is best reported by letter containing all the known data. The report shall include:

- Sources of specimen in terms of structure and particular location in structure from where specimen was obtained.
- Dimensions of test specimen.
- Maximum size and mineral character of aggregate in concrete.
- Description of conditioning, either by indication that type of conditioning outlined in section 10 was followed, or by giving details of any conditioning not conforming to section 10. In either case, report total length of conditioning period.
- Description of storage conditioning, either by indicating that type of storage outlined in section 10 was followed, or by giving details of storage methods not conforming to section 10.
- Total length of storage period, exclusive of conditioning period, prior to each length measurement.
- Length-change data, reported as percent increase or decrease in linear dimension to nearest 0.001 percent, based on initial measurement made at end of conditioning period.
- Any condition or characteristic of the concrete that may be of interest to the testing.
- Any other pertinent information

14. Precision and Bias

14.1 Precision is dependent upon the particular test conditions; no general statement can be made.

14.2 There is no known bias.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4359-92

PROCEDURE FOR

EARLY STIFFENING OF PORTLAND CEMENT (MORTAR METHOD)

INTRODUCTION

This procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. This procedure is issued under the fixed designation USBR 4359; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 359-83.

1. Scope

1.1 This designation covers the procedure for determination of early stiffening in portland cement mortar.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1030 Calibrating Specific Gravity Flasks
4183 Sampling and Acceptance of Hydraulic Cement
4185 Air Content of Hydraulic Cement Mortar
4187 Normal Consistency of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:
C 150 Standard Specification for Portland Cement[1,2]
C 359 Standard Test Method for Early Stiffening of Portland Cement (Mortar Method)[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,2]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1,2,3]
C 778 Standard Specification for Standard Sand[1]
D 1193 Standard Specification for Reagent Water[4]
E 1 Standard Specification for ASTM Thermometers[5]

3. Summary of Procedure

3.1 A mortar is prepared with the cement to be tested using specified quantities of cement, standard sand, and water. Using the modified Vicat apparatus, measurements of penetration are made at stipulated intervals after the beginning of mixing procedure. Upon completion of first series of penetration measurements, mortar is returned to mixer to be remixed. Following the remix procedure, an additional remix penetration is determined. A tabulation of the penetration measurements is included in the report (sec. 13).

4. Significance and Use

4.1 The purpose of this test procedure is to determine the degree to which a cement mortar develops early stiffening. This procedure is intended primarily for use by those interested in research on methods for determining potential false set of portland cement.

4.2 When used for estimating relative tendency of a cement to manifest early stiffening, a judgment may be made by comparing the behavior in the penetration series (secs. 12.4.1 and 12.4.2) and the remix procedure (sec. 12.4.3) to differentiate a relatively less serious and less persistent tendency to early stiffening from one that is more persistent and, consequently, more serious.

4.3 Severe false setting in a cement may cause difficulty from a placing and handling standpoint, but it is not likely to cause difficulties where concrete is mixed for a longer time than usual, as usually occurs in transit mixing or where the concrete is remixed prior to placing or transporting in concrete pumping operations. False setting is most likely noticed where concrete is mixed for a short interval in stationary mixers and transported to forms in nonagitating equipment, as on some paving jobs.

4.4 Cements with severe false setting usually require slightly more mixing water to produce same consistency, which may result in slightly lower strengths and increased drying shrinkage.

4.5 Flash set of a severity sufficient to cause difficulties from a placing and handling standpoint usually will cause cement to fail requirements for time-of-setting in ASTM C 150.

5. Terminology

5.1 *Early Stiffening*.-The early development of stiffness in working characteristics of a portland-cement paste, mortar, or concrete. Variable forms include "false set" and "flash set."

5.2 *False Set*.-The early development of stiffness in working characteristics of a portland-cement paste, mortar,

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[1] *Annual Book of ASTM Standards*, vol. 04.01.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vols. 04.03, 04.08.
[4] *Annual Book of ASTM Standards*, vol. 11.01.
[5] *Annual Book of ASTM Standards*, vols. 05.03, 14.01.

or concrete without the evolution of much heat. This type of stiffness can be dispelled and plasticity regained by further mixing without addition of water. Also known as "grab set," "premature stiffening," "hesitation set," and "rubber set."

5.3 *Flash Set.*-The early development of stiffness in working characteristics of a portland-cement paste, mortar, or concrete that usually occurs with the evolution of considerable heat. This type of stiffness cannot be dispelled nor can the plasticity be regained by further mixing without addition of water. Also known as "quick set."

6. Apparatus

6.1 *Vicat Apparatus.*-Shall conform to requirements of USBR 4187, except that the 1-mm needle shall be replaced by a mass such that the total mass of 10-mm plunger, indicator, and added mass shall be 400±0.5 grams.

6.2 *Spoon.*-Shall conform to requirement of USBR 4185.

6.3 *Mixer, Bowl, Paddle, and Scraper.*-Shall conform to requirements of USBR 4305.

6.4 *Scales, Standard Masses, and Glass Graduates.*-Shall conform to requirements of ASTM C 490.

6.5 *Thermometer.*-ASTM No. 1C or 1F, conforming to requirements of ASTM E 1.

6.6 *Trowel.*-The trowel shall have a steel blade, 4 to 6 inches (102 to 152 mm) in length, with straightedge.

6.7 *Clock Timer.*

6.8 *Containers.*-The containers shall have inside dimensions of about 2 by 2 by 6 inches (50 by 50 by 150 mm), be made of any suitable material such as sheet metal or plastic, be rigid and watertight, and be at least 2 inches (50 mm) deep (see fig. 1).

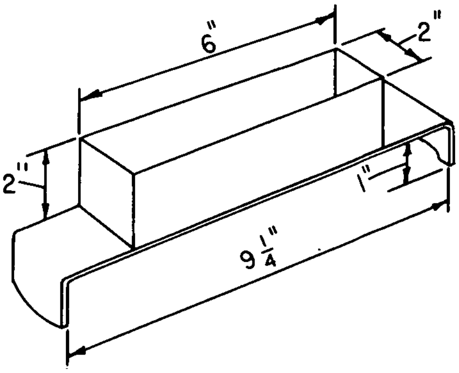

Figure 1. - Container.

7. Reagents and Materials

7.1 *Standard Sand.*-Sand shall be No. 20 to No. 30 (850 to 600 µm), graded, and conform to requirements of ASTM C 778.

7.2 *Mixing Water.*-Potable water is satisfactory for routine tests. For all referee and cooperative tests, reagent water conforming to requirements of ASTM D 1193 for Type III or Type IV grades of reagent water shall be used.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Sampling

9.1 Sample the cement in accordance with USBR 4183.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

10.2 Scales shall be calibrated to meet requirements of section 6.4 in accordance with USBR 1012.

10.3 Glass graduates shall be calibrated to meet requirements of ASTM C 490 in accordance with USBR 1030.

10.4 Compliance to section 6.1 for the Vicat apparatus shall be accomplished by using linear measurement devices complying with USBR 1000.

11. Conditioning

11.1 The temperature of room, dry materials, paddle, bowl, and containers shall be maintained between 68 and 81.5 °F (20 and 27.5 °C). The temperature of mixing water shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

11.2 The relative humidity of laboratory shall not be less than 50 percent.

12. Procedure

12.1 *Batch.*-Mix simultaneously 600 grams of cement, 300 grams of graded standard sand, 300 grams of No. 20 to No. 30 (850- to 600-µm) standard sand, and 180 mL of water for all cements except Types III and IIIA, for which amount of water shall be 192 mL.

12.2 *Mixing of Mortar.*-The mixing shall be done in mechanical mixer as follows:

12.2.1 Place sand and cement in dry bowl and mix these dry materials for a few seconds with spoon.

12.2.2 Place bowl in mixer, set paddle in place, and mix dry materials for 10 seconds at slow speed (140±5 r/min).

12.2.3 With the mixer operating at slow speed, add the entire quantity of mixing water within 5 seconds. Then, stop the mixer, quickly change to medium speed (285±10 r/min), and continue mixing for 1 minute, timing from first addition of water.

12.2.4 Stop mixer, scrape sides of mixing bowl with rubber scraper, and quickly place thermometer in mortar.

Allow mortar to stand undisturbed for remainder of a 45-second interval from time of stopping mixer.

12.2.5 Read temperature, remove thermometer, start mixer, and mix for 15 seconds at medium speed. If mortar temperature is not in the range of 73.4±3 °F (23±1.7 °C), discard the batch and adjust temperature of water or sand, or both, to give required temperature.

12.3 *Filling Container*:

12.3.1 Immediately after completion of mixing, remove bowl from mixer and, with a spoon, uniformly distribute a portion of mortar into container until the container is heaping full. When removing mortar from bowl, quickly and gently place each spoonful of mortar into container; do not remove mortar pushed up on side of bowl by the paddle. After container has been filled, reassemble mixer, cover bowl with a lid, and retain remaining mortar for a remix test to be performed later. To compact mortar in container, lift container about 3 inches (80 mm) off table with both hands and rap container twice against table surface.

12.3.2 With leading edge of trowel slightly raised, strike off mortar with one stroke of trowel along length of container. Then, remove excess mortar by using a sawing motion with straightedge of trowel along length of container in a direction opposite to that used in striking off the mortar. Smooth surface of mortar with a single stroke of trowel.

12.4 *Penetration Tests*:

12.4.1 After filling container, immediately place the 10-mm plunger of Vicat apparatus in contact with surface of mortar at midpoint of container on longitudinal centerline, and set movable indicator at zero. Release plunger 3 minutes after the starting time of wet mixing and record, as the initial penetration, the depth in millimeters that plunger has settled below surface 10 seconds after being released. Generally, plunger will settle to bottom of container and initial penetration will accordingly be recorded as +50 mm.

12.4.2 Immediately withdraw and clean plunger. After moving Vicat apparatus to desired location, determine penetrations at intervals of 5, 8, and 11 minutes after start of mixing. Do not move filled container until these measurements are completed. Make all penetrations along longitudinal centerline of container. Obtain the 5- and 8-minute penetrations at points about 1-1/2 inches (40 mm) from each end of container, and obtain 11-minute penetration at a point about midway between points where initial and 5-minute penetrations were made.

12.4.3 After completing the 11-minute penetration measurement, immediately return mortar in container to bowl, start mixer, raise bowl into mixing position, and remix at medium speed for 1 minute. Fill a clean container as outlined in section 12.3 and determine penetration 45 seconds after completion of mixing.

12.4.4 Figure 2 shows a typical calculation form.

13. Report

13.1 A suggested reporting form is shown on figure 5 of USBR 4183. The report shall show the depths of the penetrations as follows:

Initial penetration ______________ mm
5-minute penetration ______________ mm
8-minute penetration ______________ mm
11-minute penetration ______________ mm
Remix penetration ______________ mm

14. Precision and Bias

14.1 Interlaboratory test data for determination of statements of precision and bias in accordance with ASTM C 670 are being evaluated and will be included in a later revision of this test procedure.

15. Reference

15.1 For additional useful information on details of cement test methods, see "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.

Spec. or Solic. No. DC-7030	Structure DAM	Tested by W. DUFFUS Date 8-23-74
Project WASHOE - MP REGION	Item CEMENT Location DENVER LAB	Computed by W. DUFFUS Date 8-23-74
Feature MARBLE BLUFF DAM	Station ~ Offset ~ Depth ~ to ~	Checked by J. OWENS Date 8-23-74

EARLY STIFFENING OF PORTLAND CEMENT (MORTAR METHOD)

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Admixture	Water, mL	Temp., °C	Penetration				
							Initial, mm	5-min, mm	8-min, mm	11-min, mm	Remix, mm
M-6585	CALAVERAS	REDDING OR SAN ANDREAS	II LA	NONE	180	24	50+	50	49	48	50
M-6572	NEVADA CEMENT Co.	FERNLEY, NV	II LA	NONE	180	24	50+	43	4	4	50

NOTES:

Figure 2. – Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROCEDURE FOR

USBR 4403-92

TIME-OF-SETTING OF CONCRETE MIXTURES BY PENETRATION RESISTANCE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4403; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 403-80.

1. Scope

1.1 This designation covers the procedure for determination of time-of-setting of concrete with slump greater than zero by testing mortar sieved from concrete mixture. This procedure is suitable for use only when tests of mortar fraction of concrete will provide information required. Because hardening of concrete is a gradual process, any definition of time-of-setting must necessarily be arbitrary. The temperature of storage of specimens used in this procedure is to be selected by the user. Times of initial and final setting of concrete are determined in accordance with this procedure on the basis of a rate-of-hardening test made by using penetration resistance needles on mortar sieved from concrete mixture.

1.1.1 This procedure may also be applied to prepared mortars and grouts; however, when setting time of concrete is desired, test shall be performed on mortar sieved from concrete mixture and not on a prepared mortar intended to simulate mortar fraction of the concrete.

1.2 This procedure may also be used for determining effects of variables such as temperature, cement, mixture proportions, additions, and admixtures upon the time-of-setting and hardening characteristics of concrete. Procedure may also be used as a part of performance specifications[3] to determine compliance with specified time-of-setting requirements.

2. Applicable Documents

2.1 *USBR Procedures*:
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4231 Air Content of Freshly Mixed Concrete by Pressure Method

2.2 *ASTM Standards*:
C 403 Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[2]

3. Terminology

3.1 *Time of Initial Setting*.–The elapsed time, after initial contact of cement and water, required for mortar sieved from concrete to reach a penetration resistance of 500 lbf/in^2 (3.4 MPa).

3.2 *Time of Final Setting*.–The elapsed time, after initial contact of cement and water, required for mortar sieved from concrete to reach a penetration resistance of 4,000 lbf/in^2 (27.6 MPa).

4. Apparatus

4.1 *Containers for Mortar Specimens*.–Rigid, watertight, nonabsorptive, nonoiled containers, either cylindrical or rectangular in cross section. The mortar surface area shall be provided for 10 undisturbed readings of penetration resistance in accordance with section 10.2 for clear distance requirements. The minimum lateral dimension shall be 6 inches (152 mm), and the height at least 6 inches.

4.2 *Penetration Resistance Apparatus*.[3]–Spring reaction-type apparatus, graduated from 10 to 130 lbf (44 to 578 N) in increments of 2 lbf (9 N) or less, or hydraulic reaction-type apparatus with pressure gauge of 150- to 200-lbf (667- to 890-N) capacity, graduated in increments of 2 lbf or less. Indications of actual needle loads by these apparatus shall be accurate to 2 lbf. Removable needles of the following bearing areas shall be provided: 1, 1/2, 1/4, 1/10, 1/20, and 1/40 in^2 (645, 323, 161, 65, 32, and 16 mm^2). Each needle shank shall be scribed peripherally

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[3] Typical examples of instruments meeting requirements for penetration resistance apparatus are: Acme Penetrometer, manufactured by E. W. Zimmerman Construction Chemicals, Inc., Chicago, Illinois; Proctor Mortar Penetrometer Assembly, model CT-419, manufactured by Soiltest, Inc., Chicago, Illinois; and Proctor Penetration Resistance Apparatus, model H-4137, manufactured by Humbolt Manufacturing Co., Norridge, Illinois.

at an exact measurement distance of 1 inch (25.4 mm) above the bearing face. The length of the 1/40-in^2 (16-mm^2) needle shall not be more than 3-1/2 inches (89 mm) to minimize bending.

4.3 *Tamping Rod.*–A round, straight, steel rod 5/8 inch (16 mm) in diameter and about 24 inches (610 mm) in length, with tamping end rounded to a 5/8-inch-diameter hemispherical tip.

4.4 *Pipet.*–Pipet or suitable instrument for drawing off free water from surface of test specimens.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Number of Specimens

6.1 At least three separate batches shall be made for each test condition. One rate-of-hardening test shall be made on each batch. An equal number of batches for each condition shall be made on any given day. When it is impossible to make at least one test for each variable on a given day, mixing of entire series of batches shall be completed in as few days as possible, and one of the mixtures shall be repeated each day as a standard of comparison.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

8. Preparation of Mortar Specimens

8.1 From concrete mixture under test, select a representative sample of concrete of sufficient volume to provide enough mortar to fill test container, or containers, to a depth of at least 5-1/2 inches (140 mm).

8.2 Remove essentially all mortar from sample of concrete by sieving it through a No. 4 (4.75-mm) sieve onto a nonabsorptive surface.

8.3 Thoroughly remix mortar by hand methods on the nonabsorptive surface, place mortar in container, and compact by rodding. Rod specimen by holding tamping rod so as to penetrate mortar with round end. Rod mortar once for each 1 in^2 (645 mm^2) of top surface area of specimen and distribute strokes uniformly over cross section of specimen. After completion of rodding, tap sides of container lightly with tamping rod to close voids left by tamping rod and to further level surface of specimen. Upon completion of specimen preparation, mortar surface shall be at least 1/2 inch (13 mm) below top edge of container to provide space for collection and removal of bleeding water and to avoid contact between mortar surface and protective covering specified in section 9.

9. Conditioning

9.1 Store and maintain specimens at desired temperature of test. To prevent excessive evaporation of moisture, keep the specimens covered with a suitable material such as damp burlap or a tight-fitting, water-impermeable cover for duration of the test, except when bleeding water is being removed or penetration tests are being made. Specimens shall be shielded from the sun.

10. Procedure

10.1 Remove bleeding water from surface of mortar specimens by using a pipet or suitable instrument just prior to making a penetration test. To facilitate collection of bleeding water, tilt specimen carefully to an angle of about 12° from horizontal by placing a block under one side 2 minutes prior to removal of bleeding water.

10.2 Insert a needle of appropriate size, depending upon state of hardening of mortar, into penetration resistance apparatus and bring bearing surface of needle into contact with mortar surface. Gradually and uniformly apply a vertical force downward on apparatus until needle penetrates mortar to a depth of 1 inch (25.4 mm) exact measurement as indicated by scribe mark. The time required to penetrate to this 1-inch depth shall be about 10 seconds. Record the force required and time of application, measured as elapsed time after initial contact of cement and water. In subsequent penetration tests, take care to avoid areas where mortar has been disturbed by previous tests. The clear distance between needle impressions shall be at least two diameters of needle being used, but not less than 1/2 inch (13 mm). The clear distance between any needle impression and side of container shall not be less than 1 inch (25 mm).

10.3 Make penetration tests at hourly intervals for normal mixtures and normal temperatures, with the initial test being made after an elapsed time of 3 to 4 hours. For accelerated mixtures or high temperatures, it may be advisable to make initial test after an elapsed time of 1 or 2 hours and subsequent tests at 1/2-hour intervals. For low-temperature conditions or retarded concrete mixtures, initial penetration test may be deferred for an elapsed time of 4 to 6 hours, and perhaps longer. Subsequent tests may be made at 1-hour intervals unless rate of increase in penetration resistance indicates that shorter intervals are desirable.

10.4 No less than six penetration resistance determinations shall be made in each rate-of-hardening test, and the time intervals between penetration resistance determinations shall be such as to give a satisfactory rate-of-hardening curve, as indicated by equally spaced points. Continue tests until one penetration resistance of at least 4,000 lbf/in^2 (27.6 MPa) is reached.

11. Calculations

11.1 Calculate penetration resistance, in pound force per square inch (megapascals), as the force required to cause a 1-inch (25.4-mm) depth of penetration of needle divided by area of bearing face of needle.

11.2 *Time-of-Setting.*–Times of initial and final setting as defined in sections 3.1 and 3.2 shall be calculated by averaging the elapsed times determined from the curves plotted in accordance with section 12.1.2, at which penetration resistances of 500 and 4,000 lbf/in^2 (3.4 and 27.6 MPa) are reached. Time-of-setting shall be reported in hours and minutes to nearest minute.

12. Report

12.1 Figure 1 shows a typical data sheet and reporting form. The report shall include:

12.1.1 *Data on Concrete Mixture*:

- Type and proportions of cement, fine aggregate, and coarse aggregate (including maximum size); and ratio of net water content to cement content.
- Name, nature, and percentage of active ingredients (by mass of cement) of any addition or admixture used.
- Air content of fresh concrete and method of determination (USBR 4138, 4173, or 4231).
- Consistency of concrete as determined by the slump test or other test for consistency (USBR 4143).
- Temperature of mortar after sieving.
- Record of ambient temperature during test period.
- Date of test

12.1.2 *Curves.*–For each variable and condition of concrete as specified in section 6, results from each of three or more rate-of-hardening tests shall be plotted separately showing penetration resistance in pound force per square inch (megapascals) as the ordinate and elapsed time in hours and minutes as the abscissa, where 500 lbf/in^2 (3.4 MPa) and 1 hour are represented by not less than 1/2 inch (13 mm) on the graph paper. Figure 2 shows a typical plotting of curves.

13. Precision and Bias

13.1 The single-operator coefficient of variation for time of initial set has been found to be 7.1 percent. Therefore, the range of results obtained on three separate batches by same operator with same apparatus, using similar materials, on three different days, should not exceed 23 percent of their average.

13.2 The multilaboratory coefficient of variation for time of initial set, when results are based on average of three tests, has been found to be 5.2 percent. Therefore, results of two different laboratories on similar materials should not differ by more than 15 percent of their average.

13.3 The single-operator coefficient of variation for time of final set has been found to be 4.7 percent. Therefore, the range of results obtained on three separate batches by same operator with same apparatus, using similar materials, on three different days, should not exceed 16 percent of their average.

13.4 The multilaboratory coefficient of variation for time of final set, when results are based on average of three tests, has been found to be 4.5 percent. Therefore, results of two different laboratories on similar materials should not differ by more than 13 percent of their average.

NOTE 1.–The values for precision shown in sections 13.1 through 13.4 are the 1S and 2S limits as described in ASTM C 670.

13.5 This procedure has no known bias.

Spec. or Solic. No. DC-7612 4-SI-57-00690	Structure CONCRETE GRAVITY DAM	Tested by T. GAETO D. MOOTER Date 2-15-83
Project BRANTLEY	Item MIX DESIGN Location	Computed by T. GAETO Date 2-15-83
Feature BRANTLEY DAM	Station Offset Depth to	Checked by D. MOOTER Date 2-15-83

TIME-OF-SETTING OF CONCRETE MIXTURES BY PENETRATION RESISTANCE

Mix No. B4-2055
Mortar: From 4 inch MSA concrete
Sand: F.M. =3.00, percentage of total aggregate = 30
Course aggregate: 28 % of No. 4 to 3/8 inch; 22 % of 3/8 inch to 1 1/8 inch; 24 % of 1 1/8 inch to 2 1/4 inch;
and 20 % of 2 1/4 inch to 4 inch.
Cement: No. M-7522, Type II, Amount 199 lbm/yd^3. Supplier: SOUTHWEST PORTLAND, ODESSA, TX
Pozzolan: No. M-7523, Class F, Amount 59 lbm/yd^3. Supplier: WESTERN ASH, APACHE STA., COCHISE, AZ
Water: Amount 147 lbm/yd^3, W/(C+P) =0.57, pozzolan replacement of cement 20 %.
Admixtures: Type AEA, Brand NVX-LAB PREP., Dosage 12 oz/yd^3 (29.57) =355 mL/yd^3
Type D, Brand PDA-25-DUAL PREP, Dosage 4 oz/cwt (2.58) = 10.3 oz/yd^3 (29.57) =305 mL/yd^3
Type ___, Brand ___, Dosage ___ oz/cwt (2.58) = ___ oz/yd^3 (29.57) = ___ mL/yd^3

AEA (air-entraining admixture), Type A (water-reducing), Type B (retarding), Type C (accelerating), Type D (Types A and B), Type E (Types A and C), Type F (Type A, high range), Type G (Types A and B, high range), and calcium chloride (accelerating).

Batch No.	1	2	3
Time of cement-water contact	11:00 a.m.	1:00 p.m.	2:00 p.m.
Mortar temp. after seiving	57 °F	°F	°F
Room temp.	70 °F	°F	°F
Air Content:			
P = pressure meter	4.5 % P, 3.9 % G	4.3 % P, 3.0 % G	4.2 % P, 4.3 % G, minus 1 1/2 inch
G = gravimetric	% P, 3.2 % G	% P, 3.0 % G	% P, 3.0 % G, minus 4 inch
Slump	2 1/4 inch	2 1/4 inch	2 3/8 inch

Batch No. 1						Batch No. 2						Batch No. 3					
Time, p.m.	Elapsed Time		Needle size	Penetration Resistance		Time, p.m.	Elapsed Time		Needle Size	Penetration Resistance		Time, p.m.	Elapsed Time		Needle Size	Penetration Resistance	
	Hr.	Min.	in^2	lbf	lbf/in^2		Hr.	Min.	in^2	lbf	lbf/in^2		Hr.	Min.	in^2	lbf	lbf/in^2
3:50	4	50	1/4	144	576	5:04	4	04	1/4	72	288	6:30	4	30	1/4	130	520
4:50	5	50	1/10	160	1,600	6:00	5	00	1/4	177	708	7:30	5	30	1/10	138	1,380
5:50	6	50	1/20	134	2,680	6:30	5	30	1/10	109	1,090	8:00	6	00	1/20	94	1,880
6:15	7	15	1/40	92	3,680	7:01	6	01	1/20	114	2,280	8:30	6	30	1/20	132	2,640
6:25	7	25	1/40	124	4,960	7:31	6	31	1/40	71	2,840	8:52	6	52	1/40	87	3480
						7:45	6	45	1/40	66	2,640	9:01	7	01	1/40	84	3,360
						8:01	7	01	1/40	91	3,640	9:15	7	15	1/40	110	4,400
						8:12	7	12	1/40	91	3,640	9:16	7	16	1/40	111	4,400
						8:22	7	22	1/40	117	4,680						

Average Time-of-Set (from fig. 2): Initial 4 hours 35 min.; Final 7 hours 11 min.

Figure 1a. – Typical data sheet and reporting form (inch-pound units).

Spec. or Solic. No. DC-7612 4-SI-57-00690	Structure CONCRETE GRAVITY DAM	Tested by T. GAETO D. MOOTER Date 2-15-83
Project BRANTLEY	Item MIX DESIGN Location	Computed by T. GAETO Date 2-15-83
Feature BRANTLEY DAM	Station Offset Depth to	Checked by D. MOOTER Date 2-15-83

TIME-OF-SETTING OF CONCRETE MIXTURES BY PENETRATION RESISTANCE

Mix No. B4-2055

Mortar: From 100 mm MSA concrete

Sand: F.M. =3.00, percentage of total aggregate = 30

Course aggregate: 28 % of 4.75 mm to 9.5 mm; 22 % of 9.5 mm to 28.0 mm; 24 % of 28.0 mm to 57 mm; and 20 % of 57 mm to 100 mm.

Cement: No. M-7522, Type II, Amount 118 kg/m³. Supplier: SOUTHWEST PORTLAND, ODESSA, TX

Pozzolan: No. M-7523, Class F, Amount 35 kg/m³. Supplier: WESTERN ASH, APACHE STA., COCHISE, AZ

Water: Amount 87 kg/m³, W/(C+P) =0.57, pozzolan replacement of cement 20 %.

Admixtures: Type AEA, Brand NVX: LAB PREP., Dosage 12 oz/yd³ (38.67) = 464 mL/m³

Type D, Brand PDA-25: DUAL PREP., Dosage 4 oz/cwt (0.022) =0.088 oz/kg (153) (29.57)
=398 mL/m³

Type ___, Brand ___________, Dosage ___ oz/cwt (0.022) = ___ oz/kg (   ) (29.57)
= ___ mL/m³

AEA (air-entraining admixture), Type A (water-reducing), Type B (retarding), Type C (accelerating), Type D (Types A and B), Type E (Types A and C), Type F (Type A, high range), Type G (Types A and B, high range), and calcium chloride (accelerating).

Batch No.	1	2	3
Time of cement-water contact	11:00 a.m.	1:00 p.m.	2:00 p.m.
Mortar temp. after seiving	13.9 °C	14.4 °C	13.9 °C
Room temp.	21.1 °C	21.1 °C	21.1 °C
Air Content:			
P = pressure meter	4.5 % P, 3.9 % G	4.3 % P, 3.0 % G	4.2 % P, 4.3 % G, minus 37.5 mm
G = gravimetric	% P, 3.2 % G	% P, 3.0 % G	% P, 3.0 % G, minus 100 mm
Slump	57 mm	57 mm	60 mm

	Batch No. 1						Batch No. 2						Batch No. 3				
Time	Elapsed Time		Needle size	Penetration Resistance		Time	Elapsed Time		Needle Size	Penetration Resistance		Time	Elapsed Time		Needle Size	Penetration Resistance	
p.m.	Hr.	Min.	mm²	N	MPa	p.m.	Hr.	Min.	mm²	N	MPa	p.m.	Hr.	Min.	mm²	N	MPa
3:50	4	50	161	640	4.0	5:04	4	04	161	320	2.0	6:30	4	30	161	578	3.6
4:50	5	50	65	712	11.0	6:00	5	00	161	787	4.9	7:30	5	30	65	614	9.5
5:50	6	50	32	596	18.4	6:30	5	30	65	485	7.5	8:00	6	00	32	418	12.9
6:15	7	15	16	409	25.3	7:01	6	01	32	507	15.7	8:30	6	30	32	587	18.2
6:25	7	25	16	552	34.2	7:31	6	31	16	316	19.6	8:52	6	52	16	387	24.0
						7:45	6	45	16	294	18.2	9:01	7	01	16	374	23.1
						8:01	7	01	16	405	25.1	9:15	7	15	16	489	30.3
						8:12	7	12	16	405	25.1	9:16	7	16	16	494	30.3
						8:22	7	22	16	520	32.2						

Average Time-of-Set (from fig. 2): Initial 4 hours 35 min.; Final 7 hours 11 min.

Figure 1b. – Typical data sheet and reporting form (SI-metric).

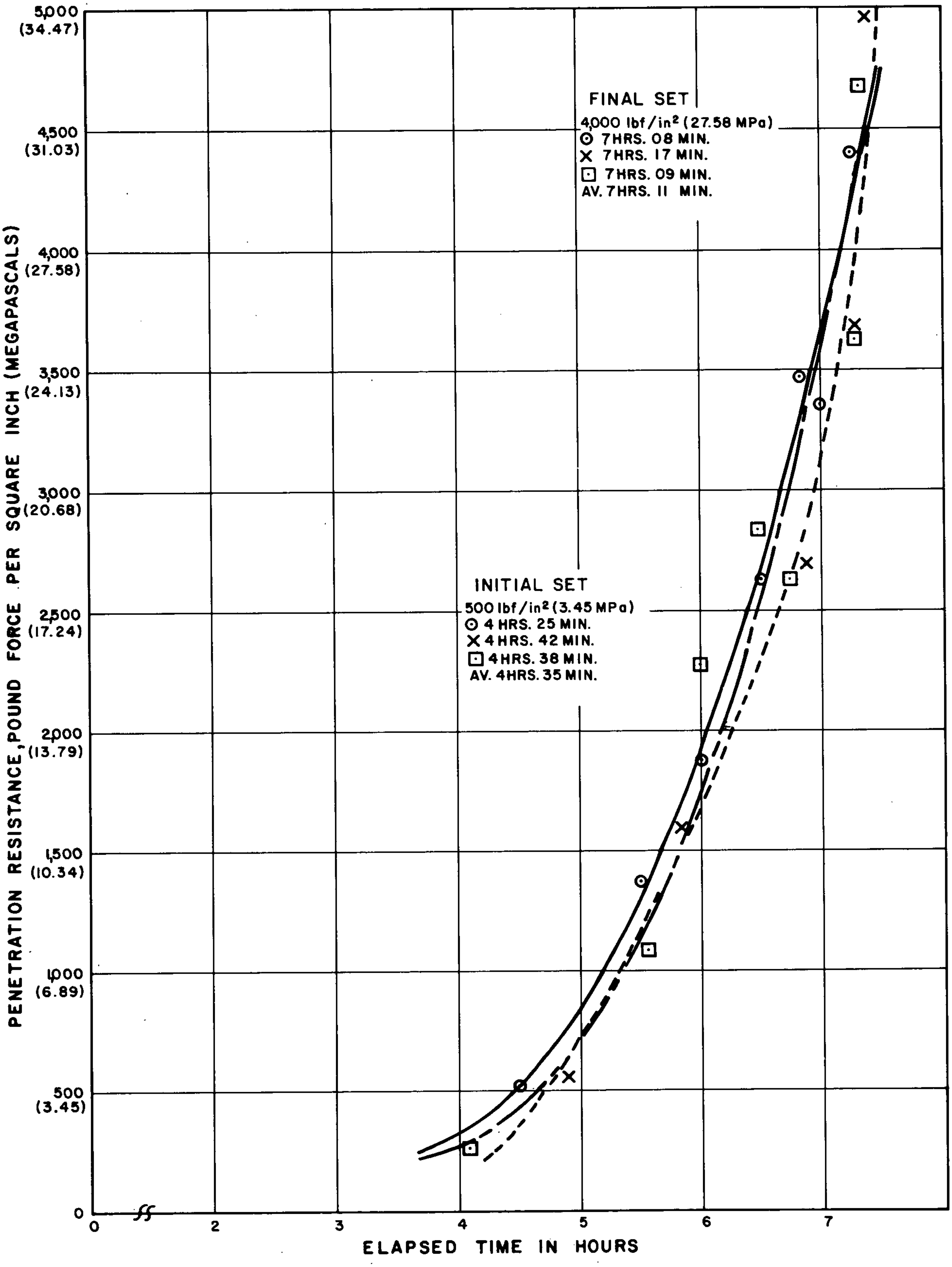

Figure 2. – Results of rate-of-hardening tests.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4426-92

PROCEDURE FOR

DRYING SHRINKAGE OF CONCRETE BLOCK

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4426; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 426-70 (Reapproved 1982).

1. Scope

1.1 This designation covers a routine standardized procedure for determining drying shrinkage of concrete block, brick, or other concrete products under specified accelerated drying conditions. This procedure is similar in principle to the method described in British Standard 1881, "Methods of Testing Concrete."

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1007 Calibrating Dial Indicators
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
2.2 *ASTM Standards*:
C 426 Standard Test Method for Drying Shrinkage of Concrete Block[1]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[2]
2.3 *British Standard*:
1881 Methods of Testing Concrete
2.4 *National Institute of Standards and Technology*[3]:
Circular 512 Methods of Measuring Humidity and Testing Hydrometers[4]
2.5 *American National Standard*:
B5.10 Detailed Requirements for Twist Drills

3. Definitions

3.1 *Drying Shrinkage*.–In this method, drying shrinkage is the change in linear dimension of test specimen due to drying from a saturated condition to an equilibrium weight and length under specified accelerated drying conditions.

4. Apparatus

4.1 *Measuring Instruments*.–The instruments for measuring drying shrinkage shall be so designed as to permit or provide the conditions described in 4.1.1 through 4.1.5.

NOTE 1.–Strain gauges may be obtained with various gauge lengths. The 10-inch (254-mm) gauge length is recommended for use with regular concrete block; however, particular sizes of products may require other gauge lengths. The length of the shrinkage specimen shall not be less than required for a minimum gauge length (distance between gauge plugs) of 6 inches (152 mm). The Whittemore extensometer (fig. 1) has been found satisfactory for use with regular size block.

4.1.1 A means of positive contact with the specimen that will ensure reproducible measurements of length.

4.1.2 A means for precise measurement that consists of a dial micrometer or other measuring device graduated to read in 0.0001-inch (0.0025-mm) units, accurate within 0.0001 inch in any 0.0010-inch (0.0254-mm) range, and within 0.0002 inch (0.0051 mm) in any 0.0100-inch (0.2540-mm) range.

4.1.3 Sufficient range in measuring device to allow for small variations in gauge lengths.

NOTE 2.–If shrinkage reference points are set carefully to position, a dial micrometer with a travel of 0.2 or 0.3 inch (5.1 or 7.6 mm) provides ample range in the instrument.

4.1.4 A means for checking the measuring device at regular intervals against a standard reference.

NOTE 3.–A standard reference bar shall be furnished by the manufacturer of the instrument. A standard bar of ordinary steel is satisfactory, but corrections must be made for variations in its length due to temperature changes. When a more nearly constant datum is desired, Invar steel is preferable because of its low coefficient of thermal expansion. The standard reference bar should be protected from air currents when not in use by placing it inside a closed wooden box.

4.1.5 Convenient and rapid measurement of specimens.

4.2 *Comparator*.–The instrument for measuring volume change of concrete prisms as described in ASTM C 490 may be used for specimens which will not accommodate a 10-inch (254-mm) gauge, and it is desired to measure the specimen end to end, see figure 2.

4.3 *Gauge Plugs*.–Gauge plugs shall be made from metal that is resistant to corrosion. When used with strain

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[1] *Annual Book of ASTM Standards*, vol. 04.05.
[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.
[3] Formerly National Bureau of Standards.
[4] This reference is made for information on measurement of the relative humidity in drying ovens.

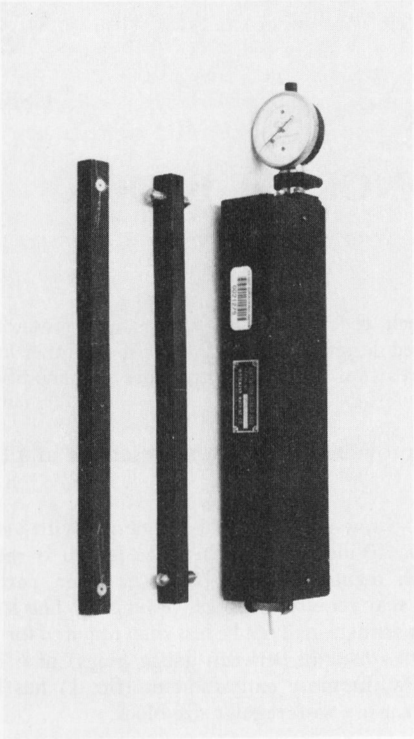


Figure 1. - Whittemore extensometer, suitable for measurement of length changes. From ASTM C 426, vol. 04.05, 1984.

gauges, the plugs shall be 3/8 to 1/2 inch (9.5 to 12.7 mm) in diameter and 1/2±1/8 inch (12.7±3.2 mm) in thickness. Plugs used with the measuring instrument described in ASTM C 490 shall consist of the 1/4-inch (6.4-mm) diameter stainless steel gauge studs shown in C 490.

NOTE 4.-When spherically shaped plugs are used, the contact point of the dial indicator should be recessed concave. The radius of the concave should be greater than the radius of the plug.

4.3.1 As an alternative procedure, gauge plugs used with strain gauges may be attached to surface of specimen with epoxy or polyester resin. The method of application of the plugs to surface of the specimens is described in 8.1.1. These plugs shall be 3/8 to 1/2 inch (9.5 to 12.7 mm) in diameter and 3/8±1/8 inch (9.5±3.2 mm) in thickness.

4.4 *Drying Oven.*-A reasonably airtight, insulated cabinet providing a minimum storage capacity of three whole block test specimens and capable of maintaining a constant temperature of 122±2 °F (50±1.1 °C). A suitable oven construction is shown on figure 3. The oven should also provide the features described in 4.4.1 through 4.4.4.

4.4.1 A minimum of 1-inch (25-mm) clearance on all sides of each test specimen.

4.4.2 A constant, uniform temperature of 122±2 °F (50±1.1 °C) throughout cabinet attained by means of an electrical heat source (note 5) and suitable thermal insulation.

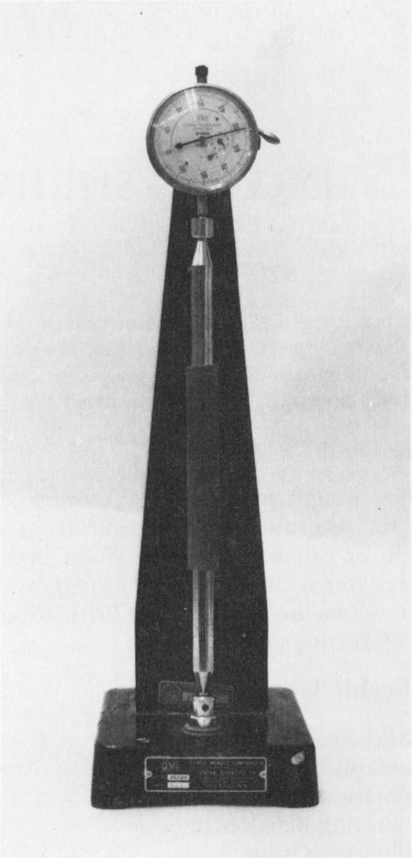


Figure 2. - A suitable apparatus for measurement of length changes. From ASTM C 490, vol. 04.02, 1984.

NOTE 5.-Direct heating of test specimens with combustion products of gas or other carbonaceous fuels is not satisfactory due to presence of carbon dioxide and water, and their possible effect on the drying characteristics of portland cement products.

4.4.3 A means of drying specimens to a condition of equilibrium with a relative humidity of 17±2 percent (note 6). Calcium chloride ($CaCl_2$), if used for this purpose, shall be in flake form.

NOTE 6.-The air immediately above a saturated solution of calcium chloride ($CaCl_2$) at 122 °F (50 °C) is about 17 percent. Suitable dishes or trays shall be provided to give an exposed solution area of not less than 25 in^2/ft^3 (5700 cm^2/m^3) of oven volume. Dishes on trays shall contain sufficient solid calcium chloride so that the crystals will be exposed above the surface of the solution throughout the test. The calcium chloride solution shall be thoroughly stirred every 24 hours, more often if necessary, to prevent formation of lumps and the crusting over of the solution, see reference given in 2.4.

4.4.4 Moderate circulation of air within oven, over and around all test specimens and drying agent.

4.5 *Cooling Chamber.*-An airtight enclosure of sufficient capacity for cooling a minimum of three whole block test specimens.

4.6 *Immersion Tank.*-A suitable container for completely immersing three whole block test specimens in water maintained at 73.4±2 °F (23±1.1 °C).

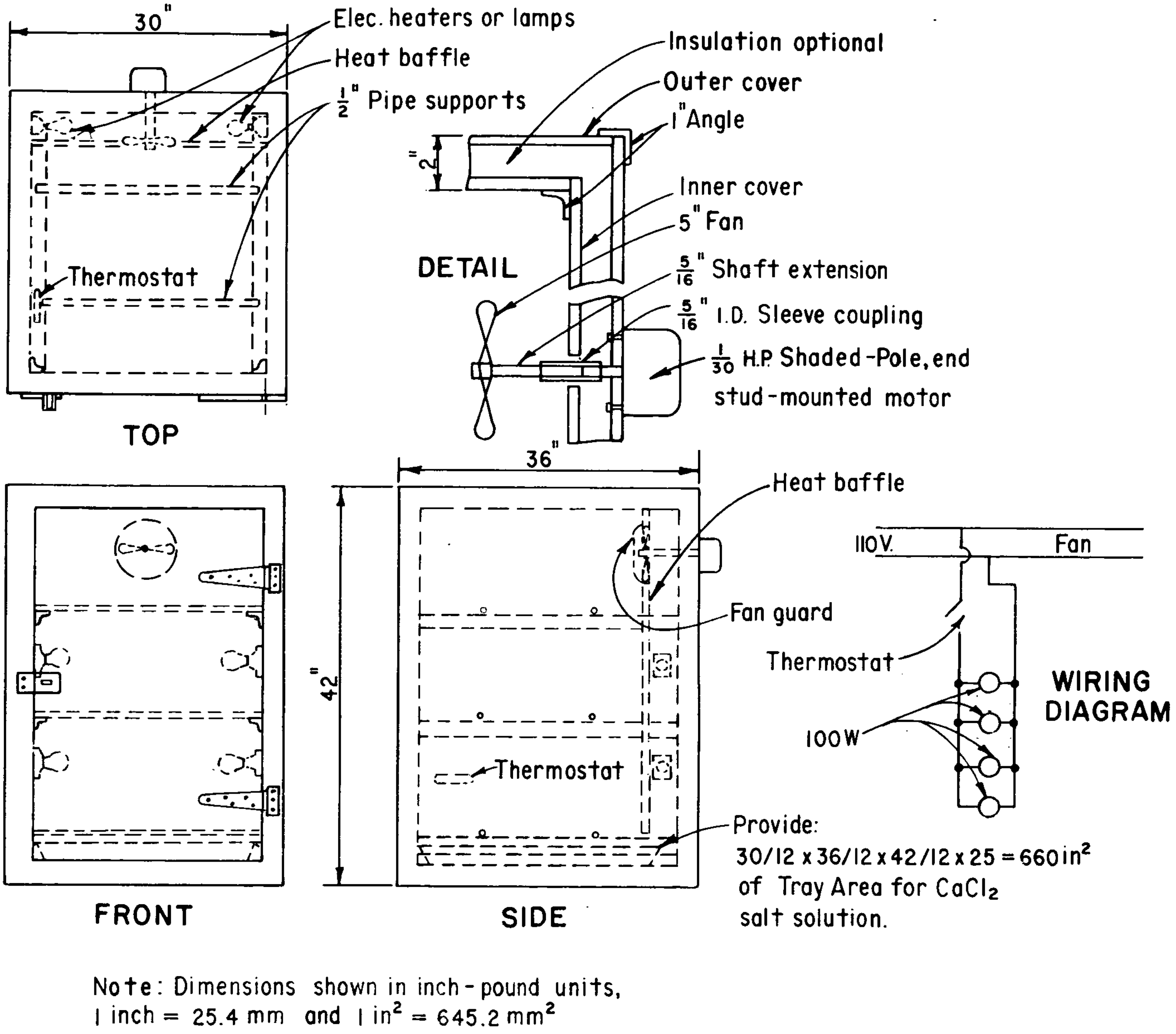


Figure 3. – Drying oven suitable for determining drying shrinkage of concrete block. From ASTM C 426, vol. 04.05, 1984.

4.7 *Balance or Scale.*–The balance shall be sensitive to within 0.1 percent of the mass of smallest specimen tested.

5. Reagents and Materials

5.1 Reagants and materials are covered under section 4.4.3 and note 6.

6. Precautions

6.1 These test procedures may involve hazardous materials, operations, and equipment, and do not claim to address all safety problems associated with their use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 *Reference Bar.*–The standard reference bar should be protected against air currents as specified in note 3.

6.3 *Gauge Plugs.*–The gauge plugs shall be made of metal that is resistant to corrosion, and shall meet the specifications outlined under section 4.3 and note 4. If any cementing agent for attaching plugs to specimens (sec. 4.3.1) is substituted for portland cement, tests should be performed as instructed in note 9.

6.4 *Drying Oven.*–Direct heating of test specimens with the combustion products of gas or other carbonaceous fuels may have an effect on the drying characteristics of portland cement products, as outlined in note 5.

6.5 *Specimens*:

6.5.1 The initial reading of specimen length at saturation must be taken with the gauge line at about water level in compliance with section 11.2.

6.5.2 If some masonry units exude moisture faster in the initial drying period than the calcium chloride solution can absorb, the units may be allowed to drain for 48 hours in room air, as outlined in section 11.4 and note 11.

7. Test Specimens

7.1 The test specimens selected shall be whole units, free of visible cracks or other structural defects, which shall be representative of the lot from which they are selected (note 7). Portions of face shells (see 7.1.1) may be used for testing in lieu of whole units providing they are dry cut lengthwise from both faces of hollow units at least 12 inches (305 mm) in length. Units previously subjected to tests involving temperatures exceeding 150 °F (65.6 °C) shall not be used in drying shrinkage tests.

NOTE 7.–In tests of short units such as concrete brick by this method, use of a 10-inch (254-mm) Whittemore strain gauge is feasible when two units are butted together and joined using an epoxy resin cement to form an extremely thin joint between the units. The abutting ends of the units should be ground to ensure intimate contact and a thin joint; these precautions are necessary to ensure the thinnest joints practicable and thereby avoid abnormal shrinkage indications. Some laboratories have obtained satisfactory results using a 10-inch Whittemore strain gauge on specimens joined with unfilled epoxy cements.

7.1.1 The number of specimens selected should consist of three whole units or six, half-face shells. The half-face shells should be at least 4 inches (102 mm) wide and should be same length as shell. The shells should be removed from diagonally opposite ends of the two opposite face shells as shown on figure 4. Half-face shell specimens must be dry cut from hollow units not less than 12 inches (305 mm) in length.

8. Preparation of Apparatus

8.1 *Inserts for Strain Gauge Measurements on Whole Units and Half-Face Shell Specimens.*–Place a pair of gauge plugs at or near, and parallel to, the centerline in each of two opposite faces of the whole unit specimen. Place a gauge line on both interior and exterior sides of each half-face shell specimen. Drill the gauge plug holes with a drill that is slightly smaller than plug diameter to provide a snug fit (note 8). The depth of the holes shall be such that the exposed surface of inserted gauge plug is about 0.1 inch (2.5 mm) below surface of specimen. The cementing agent shall be portland cement paste or an approved alternate cementing agent (note 9). Prior to setting plug, plug holes shall be moistened when hydraulic cement is used, but shall be dry and dust free when plugs are set in epoxy or polyester resins or other nonhydraulic cementing materials. After cementing material has been placed in hole, insert gauge plug and prick punch plug to proper gauge length with gauge bar provided. Wipe off excess cementing material and allow remainder to cure. After cementing material is sufficiently hard, drill receiving holes for strain gauge points with a No. 56 to No. 60 twist drill, see section 2.5.

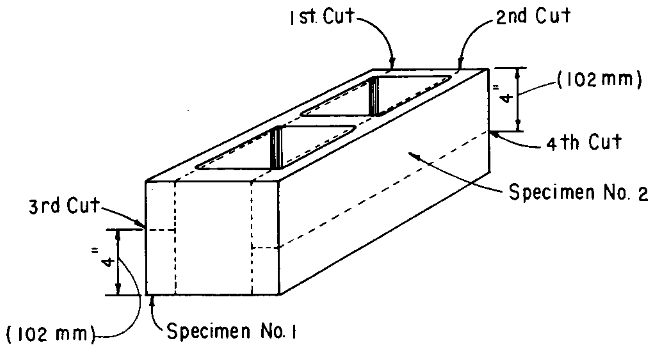


Figure 4. – View of sawed block showing a suggested sequence of cuts and location of two half-face shell specimens. From ASTM C 426, vol. 04.05, 1984.

NOTE 8.–A 5/16-inch (7.9-mm) diameter, carbide-tipped masonry drill has been found satisfactory for gauge plugs 3/8 inch (9.5 mm) in diameter.

NOTE 9.–A number of cementing agents have been reported satisfactory for setting gauge plugs. Materials such as dental cement and some of the polyester and epoxy resins reduce the preparation time of shrinkage test specimens. Tests to determine the effect of water immersion and subsequent drying on the material's adhesion should be made prior to substitution of any cementing agent for portland cement.

8.1.1 When gauge plugs used with strain gauges are attached to surface of concrete with epoxy or polyester resin, drill receiving holes for strain gauge points prior to attachment of gauge plugs. Attach plugs with epoxy or polyester resin (note 9) using strain gauge punch bar or other convenient template to set gauge holes proper distance apart. The surface of metal gauge plugs which will be in contact with resin should be roughened with emery cloth.

8.2 *Inserts for Comparator Measurements.*–Mount on opposite ends of test specimen's spherically shaped gauge plugs, for use with the type of comparator described in ASTM C 490. Drill a shallow recess (note 10) at desired location using a drill size slightly smaller than plug diameter. Fill recess with cementing material and firmly press plug into position, taking care that cement extends slightly above the level of center of sphere. After cementing material is sufficiently hard, clean excess material from exposed portion of gauge plug.

NOTE 10.–Satisfactory results without a drilled recess have been reported with the use of quick-setting cementing materials (note 9).

9. Calibration and Standardization

9.1 *Shrinkage Measurement Devices*:

9.1.1 The Whittemore extensometer (fig. 1) shall comply with USBR 1000, and be calibrated to a standard reference bar (note 3) or gauge block furnished by the manufacturer. The dial gauge shall be calibrated in accordance with USBR 1007.

9.1.2 Dial micrometers (4.1.2) shall also be calibrated in accordance with USBR 1000.

9.1.3 Comparator (4.2) shall meet the specifications as outlined in sections 5.4.1 and 5.4.2 of ASTM C 490, and the measuring device and dial gauge shall be calibrated against a reference bar as outlined under section 5.4.3 of C 490.

9.2 *Gauge Plugs.*-The gauge plugs shall comply with the requirements of section 4.3.

9.3 *Drying Oven.*-The drying oven shall conform to the requirements of sections 4.4 through 4.4.4 and shall be calibrated in accordance with USBR 1020.

9.4 *Balance or Scale.*-The balance or scale shall conform to requirements of section 4.7, and shall be calibrated in accordance with USBR 1012.

9.5 *Thermometer.*-The thermometer for checking the water in the immersion tank shall be accepted on manufacturer's certification.

10. Conditioning

10.1 *Oven.*-The temperature of the oven shall be established as specified under section 4.4.2. The humidity shall be stabilized as specified under section 4.4.3 and note 6.

10.2 *Cooling Chamber.*-The cooling chamber shall be airtight as specified under section 4.5, and be maintained in a temperature-controlled room as specified under section 11.5 and note 12.

10.3 *Immersion Tank.*-The temperature of the water in the immersion tank shall be as specified under section 4.6.

10.4 *Specimens*:

10.4.1 If portions of face shells are used as test specimens, they shall be prepared as specified in sections 7.1 and 7.1.1, note 7, and as shown on figure 4.

10.4.2 Install gauge plugs as directed under sections 8.1, 8.1.1, and 8.2, including notes 8, 9, and 10.

10.5 *Laboratory Atmosphere.*-The temperature variation in the laboratory from the standard temperature of 73.4 °F (23 °C) at the time readings are made shall not exceed ±5 °F (±2.8 °C) in accordance with note 14.

11. Procedure

11.1 Immerse specimens for drying shrinkage determination in water at 73.4±2 °F (23±1.1 °C) for 48 hours.

11.2 Obtain initial length reading on test specimen. Take initial reading of specimen length, at saturation, with unit positioned in water tank so that its gauge line is about at the level of the water surface to avoid error due to cooling evaporation. Accompany length readings of test specimens by length readings of standard reference bar, see 12.2 and 12.3 for methods of adjusting and correcting length readings.

11.3 Obtain saturated surface-dry mass of test specimen. A saturated surface-dry condition shall be obtained by draining test specimen for 1 minute over a 3/8-inch (9.5-mm), or larger, mesh and removing visible surface water by blotting with a damp cloth.

11.4 Store test specimens for drying in the oven as described in 4.4. In exceptional circumstances, it is permissible to surface dry specimens in room air before storing in oven (note 11). To ensure uniformity of drying, individual specimens should be rotated to different positions in drying oven each time readings are taken.

NOTE 11.-Reports have indicated that moisture is exuded faster by some masonry units during the early part of the drying period than can be absorbed by the calcium chloride solution, causing condensation to form on interior surfaces of oven. Where this situation is encountered, it shall be permissible to allow units to lose excess water for periods up to 48 hours in room air before transfer to drying oven, provided effect of such deviation permitted under 11.4 has been determined to be negligible.

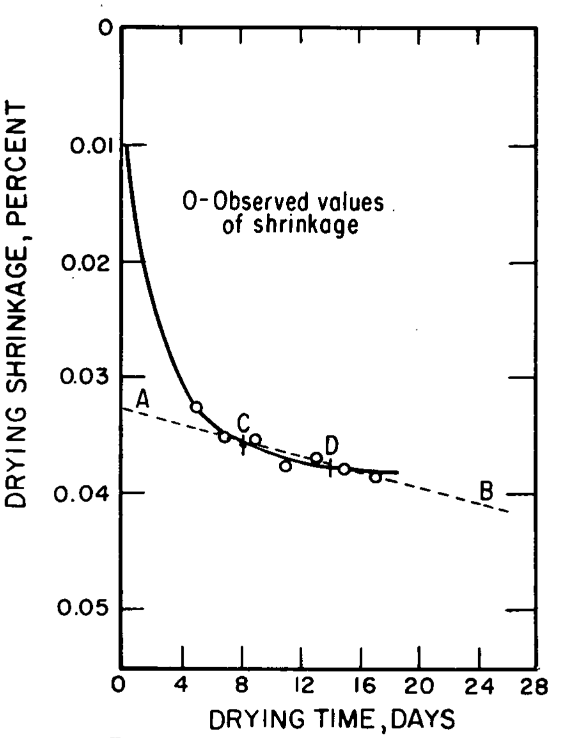
11.5 After 5 days of drying, including any period of preliminary drying in room air up to 48 hours, remove shrinkage specimens from drying oven and cool to 73.4±2 °F (23±1.1 °C), see note 12. Following cooling, obtain specimen length reading, mass determination, and length reading of standard reference bar.

NOTE 12.-Use a cooling chamber consisting of a steel, drum-type container equipped with a ring-sealed, rubber-gasketed-type cover. The drum cover should be equipped with a thermometer, the bulb of which is in the proximity of the uppermost test specimen. The drum must be stored in a temperature-controlled room to ensure that its final equilibrium temperature will be 73.4 °F (23 °C). Length measurements made at temperatures other than 73.4 °F shall be corrected as shown in 12.3.

11.6 Return test specimens to drying oven for a second period of drying. The duration of the second, and subsequent, drying periods shall be 48 hours. Following the second period of drying, repeat cooling, length readings, and mass determination as specified in 11.5.

11.7 Continue 48-hour drying periods in specified oven, followed by length and mass determinations after cooling under specified conditions (note 12) until the equilibrium condition of specimens has been reached. Equilibrium is considered to be the prevailing condition when the average length change from 6 previous days of drying is 0.002 percent, or less, and when the average mass loss in 48 hours of drying is 0.2 percent, or less, as compared to the last previously determined mass.

NOTE 13.-When uniform attainment of equilibrium length is not apparent in the tabular data, the value of equilibrium shrinkage may be obtained from shrinkage-time curves drawn through experimental points as illustrated on figure 5. The dotted line (AB) on this figure has a slope corresponding to the limiting value of rate of shrinkage (0.002 percent in 6 days), and can be fitted to the experimental curve in such a manner that the points of intersection (C and D) is 0.002 percent. The value of equilibrium shrinkage shall be taken as the shrinkage corresponding to point D expressed to nearest 0.001 percent. Data for which the rate of shrinkage is obviously within the prescribed limit need not be plotted, but the principle of selecting point D should be followed. That is, final percent shrinkage is the greater of two values agreeing within 0.002 percentage points over a period of 6 days.



Note: The interval CD is 6 days on the time scale and 0.002 percent on the shrinkage scale. Point D defines equilibrium shrinkage value.

Figure 5. - Graphical method of determining equilibrium shrinkage. From ASTM C 426, vol. 04.05, 1984.

12. Calculations

12.1 Calculate drying shrinkage as a percentage of gauge length:

$$SL = \frac{\Delta L}{G} (100) \qquad (1)$$

where:

SL = linear drying shrinkage, percent;
ΔL = change in linear dimension of specimen due to drying from saturated condition to equilibrium mass and lengths as specified in 11.7; and
G = test specimen gauge length.

12.2 *Adjustment for Variation in Reference Bar Readings.*-Adjust the reported change in linear dimension of test specimen for variations in reference bar gauge readings that are due to causes other than temperature changes:

$$\Delta L_1 = (L_1 - R_1) - (L_2 - R_2) \qquad (2)$$

where:

ΔL_1 = change in linear dimension of specimen due to variations in reference bar readings not caused by temperature changes,
L_1 = initial length of test specimen at R_1 reading,
L_2 = final length of test specimen at R_2 reading,
R_1 = inital length reading of reference bar, and
R_2 = final length of reference bar.

12.3 *Method of Correcting Length Readings to Standard Temperature.*-Correct length readings taken at temperatures other than 73.4 °F (23 °C):

$$L = L_x - (T_x - 73.4)\, G_x\, Q \qquad (3)$$

where:

L = length of specimen or reference bar at 73.4 °F,
L_x = length of specimen or reference bar at temperature T_x (note 14),
G_x = gauge length of specimen or reference bar at temperature T_x, and
Q = thermal coefficient of expansion of material (note 15).

NOTE 14.-The variation of the temperature in the laboratory from the standard temperature of 73.4 °F (23 °C) at the time readings are made on the test specimens shall not exceed ±5 °F (2.8 °C).

NOTE 15.-The coefficient Q for mild steel is $(6.5\mu\text{in/in})/^\circ\text{F}$ or $(11.7\mu\text{m/m})/^\circ\text{C}$. The coefficient Q for concrete, if unknown, may be assumed to be $(4.5\mu\text{in/in})/^\circ\text{F}$ or $(8.1\mu\text{m/m})/^\circ\text{C}$.

12.4 A sample calculation form covering sections 12.1, 12.2, and 12.3 is shown on figure 6.

13. Report

13.1 A typical report form is shown on figure 7. The report shall include:

- Identification of kind of product and number of specimens for each condition of test.
- Source of specimens.
- Kind of aggregate, type of portland cement, and method of producing product.
- Condition of curing and drying prior to test.
- Age of specimens at start of shrinkage test.
- Total length of drying period prior to each length measurement.
- Mass of test specimens as received, saturated, and at time of each length measurement, including equilibrium.
- Total linear drying shrinkage percent from saturation to each length measurement, including the length measured at equilibrium.
- Any other pertinent information.

14. Precision and Bias

14.1 The precision and bias for this test procedure have not been established.

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN Date 3-3-67 3-18-67
Project FRY-ARK	Item 8-by8-by16-inch Grade N, Type I Masonry Units Location DENVER LAB	Computed by E. DUNSTAN Date 3-3-67 3-18-67
Feature OFFICE BUILDING—SALIDA, CO	Station ~ Offset ~ Depth ~ to ~	Checked by D. PARADY Date 3-3-67 3-18-67

Gauge 16

DRYING SHRINKAGE OF CONCRETE BLOCK

1 Time Frame	2 Immersion Time, hours	3 Drying Time, hours		4 T_x Temp., °F	5 G Gauge Length, inches	Specimen Length, inches 6	7	8	9 Temp. Corr. Ref. Bar, Eq. (3), inches	10 Temp. Corr. Specimen, Eq. (3), inches	11 ΔL_1 Ref. Dial Variation, Eq. (2), inch	12 Corr. Specimen Length, inches	13 Mass, lbm	14 Shrinkage Equilibrium		15 SL Drying Shrinkage Eq. (1), %
		Air	Oven			Side No. 1	Side No. 2	L_x (6+7)/2 Average						Length Loss, %	Mass Loss, %	
Spec. No.1*	(As Received)												36.50			
SSD-A	48			73.4	10.0000	10.2140	10.2060	10.2100				10.2100	38.21			
OD-B		48	72	73.4	10.0000	10.2110	10.2036	10.2073				10.2073	36.28	0.0264	5.1	0.028
OD-C			120	75.4	10.0001	10.2107	10.2034	10.2071	10.0000	10.2070	+0.0003	10.2073	36.29	NONE	GAIN	0.028
OD-D			168	73.4	10.0000	10.2107	10.2034	10.2071				10.2071	36.27	0.0020	0.06	0.028
OD-E			216	71.4	9.9999	10.2106	10.2033	10.2070	10.0000	10.2071	-0.0000	10.2071	36.27	NONE	NONE	0.029
OD-F			264	73.4	10.0000	10.2107	10.2032	10.2070				10.2070	36.27	0.0010		0.029
OD-G																
Spec. No.2*	(As Received)												36.40			
SSD-A	48			73.4	10.0000	10.1895	10.1980	10.1938				10.1938	38.19			
OD-B		48	72	73.4	10.0000	10.1870	10.1953	10.1912				10.1912	36.34	0.02551	4.8	0.026
OD-C			120	73.4	10.0000	10.1870	10.1951	10.1911				10.1911	36.31	0.00098	0.08	0.026
OD-D			168	73.4	10.0000	10.1868	10.1949	10.1909				10.1909	36.31	0.00196	NONE	0.028
OD-E			216	73.4	10.0000	10.1868	10.1947	10.1908				10.1908	36.28	0.00098	0.08	0.029
OD-F																
OD-G																
Spec. No.3*	(As Received)												36.70			
SSD-A	48			73.4	10.0000	10.1789	10.1780	10.1785				10.1785	38.44			
OD-B		48	72	73.4	10.0000	10.1760	10.1754	10.1757				10.1757	36.57	0.02751	4.9	0.028
OD-C			120	73.4	10.0000	10.1759	10.1753	10.1756				10.1756	36.56	0.00098	0.03	0.028
OD-D			168	73.4	9.9999	10.1757	10.1750	10.1754			+0.0001	10.1755	36.56	0.00098	NONE	0.029
OD-E			216	73.4	10.0000	10.1756	10.1750	10.1753				10.1753	36.56	0.00197		0.031
OD-F			264	73.4	10.0000	10.1756	10.1750	10.1753				10.1753	36.56	∞		0.031
OD-G															AVG.	0.030

* As Received.

Figure 6a. – Typical data and calculation form (inch-pound units).

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN 3-3-67 Date 3-18-67
Project FRY-ARK	Item 203-by 203-by 406-mm Grade N, Type I, Masonry Units Location DENVER LAB	Computed by E. DUNSTAN 3-3-67 Date 3-18-67
Feature OFFICE BUILDING-SALIDA, CO	Station ~ Offset ~ Depth ~ to ~	Checked by D. PARADY 3-3-67 Date 3-18-67

Gauge 17

DRYING SHRINKAGE OF CONCRETE BLOCK

1 Time Frame	2 Immersion Time, hours	3 Drying Time, hours		4 T_x Temp., °C	5 G Gauge Length, mm	Specimen Length, mm			9 Temp. Corr. Ref. Bar, Eq. (3), mm	10 Temp. Corr. Specimen, Eq. (3), mm	11 ΔL_1 Ref. Dial Variation, Eq. (2), mm	12 Corr. Specimen Length, mm	13 Mass, kg	14 Shrinkage Equilibrium		15 SL Drying Shrinkage Eq. (1), %
		Air	Oven			6 Side No. 1	7 Side No. 2	8 L_x (6+7)/2 Average						Length Loss, %	Mass Loss, %	
Spec. No.1*	(As RECEIVED)												16.56			
SSD-A	48			23.0	254.000	259.436	259.232	259.334				259.334	17.33			
OD-B		48	72	23.0	254.000	259.359	259.171	259.265				259.265	16.46	0.0266	5.0	0.027
OD-C			120	24.1	254.003	259.352	259.166	259.259	254.001	259.258	+0.009	259.267	16.46	GAIN	NONE	0.026
OD-D			168	23.0	254.000	259.352	259.166	259.259				259.259	16.45	0.0027	0.06	0.029
OD-E			216	21.9	253.997	259.349	259.164	259.257	253.999	259.258	-0.001	259.257	16.45	0.0031	NONE	0.030
OD-F			264	23.0	254.000	259.352	259.161	259.257				259.257	16.45	NONE		0.030
OD-G																
Spec. No.2*	(As RECEIVED)												16.51			
SSD-A	48			23.0	254.000	258.813	259.029	258.921				258.921	17.32			
OD-B		48	72	23.0	254.000	258.750	258.961	258.856				258.856	16.48	0.0251	4.8	0.025
OD-C			120	23.0	254.000	258.750	258.956	258.853				258.853	16.47	0.0012	0.06	0.026
OD-D			168	23.0	254.000	258.745	258.950	258.848				258.848	16.47	0.0019	NONE	0.028
OD-E			216	23.0	254.000	258.745	258.945	258.845				258.848	16.46	NONE	0.06	0.028
OD-F																
OD-G																
Spec. No.3*	(As RECEIVED)												16.65			
SSD-A	48			23.0	254.000	258.544	258.521	258.533				258.533	17.44			
OD-B		48	72	23.0	254.000	258.470	258.455	258.463				258.463	16.59	0.0271	4.9	0.027
OD-C			120	23.0	254.000	258.468	258.453	258.461				258.461	16.58	0.0008	0.06	0.028
OD-D			168	23.0	253.997	258.463	258.445	258.454			+0.004	258.458	16.58	0.0012	NONE	0.029
OD-E			216	23.0	254.000	258.460	258.445	258.453				258.453	16.58	0.0019		0.031
OD-F			264	23.0	254.000	258.460	258.445	258.453				258.453	16.58	NONE		0.031
OD-G															AVG.	0.030

* As Received.

Figure 6b. – Typical data and calculation form (SI-metric).

Spec. or Solic. No.	Structure WAREHOUSE	Tested by E. DUNSTAN 3-3-67 3-18-67 Date
Project FRY-ARK	Item MASONRY UNITS Location DENVER LAB	Computed by E. DUNSTAN 3-3-67 3-18-67 Date
Feature OFFICE BUILDING-SALIDA, CO	Station ~ Offset ~ Depth ~ to ~	Checked by D. PARADY 3-3-67 3-18-67 Date

DRYING SHRINKAGE OF CONCRETE BLOCK

Block Produced By: VALLEY BLOCK CO., DENVER, CO Date Produced: 1-2-67

Aggregate: Type NORMAL DENSITY, MSA NO. 4 ~~inches (mm)~~, Source CLEAR CREEK-DENVER, CO

Cement: Type I, Brand IDEAL, Supplier PORTLAND, CO

Pozzolan: Class NA, Source NA, Supplier NA, Cementitious NA %

Other Additives: NA

Method of Curing and Drying Prior to Test: STEAM (24 HOURS) - AIR CURE (REST)

Nominal Size: 8- BY 8- BY 16- inches ~~(mm)~~, Grade: N, Type: I HOLLOW-LOAD BEARING

Specimen No.	Age of Specimen, days	Time Immersed, hours	Drying Time, hours		*D* As Rec'd. Mass, lbm ~~(kg)~~	*B* SSD Mass, lbm ~~(kg)~~	A_x Drying Cycle Mass, lbm ~~(kg)~~	Absorption $\frac{B-A}{A}(100)$, percent	*MC** $\frac{D-A}{B-A}(100)$, percent	Drying Shrinkage, percent
			Air	Oven						
1	60				36.50					
		48				38.21				
			48	72			36.28			0.027
				120			36.29			0.027
				168			36.27			0.030
				216			36.27			0.030
				264			36.27	5.3	11.9	0.030
2	60				36.40					
		48				38.19				
			48	72			36.34			0.026
				120			36.31			0.028
				168			36.31			0.030
				216			36.28	5.3	6.3	0.030
3	60				36.70					
		48				38.44				
			48	72			36.57			0.027
				120			36.56			0.028
				168			36.56			0.029
				216			36.56			0.031
				264			36.56	5.1	7.4	0.031
					AVERAGES OF END RESULTS			5.2	8.5	0.030

* *MC* = Moisture content as defined in USBR 4140.

Figure 7. – Typical reporting form for concrete masonry units.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4430-92

PROCEDURE FOR

FINENESS OF HYDRAULIC CEMENT BY NO. 325 (45-μm) SIEVE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4430; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 430-83.

1. Scope

1.1 This designation covers the procedure for determination of fineness of hydraulic cement by means of the No. 325 (45-μm) sieve.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1040 Calibrating Pressure Gauges
4183 Sampling and Acceptance of Hydraulic Cement
2.2 *ASTM Standards*:
C 430 Standard Test Method For Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]
E 177 Standard Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[3]

3. Apparatus

3.1 *Sieve*.–The sieve frame shall be of metal not subject to corrosion by water and shall be circular, 2.0 ± 0.25 inches (50.80 ± 6.35 mm), in diameter. The depth of the sieve from top of frame to cloth shall be 3.0 ± 0.25 inches (76.20 ± 6.35 mm). The frame shall have either (1) side walls 3.5 ± 0.25 inches (88.90 ± 6.35 mm) in total height, or (2) legs of sufficient length, 0.5 inch (13 mm) minimum, to allow air circulation beneath sieve cloth. The sieve frame shall be fitted with a No. 325 (45-μm) stainless steel, AISI type 304, woven-wire sieve cloth, conforming to requirements of ASTM E 11. The cloth shall be mounted in frame without distortion, looseness, or wrinkling. For a sieve fabricated by soldering cloth to frame, the joint shall be made smooth to prevent cement from catching in joints between cloth and frame. Two-piece sieves shall clamp tightly on cloth to prevent cement from catching in joints between cloth and frame.

3.2 *Spray Nozzle*.–The spray nozzle (fig. 1) shall be constructed of metal not subject to corrosion by water, and shall have an inside diameter of 0.6875 inch (17.46 mm) with a central hole drilled in line with longitudinal axis, an intermediate row of eight holes drilled 0.2344 inch (5.95 mm) center-to-center at an angle of 5° from longitudinal axis, and an outer row of eight holes drilled 0.4375 inch (11.11 mm) center-to-center at an angle of 10° from longitudinal axis. All holes shall be 0.02 inch (0.51 mm) in diameter.

3.3 *Pressure Gauge*.–The pressure gauge shall be 3 inches (76 mm) minimum diameter, shall be graduated in 1-lbf/in^2 (6.9-kPa) increments, and shall have a maximum capacity of 30 lbf/in^2 (207 kPa). The accuracy at 10 lbf/in^2 (69 kPa) shall be ±0.25 lbf/in^2 (±1.72 kPa).

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Calibration of Sieve

5.1 Place 1.000 gram of current lot of National Institute of Standards and Technology[4] standard sample No. 114 on a clean, dry, No. 325 (45-μm) sieve and proceed as described in section 7. The sieve correction factor is the difference between test residue obtained and assigned residue value indicated by electroformed sheet sieve fineness specified for standard sample, expressed as a percentage of test residue.

NOTE 1.–Please note that sieve correction factor, as specified, is a factor to be multiplied by residue obtained, and amount to be added to or subtracted from residue in any given test is therefore proportional to amount of residue. After 100 determinations, sieve should be recalibrated.

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[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 14.02.

[4] Formerly National Bureau of Standards.

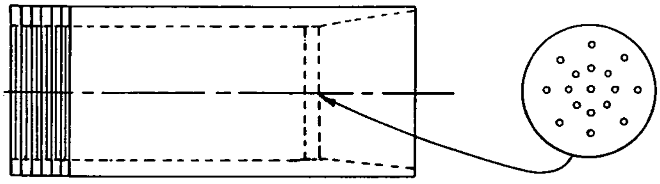

Figure 1. - Spray nozzle: 17 holes of 0.02-inch (0.51-mm) diameter. Using outside threads rather than inside threads (as shown) is permissible.

5.1.1 *Example of Determination of Sieve Correction Factor*:

Residue on No. 325 (45-μm) sieve, sample No. 114	=	12.2%
Residue for a 1-gram sample	=	0.122 g
Residue on sieve being calibrated	=	0.093 g
Difference	=	+0.029 g

$$\text{Correction factor} = \frac{+0.029}{0.093}(100) = +31.18 = +31.2\%$$

5.1.2 A typical calculation and calibration form is shown on figure 2.

5.2 The spray nozzle shall be checked to comply with section 3.2 by using linear measurement devices in accordance with USBR 1000.

5.3 The pressure gauge shall be calibrated to comply with section 3.3 in accordance with USBR 1040.

6. Conditioning

6.1 Conditioning of samples is covered in section 7.

7. Procedure

7.1 Place a 1.000-gram sample of cement on a clean, dry, No. 325 (45-μm) sieve. Wet sample thoroughly with a gentle stream of water. Remove sieve from under the nozzle and adjust pressure on spray nozzle to 10±0.5 lbf/in^2 (69±3.4 kPa). Return sieve to its position under nozzle and wash for 1 minute, moving sieve with a circular motion in a horizontal plane at the rate of one motion per second. Bottom of spray nozzle should extend below top of sieve frame about 0.5 inch (13 mm). Immediately upon removing sieve from spray, rinse once with about 3 in^3 (50 cm^3) of distilled or deionized water, being careful not to lose any residue, and then blot lower surface gently upon a damp cloth. Dry sieve and residue in an oven or over a hot plate (note 2), supporting sieve in such a manner that air may pass freely beneath it. Cool sieve; then brush residue from sieve and determine mass on an analytical balance capable of reproducing results within 0.0005 gram (note 3).

NOTE 2.-Care should be taken not to heat sieve to the point of softening the solder.

NOTE 3.-After five determinations, sieve should be dipped in dilute acetic acid (1+6) or dilute hydrochloric acid (1+10) and immediately rinsed with distilled or deionized water to remove particles lodged in meshes.

8. Calculation

8.1 Calculate fineness of cement to nearest 0.01 percent as follows:

$$R_c = R_s(100 + C) \quad (1)$$

$$F = 100 - R_c \quad (2)$$

where:

F = fineness of cement expressed as corrected percentage passing No. 325 (45-μm) sieve,
R_c = corrected residue in percent,
R_s = residue from sample retained on No. 325 (45-μm) sieve in grams, and
C = sieve correction factor in percent (determined as prescribed in section 5); may be either plus or minus.

8.1.1 *Example*:

Sieve correction factor, C	= + 31.2%
Residue from sample being tested, R_s	= 0.088 g
Corrected residue, R_c	= 0.088 (100 + 31.2) = 11.55%
Corrected amount passing, F	= 100 - 11.55 = 88.45%

8.1.2 A typical calculation form is shown on figure 3.

9. Report

9.1 A suggested reporting form is shown on figure 5 of USBR 4183.

10. Precision and Bias

10.1 *Normal Fineness Product*.-The multilaboratory precision has been found to be ±0.75 percent (IS) as defined in ASTM E 177; therefore, results of properly conducted tests from two different laboratories on identical samples of cement should agree 95 percent of time within ±2.1 percent.

10.2 *High Fineness Product*.-The multilaboratory precision has been found to be ±0.50 percent (IS) as defined in ASTM E 177; therefore, results of properly conducted tests from two different laboratories on identical samples of cement should agree 95 percent of time within ±1.4 percent.

10.3 There is no known bias.

Spec. or Solic. No. NA	Structure NA	Calibrated by K. MITCHELL Date 2-4-87
Project NA	Item CEMENT STD. SAMPLE 114-M Location DENVER LAB	Computed by K. MITCHELL Date 2-4-87
Feature NA	Station NA Offset NA Depth NA to NA	Checked by N. JOHNSON Date 2-4-87

CALIBRATION OF No. 325 (45-μm) SIEVE

Standard Sample No.	Standard Sample Assigned Residue, percent	Sieve ID No.	Mass of Sample, grams	Measured Residue, grams	Assigned Residue, grams	Difference, grams	Correction Factor,[1] percent
114M	6.9	10	1.000	0.044	0.069	+0.025	+56.8
do	do	11	1.000	0.054	0.069	+0.015	+27.8

NOTES:

[1] Correction factor $= \frac{\text{difference}}{\text{measured residue}} = \frac{0.025}{0.044} (100) = 56.8\ \%$

Figure 2. – Sample calculation and calibration form.

Spec. or Solic. No. NA	Structure NA	Tested by K. MITCHELL Date 6-6-82
Project NA	Item CEMENT REF. LAB SAMPLES Location ~	Computed by K. MITCHELL Date 6-6-82
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by N. JOHNSON Date 6-6-82

FINENESS OF HYDRAULIC CEMENT BY No. 325 (45-µm) SIEVE

Sample No.	Sieve ID No.	Brand Name	Plant ID	Type or Class	Mass of Sample, grams	Measured Residue, grams	Sieve Correction Factor, percent	Corrected Residue,[1] percent	Percent Passing
CCRL-83	7	NI	NI	NI	1.000	0.0402	+27.8	5.14	94.86
CCRL-84	11	NI	NI	NI	1.000	0.0241	+27.8	3.08	96.92

NOTES:

[1] Corrected residue = measured residue times 100 plus sieve correction factor
= 0.0402 (100 + 27.8) = 5.14 %

NI = Not Identified

Figure 3. – Sample data and calculation form.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4441-92

PROCEDURE FOR

EFFECTIVENESS OF MINERAL ADMIXTURES IN PREVENTING EXCESSIVE EXPANSION OF CONCRETE DUE TO ALKALI-AGGREGATE REACTION

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. This procedure is issued under the fixed designation USBR 4441; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 441-81.

1. Scope

1.1 This designation covers the procedure for determination of effectiveness of mineral admixtures in preventing excessive expansion caused by the reaction between aggregates and alkalies in portland cement mixtures. The evaluation is based on the expansion developed by cement-admixture combinations in mortar bars, made with reactive aggregates (Pyrex glass), during storage under prescribed conditions of test. The procedure may be used:

(1) as a preliminary or screening test to evaluate relative effectiveness of a number of different admixtures being considered for use to prevent excessive expansion due to alkali-aggregate reaction, and

(2) to evaluate admixtures proposed for use on a particular job to prevent excessive expansion due to alkali-aggregate reaction by testing in the quantity and in combination with the cement or cements to be used on the job.

2. Applicable Documents

2.1 *USBR Procedures*:

4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens

4227 Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]

C 150 Standard Specification for Portland Cement[2]

C 441 Standard Test Method for Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete Due to the Alkali-Aggregate Reaction[3]

C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[2]

C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[3]

3. Summary of Procedure

3.1 This procedure provides for two methods of evaluation as follows:

3.1.1 The expansion of mortar bars containing a high-alkali cement, a mineral admixture, and Pyrex glass[4] aggregate is compared to the expansion of companion bars without the mineral admixture.

3.1.2 Mortar bars containing Pyrex glass aggregate, cement, and mineral admixture, proposed for use on a specific project, are measured to determine if expansion exceeds specifications limits.

4. Significance and Use

4.1 Many mineral admixtures are effective in reducing the expansion that occurs when reactive aggregates react with alkalies in cement. A measure of the effectiveness of the mineral admixture in reducing this expansion is obtained in this procedure, and can be used as a screening test for admixtures that are to be used in concretes containing reactive aggregates.

4.2 This procedure can also be used to measure the amount of expansion that occurs when a mineral admixture is used in combination with a cement proposed for use

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[1] *Annual Book of ASTM Standards*, vol. 04.02, 04.03.

[2] *Annual Book of ASTM Standards*, vol. 04.01, 04.02.

[3] *Annual Book of ASTM Standards*, vol. 04.02.

[4] Pyrex brand glass No. 7740 is available as quenched lump cullet from the Corning Glass Works, Corning, NY. Glass rods are available from laboratory supply houses; use of 10-mm-diameter rods is preferred.

on a specific job. A maximum expansion of 0.020 percent at 14 days is usually specified when a job mixture is used in accordance with section 9.2.3.

4.3 Although the reduction in expansive reaction is evaluated at 14 days, readings are usually continued for at least 1 year. Some pozzolans have been found effective in reducing early-age expansions, but excessive expansions have occurred at later ages. Petrographic analysis and other tests on pozzolanic materials should be used as additional safeguards against undesirable expansions.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 490.

6. Apparatus

6.1 The apparatus shall be as described in USBR 4227.

7. Materials

7.1 *Pyrex Glass.*–Crushed Pyrex glass No. 7740 (quenched, lump cullet or solid glass rod) crushed and graded according to table 1 shall be used. After Pyrex glass has been separated into various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from aggregate. The portions retained on various sieves shall then be dried and, unless used immediately, each such portion shall be stored individually in a clean container provided with a tight-fitting cover.

Table 1. - Grading requirements.

Sieve Size		Mass,
Passing	Retained on	percent
No. 4 (4.75 mm)	No. 8 (2.36 mm)	10
No. 8 (2.36 mm)	No. 16 (1.18 mm)	25
No. 16 (1.18 mm)	No. 30 (600 μm)	25
No. 30 (600 μm)	No. 50 (300 μm)	25
No. 50 (300 μm)	No. 100 (150 μm)	15

7.2 *Cement.*–A high-alkali cement, conforming to ASTM C 150 and containing about 1.0 percent total alkalies as Na_2O (sodium oxide) [percent Na_2O plus 0.658 percent K_2O (potassium oxide)] shall be used in preparation of mortar bars for the percent reduction in expansion test. The cement to be used on job shall be used in combination with admixture in the proportions to be used on job, and in preparation of mortar bars for job mix evaluation.

7.3 *Mineral Admixtures.*–Admixtures conforming to ASTM C 618 shall be used in preparation of mortar bars for the present reduction in expansion test.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Sampling, Test Specimens, and Test Units

9.1 Obtain samples of mineral admixture in accordance with applicable provisions of USBR 4311.

9.2 *Proportioning and Consistency of Mortar*:

9.2.1 *Control Mixture.*–The quantities of dry materials for control mixture shall be 400 grams of high-alkali cement (note 1) and 900 grams of Pyrex glass aggregate, made by recombining portions retained on various sieves in the grading prescribed in section 7.1.

NOTE 1.–If a high-alkali cement containing about 1.0 percent total alkalies as Na_2O is not available, any cement meeting requirements of ASTM C 150 may be used provided average expansion of mortar bars made from control mixture is 0.10 percent or more at 14 days.

9.2.2 *Test Mixture.*–The quantities of dry materials for test mixture shall be 300 grams of high-alkali cement, a mass of admixture having an absolute volume equal to absolute volume of 100 grams of portland cement (100 times specific gravity of admixture divided by 3.15) and 900 grams of Pyrex glass aggregate, made by recombining portions retained on various sieves in the grading prescribed in 7.1.

NOTE 2.–A smaller quantity of admixture and a proportionately larger quantity of cement may be used if there is evidence that it is unusually effective in reducing expansion due to alkali-aggregate reaction, and that use of a smaller quantity is likely to produce a large reduction of expansion of test mixture as compared to that of control mixture.

9.2.3 *Job Mixture.*–The quantities of dry materials used for job mixture shall be in accordance with requirements of sections 9.2.1 and 9.2.2 except that cement to be used on job shall be used instead of high-alkali cement. Also, the quantity of admixture, by absolute volume, used to replace cement shall be equivalent to that proposed for use on job.

9.2.4 *Flow.*–The amount of mixing water, measured in milliliters, shall be such as to produce a flow between 100 and 115 percent as determined in accordance with USBR 4109.

9.3 *Preparation of Test Specimens*:

9.3.1 *Dimensions and Number of Test Specimens.*–Make three 1- by 1- by 11-1/4-inch (25- by 25- by 286-mm) test specimens having an effective gauge length of 10 inches (254 mm) from each batch of each mortar mixture. One set of three specimens shall represent each test or job mixture. On same day that test specimens are made, make one set of three specimens representing control mixture and store in same container with corresponding test specimens. Make all specimens stored in a given container on same day, and do not open container again or remove it from storage until 13 days have elapsed. If more specimens from test or job mixtures, or both, are made on a given day than can be stored in a single container with specimens from control mixture made on that day, make additional control mixture specimens for each additional storage container used.

9.3.2 *Preparation of Molds.*–Prepare molds as specified in USBR 4227 or ASTM C 490.

9.3.3 *Mixing of Mortar.*–Mix mortar as specified in USBR 4227 or 4305, except add admixture with cement to water.

9.3.4 *Molding Test Specimens.*–Mold specimens as specified in USBR 4227.

10. Calibration and Standardization

10.1 Calibration and standardization shall be as outlined in section 10 of USBR 4227.

11. Conditioning

11.1 The temperature of the dry materials, water, molding room, and moist cabinet; and humidity of laboratory and moist cabinet shall conform to requirements of section 11 of USBR 4227.

11.2 Store test specimens in accordance with requirements of section 11 of USBR 4227.

12. Procedure

12.1 Test specimens in accordance with requirements and at times stipulated in USBR 4227.

12.2 Readings and observations should be recorded on their appropriate data form; a typical form is shown on figure 1.

13. Calculation

13.1 For tests of mixtures proportioned in accordance with sections 9.2.1 and 9.2.2, calculate reduction of mortar expansion resulting from use of an admixture as follows, and report result to nearest 0.1 percent.

$$R_e = \frac{E_c - E_t}{E_c} (100) \tag{1}$$

where:

R_e = percent of reduction of mortar expansion,
E_t = average expansion of mortar bars from test mixture, and
E_c = average expansion of mortar bars from control mixture.

13.2 For test mixtures proportioned in accordance with 9.2.3, report average expansion of mortar bars as the expansion of the combination proposed for use in the work. Indicate contraction (negative expansion) by prefixing a minus sign to percentage expansion reported.

13.3 A typical calculation form is shown on figure 1.

14. Reports

14.1 Figure 1 may also be used as a typical reporting form. The report shall include:

- Type of portland cement used and its total alkali content as Na_2O in percent. If test is applied to a cement-admixture combination to be used in specific work, the type, brand, and manufacturing location of the cement shall be reported.
- Type and proportion of admixture used. If test is applied to a cement-admixture combination to be used in specific work, the type, brand, source, proportion, and nature of admixture shall be reported.
- If control mixture and test mixture are prepared as specified in sections 9.2.1 and 9.2.2, the average expansion of mortar bars prepared from control mixture and average expansion of mortar bars from test mixture shall be reported, in percent. Also, reduction in mortar expansion resulting from use of admixture shall be reported, in percent.
- Average expansion of mortar bars prepared as specified in section 9.2.3 from job mixtures, in percent.

15. Precision and Bias

15.1 Within laboratory variability shall be considered satisfactory if percentage expansion of each specimen made from same cement-aggregate combination is within 0.003 of the average, except that, if average expansion exceeds 0.020 percent, repeatability shall be considered satisfactory if percentage expansion of each specimen molded from same cement-aggregate combination is within 15 percent of average.

15.2 This procedure has no known bias.

Spec. or Solic. No. RESEARCH	Structure ~	Tested by K. MITCHELL Date 10-23-79
Project ~	Item ~ Location DENVER LAB	Computed by K. MITCHELL Date 10-23-79
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by J. OWENS Date 11-6-79

EFFECTIVENESS OF MINERAL ADMIXTURES IN PREVENTING EXCESSIVE EXPANSION OF CONCRETE DUE TO ALKALI-AGGREGATE REACTION

MIX DATA

Cement 1 2 Sample No. 7488 Type II Brand PACIFIC PORTLAND Source REDWOOD CITY, CA

Admixture 1 2 Sample No. 7173 Type FLY ASH Class NA Brand AIROX-W Source SANTA MARIA, CA

Aggregate 1 2 Sample No. PYREX MSA GLASS inch (mm) Supplier ~ Source ~

				Control Mix No. 108 Pyrex Glass				Test Mix No. 109 Pyrex Glass w/ Admix.				Job Mix No. ___ Proj. Agg. w/ ___% Cement Rep. by Mass*							
												Reactive				Nonreactive			
	Spec. Grav.	Abs. %	Total Alkali as Sodium Oxide	Mass lbm [✓ grams]	Agg. %	W/C or W/C+P	Flow %	Mass lbm [✓ grams]	Agg. %	W/C or W/C+P	Flow %	Mass lbm grams	Agg. %	W/C or W/C+P	Flow %	Mass lbm grams	Agg. %	W/C or W/C+P	Flow %
Cement 1	3.10	—	1.19	400		0.43		300		0.45									
Cement 2																			
Admixture 1	2.33	—						75.2											
Admixture 2																			
Water				172			112	168			103								
Aggregate 1				900				900											
Aggregate 2																			
Sieve Size																			
3/8 inch (9.5 mm)																			
No. 4 (4.75 mm)																			
No. 8 (2.36 mm)				90	10			90	10										
No. 16 (1.18 mm)				225	25			225	25										
No. 30 (600 µm)				225	25			225	25										
No. 50 (300 µm)				225	25			225	25										
No. 100 (150 µm)				135	15			135	15										
Pan				—	0			—	0										
Totals				900	100			900	100										

* Mix is proportioned by volume of cement and admixture: mass of admixture times specific gravity, then divided by specific gravity of cement.

TEST DATA

Date Cast 10-23-79 Specimen Size 1x1x11¼ inches ~~(mm)~~ Comparator No. 2 Gauge Length 10 inches ~~(mm)~~ Storage 100 °F ~~(°C)~~

		CONTROL Mix							TEST Mix						
		A		B		C			A		B		C		
Date	Age	Dial Reading [✓ inch] mm	Length Change %	Dial Reading [✓ inch] mm	Length Change %	Dial Reading [✓ inch] mm	Length Change %	Average %	Dial Reading [✓ inch] mm	Length Change %	Dial Reading [✓ inch] mm	Length Change %	Dial Reading [✓ inch] mm	Length Change %	Average %
10-24-79	1 day	0.1502		0.1426		0.1457			0.1493		0.1414		0.1496		
11-6-79	14 days	0.1927	0.425	0.1847	0.421	0.1892	0.435	0.427	0.1681	0.188	0.1597	0.183	0.1641	0.145	0.172
	1 month														
	2 months														
	3 months														
	4 months														
	6 months														
	9 months														
	1 year														
	2 years														
	3 years														

SPOTS OPEN CRACK WARP FINE CRACK POPOUTS

$$R_e = \frac{E_c - E_t}{E_c}(100) = \frac{0.427 - 0.172}{0.427}(100) = 59.7\%$$

Figure 1. – Sample form on mix design and test data on measuring expansion of mortar bars.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4451-92

PROCEDURE FOR

EARLY STIFFENING OF PORTLAND CEMENT (PASTE METHOD)

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4451; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 451-83.

1. Scope

1.1 This designation covers the procedure for determination of early stiffening in portland cement paste.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
4183 Sampling and Acceptance of Hydraulic Cement
4187 Normal Consistency of Hydraulic Cement
4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:
C 150 Standard Specification for Portland Cement[1]
C 451 Standard Test Method for Early Stiffening of Portland Cement (Paste Method)[2]
C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1]
D 1193 Standard Specification for Reagent Water[3]

3. Summary of Procedure

3.1 A paste is prepared with the cement to be tested using sufficient water to give a required initial penetration as measured by the Vicat apparatus at a stipulated time after completion of mixing. A second penetration, termed the final penetration, is measured at a later stipulated time. The ratio of final to initial penetration is calculated as a percentage.

4. Significance and Use

4.1 The purpose of this test procedure is to determine the degree to which a cement paste develops early stiffening or to establish whether a cement complies with a specification limit on early stiffening.

4.2 When used for establishing compliance with a specification limit, the specification requirement is customarily stated in terms of minimum allowable final penetration, in percent, and calculated in accordance with section 13. When used for estimating relative tendency of a cement to manifest early stiffening, additional information of value may be obtained if remix procedure described in section 12.5 is used. Under some conditions, a judgment may be made by comparing behavior in initial test and in remix procedure to differentiate a relatively less serious and less persistent tendency to early stiffening from one that is more persistent and, consequently, more serious.

4.3 Severe false setting in a cement may cause difficulty from a placing and handling standpoint; however, it is not likely to cause difficulties where concrete is mixed for a longer time than usual, as usually occurs in transit mixing, or where it is remixed prior to placing or transporting, as occurs in concrete pumping operations. False setting is most likely to be noticeable where concrete is mixed for a short interval in stationary mixers and transported to the forms in nonagitating equipment, such as on some paving jobs.

4.4 Cements with severe false setting usually require slightly more water to produce same consistency, which may be expected to result in slightly lower strengths and increased drying shrinkage.

4.5 Flash set of a severity sufficient to cause difficulties from a placing and handling standpoint usually will cause cement to fail requirements for time-of-setting in ASTM C 150.

5. Terminology

5.1 *Early Stiffening*.–The early development of a perceptible difference in working characteristics of a portland cement paste, mortar, or concrete may be also defined as false set or quick or flash set.

5.2 *False Set*.–The rapid development of stiffness in a mixed portland cement paste, mortar, or concrete without the evolution of much heat, which stiffness can be dispelled

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.01.
[3] *Annual Book of ASTM Standards*, vol. 11.01.

and plasticity regained by further mixing without addition of water. False set, grab set, premature stiffening, hesitation set, early stiffening, and rubber set are other terms referring to this same phenomenon; however, false set is preferred term.

5.3 *Quick or Flash Set*.-The rapid development of rigidity in a mixed portland cement paste, mortar, or concrete, usually with the evolution of considerable heat, which rigidity cannot be dispelled nor can the plasticity be regained by further mixing without addition of water. Quick set is preferred term.

6. Apparatus

6.1 *Scales and Standard Masses*.-Shall conform to requirements of ASTM C 490.

6.2 *Glass Graduates*.-Shall conform to requirements of ASTM C 490.

6.3 *Vicat Apparatus*.-Shall conform to requirements of USBR 4187.

6.4 *Trowel*.-Trowel shall have a steel blade 4 to 6 inches (100 to 150 mm) in length, with straight edges.

6.5 *Mixer, Bowl, Paddle, and Scraper*.-Shall conform to requirements of USBR 4305.

7. Reagents and Materials

7.1 *Mixing Water*.-Potable water is satisfactory for routine tests. For all referee and cooperative tests, reagent water conforming to requirements of ASTM D 1193 for Type III or Type IV grades of reagent water shall be used.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Sampling

9.1 Sample cement in accordance with USBR 4183.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly.

10.2 Scales shall be calibrated to meet requirements of ASTM C 490 in accordance with USBR 1012.

10.3 Standard masses shall be calibrated to conform to ASTM C 490 by comparing to standard masses issued by NIST (National Institute of Standards and Technology), formerly NBS (National Bureau of Standards).

10.4 Glass graduates shall be accepted on certification by manufacturer to conform to requirements of section 4.2 of USBR 4187 and ASTM C 490.

10.5 The Vicat apparatus shall be calibrated to conform to requirements of USBR 4187 by using scales conforming to ASTM C 490 and linear measurement devices in accordance with USBR 1000.

10.6 The mixer, bowl, paddle, and scraper shall be checked to conform with USBR 4305 by using a revolution counter and linear measurement devices meeting the standards of USBR 1000.

11. Conditioning

11.1 *Temperature and Humidity*:

11.1.1 The temperature of the room shall be maintained between 68 and 81.5 °F (20 and 27.5 °C) and temperature of dry materials, paddle, bowl, conical ring, and baseplate shall be within the same range at time of test. Temperature of mixing water shall not vary from 73.4 °F (23 °C) by more than ±3 °F (±1.7 °C).

11.1.2 Relative humidity of laboratory shall not be less than 50 percent.

12. Procedure

12.1 *Preparation of Cement Paste*.-Mix 500 grams of cement with sufficient water to produce a paste with an initial penetration of 32±4 mm using the following procedure:

12.1.1 Place dry paddle and dry bowl in mixing position in mixer.

12.1.2 Introduce materials for a batch into bowl and mix as follows:

(1) Place all mixing water in bowl.

(2) Add cement to water and allow 30 seconds for absorption of water.

(3) Start mixer and mix at slow speed (140±5 r/min) for 30 seconds.

(4) Stop mixer for 15 seconds and scrape down into batch any paste that may have collected on sides of bowl.

(5) Start mixer and mix at medium speed (285±10 r/min) for 2.5 minutes.

12.2 *Molding Test Specimens*.-Quickly form cement paste into a ball with gloved hands. Press ball, resting in palm of one hand, into larger end of conical ring of Vicat apparatus (fig. 1, USBR 4187) held in other hand, completely filling ring with paste. Remove excess paste at larger end of ring by a single movement of palm of hand. Place ring on its larger end on the glass plate and slice off excess paste at smaller end (top) of ring by a single oblique stroke of a sharp-edged trowel held at a slight angle to top of ring. Smooth top of specimen, if necessary, with one or two light touches of pointed end of trowel. During the operation of cutting and smoothing, take care not to compress the paste.

12.3 *Determination of Initial Penetration*.-Place the paste, that is confined in ring and resting on glass plate, under the rod of apparatus about one third of the diameter from the edge. Move the plunger end of rod into contact with surface of paste and tighten setscrew. Then, set movable indicator to upper zero mark of scale and release rod exactly 20 seconds after completion of mixing. The apparatus shall be free of all vibrations during test. Consider the paste to have proper consistency when rod settles to a point 32±4 mm below original surface of paste within 30 seconds after being released. This consistency is the initial penetration. Make trial pastes with varying percentages of water until this consistency is obtained. During the 30-second interval for initial penetration, return excess paste to bowl and cover bowl and mixing paddle with a lid.

12.4 *Determination of Final Penetration.*-After completion of initial penetration reading, remove plunger from paste, clean it, and reset ring and plate in a new position. This operation should be performed with as little disturbance as possible to paste confined in ring. Then, move plunger so that it is once again in contact with surface of paste, tighten setscrew, and set movable indicator to upper zero mark of scale. Release the rod 5 minutes after completion of mixing period, and determine final penetration 30 seconds after release of rod.

12.5 *Determination of Remix Penetration.*-If penetrations determined by the previous determinations show cement to be rapid stiffening, information as to the nature of the stiffening may be obtained as follows:

12.5.1 Upon completion of measurement of 5-minute penetration (sec. 12.4), immediately return paste in mold to bowl. Start mixer, raise bowl into mixing position, and remix contents of bowl at medium speed (285±10 r/min) for 1 minute. Fill ring and determine penetration in same manner as specified in sections 12.2 and 12.3.

13. Calculation

13.1 Calculate the percent final penetration based on ratio of final to initial penetration as follows:

$$P = \frac{B}{A}(100) \qquad (1)$$

where:

P = percent final penetration,
A = initial penetration in millimeters, and
B = final penetration in millimeters.

13.2 Figure 1 shows a suggested worksheet and computation form.

14. Report

14.1 A suggested reporting form is shown on figure 5 of USBR 4183. Report results of test as follows:

Initial penetration ______ mm
Final penetration ______ mm
Percent final penetration ______ %
Remix penetration ______ mm

15. Precision and Bias

15.1 The precision and bias for this test procedure have not been established at this time.

16. Reference

16.1 For additional useful information on details of cement test methods, reference may be made to "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, vol. 04.01.

Spec. or Solic. No. DC-7150	Structure TUNNEL	Tested by K. MITCHELL Date 9-28-81
Project CENTRAL UTAH BONNEVILLE UNIT	Item TUNNEL LINING Location DENVER LAB	Computed by K. MITCHELL Date 9-28-81
Feature VAT TUNNEL	Station ENTIRE ~~Offset~~ LENGTH Depth — to —	Checked by W. DUFFUS Date 9-28-81

EARLY STIFFENING OF PORTLAND CEMENT (PASTE METHOD)

Sample No.	Brand Name	Plant ID	[✓ Type] or Class	Admixture	Water, mL	Penetration			Remix Penetration, mm
						Initial, mm	Final, mm	Percent	
M-7414	IDEAL CEMENT	DEVIL'S SLIDE, UTAH	II LA	—	126	35	35	100	—
M-7414	do	do	do	WRA 1.3 mL	111	30	10	33	6

NOTES:

Figure 1. - Sample data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4457-92

PROCEDURE FOR

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF AIR-VOID SYSTEM IN HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4457; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 457-82a.

1. Scope

1.1 This designation covers the procedure for microscopical determinations of air-void content, and the specific surface, spacing factor, and air-paste ratio of the air-void system in hardened concrete. Two methods (note 1) are described: (1) Linear Traverse (Rosiwal) Method [1][1], which is currently in use by the Bureau of Reclamation; and (2) Modified Point-Count Method [2,3,4,5].

1.2 This procedure is based upon measurement of the air-void system in hardened concrete by prescribed microscopical methods on sawed and ground sections intersecting portions of the interior of the samples, or specimens of concrete from the field or laboratory (note 2).

NOTE 1.-This procedure does not include a description of the areal traverse method [6]; or [7], in which air voids are relegated to a series of size ranges where number of voids per unit volume of concrete can be calculated.

NOTE 2.-The spacing factor is a useful index related to maximum distance of any point in cement paste from periphery of an air void. The calculation of this spacing factor is based on an assumption that all air voids in sample are equal-sized spheres arranged in a simple cubic lattice throughout cement paste. The geometrical principles were developed primarily by T. C. Powers [8].

1.3 This procedure does not attempt to describe, in detail, the alternative procedures by which surfaces for examination may be prepared or the techniques of microscopical observation and measurement, because it is assumed that work will be performed by or under the supervision of a microscopist or personnel adequately instructed in these methods. The intent of this procedure is to outline the principles of the two methods and to establish standards for performance of the techniques in evaluating an air-void system in hardened concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
2.2 *ASTM Standards*:
C 457 Standard Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete[2]

3. Definitions

3.1 *Air Void*.-An air void is a small space enclosed by cement paste in concrete and occupied by air. This term does not refer to capillary or other openings of submicroscopical dimensions or to voids within particles of aggregate. An air void is almost invariably larger than 2 μm in diameter. The term "air voids" includes both "entrapped" and "entrained" air voids.

3.2 *Linear Traverse (Rosiwal) Method*.-This method is the determination of volumetric composition of a solid by integrating distance traversed across areas of each component along a line, or along regularly spaced lines, in one or more planes intersecting a sample of the solid. Finely ground sections of concrete are examined microscopically along a series of regularly spaced lines, and the following data are obtained: (1) total number of sections of air voids intersected, (2) total distance traversed across sections of voids, (3) total distance traversed across remainder of concrete, and (4) total distance traversed across paste, if desired.

3.3 *Point-Count Method*.-This method involves the determination of volumetric composition of a solid by observation of frequency that areas of each component coincide with a regular system of points in one or more planes intersecting a sample of solid.

3.4 *Modified Point-Count Method*.-This is the point-count method supplemented by determination of frequency

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[1] Numbers in brackets refer to entries in References, section 19.

[2] *Annual Book of ASTM Standards*, vol. 04.02.

that areas of each component of a solid are intersected by regularly spaced lines in one or more planes intersecting a sample of solid. Finely ground sections of the concrete are examined microscopically along a series of regularly spaced lines, and the following data are obtained: (1) total number of sections of air voids intersected, (2) frequency that regularly spaced points on line of traverse are superimposed on sections of air voids, and (3) total number of points superimposed on paste, if desired.

3.5 *Air-Void Content.*-The air-void content is the proportional volume of air voids in concrete expressed as the volume percent of the hardened concrete.

3.6 *Paste Content.*-The paste content is the proportional volume of cement paste in concrete expressed as the volume percent of the hardened concrete. This volume is calculated as either the simple summation of proportional volumes of cement and water included in concrete mixture, or as determined by microscopical analysis of the hardened concrete by traversing the prepared sections, [9,10].

3.7 *Specific Surface.*-The specific surface is the surface area of air voids in hardened concrete, expressed as the area per cubic unit length of the air-void volume.

3.8 *Chord Intercept.*-The chord intercept is the average length of the chord across cross sections of air voids intercepted by a line of microscopical traverse.

3.9 *Number of Air Voids Per Unit Length of Traverse.*-This is the number of air voids intercepted by a line of microscopical traverse expressed as number of air voids per inch or per millimeter of traverse.

3.10 *Spacing Factor.*-The spacing factor is a useful index related to maximum distance of any point in cement paste from periphery of an air void (note 2).

3.11 *Air-Paste Ratio.*-The air-paste ratio is the ratio of volume of air to volume of paste in the hardened concrete.

4. Sampling and Conditioning

4.1 Samples of hardened concrete for determination of air-void content and for determination of specific surface and spacing factor of air-void system may be obtained from specimens cast in the field or laboratory; or by coring, sawing, or otherwise removing concrete from structures. The method used for securing the small portion or portions of concrete for microscopical measurement and the location from which they are obtained will depend on objectives of program. Care should be taken in selecting and securing the portions for measurements so as to provide reliable data of type desired. Generally, samples of hardened concrete from structures or large test specimens should be secured in accordance with USBR 4042. Each sample should be sufficient to provide at least the minimum area of finished surface for microscopical measurement as shown in table 1.

4.2 To determine compliance of hardened concrete with requirements of specifications on air-void content or on specific surface and spacing factor of air-void system, a sample of the concrete should be obtained from at least three locations in body of concrete and microscopical measurements should be made on at least one section prepared from each of at least three of such samples.

Table 1. - Minimum area of finished surface for microscopical measurement.

Nominal or observed maximum size of aggregate in concrete	Total minimum area to be traversed for determination of specific surface or spacing factor based on direct measurement of:			
	Total air-void content[1]		Paste-air ratio	
	in^2	(mm^2)	in^2	(mm^2)
6 inches (150 mm)	250	(161 290)	100	(64 516)
3 inches (75 mm)	65	(41 935)	30	(19 355)
1-1/2 inches (37.5 mm)	24	(15 484)	15	(9 677)
1 inch (25.0 mm)	12	(7 742)	12	(7 742)
3/4 inch (19.0 mm)	11	(7 097)	11	(7 097)
1/2 inch (12.5 mm)	10	(6 452)	10	(6 452)
3/8 inch (9.5 mm)	9	(5 806)	9	(5 806)
No. 4 (4.75 mm)	7	(4 516)	7	(4 516)

[1] The indicated area values refer to reasonably homogeneous, well-compacted concrete. The microscopical measurement should be made on a proportionately larger area of sections if concrete is markedly heterogeneous in distribution of aggregate or has large air voids. If more than one finished surface is taken from a single portion of the concrete, the finished surfaces shall be separated by a distance greater than one-half of nominal or observed maximum size of aggregate.

5. Apparatus and Materials

5.1 The apparatus and materials necessary for fabrication of finely-lapped surfaces for this procedure are as follows:

5.1.1 *Diamond Saw.*-Slabbing saw with an automatic feed, and blade large enough to make at least a 7-inch (178-mm) cut in one pass. A cutting lubricant for the saw is also necessary.

5.1.2 *Horizontal Lap Wheel.*-A steel, cast iron, or other metal lap wheel, preferably at least 16 inches (406 mm) in diameter and large enough to grind at least a 4- by 6-inch (102- by 152-mm) area.

5.1.3 *Free Abrasive Machine.*-This machine uses abrasive grit in the lubricant, with sample holders rotating on a rotating table. This type of machine greatly increases speed of preparation of finely ground surfaces.

5.1.4 *Polishing Wheel.*-A polishing wheel at least 8 inches (203 mm) in diameter, preferably with a two-speed or vibratory polisher.

5.1.5 *Hotplate or Oven.*-Shall be thermostatically controlled to permit drying and impregnating specimens with resin or wax for preparing thin sections, ground surfaces, and polished sections.

5.1.6 *Abrasives.*-Silicon-carbide grits: No. 100 (150 μm), No. 220 (63 μm), No. 320 (31 μm), No. 600 (16 μm), and No. 800 (12 μm); with optical finishing powders such as M-303, M-204, and M-309; and polishing powders as needed.

5.2 Apparatus and materials other than those described have been used satisfactorily.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 Precautionary measures are given in note 3, section 7.2 concerning fumes from xylene (if used).

7. Preparation of Sections

7.1 Unless objectives of program dictate a special method, sections for microscopical measurement should be sawed approximately at right angles to a formed or finished surface included in sample of hardened concrete, preferably across layers in which fresh concrete was deposited. Individual sections should be as large as can be ground and traversed satisfactorily with available equipment. The required area may be traversed on one or more prepared sections of concrete. Best results are obtained if selected traverse length is spread uniformly over maximum of available prepared surface of concrete to compensate to the fullest practicable degree for heterogeneity of the concrete.

7.2 After sawing of a slab of hardened concrete, the surface should be ground with successively finer abrasives, such as a No. 100 (150-µm) silicon-carbide abrasive to remove saw marks; and then successively with the No. 220, 320, 600, and 800 (63-, 31-, 16-, and 12-µm) abrasives until surface is suitable for microscopical observation (note 3). All surfaces of slab should be washed and scrubbed thoroughly with a brush after sawing; and after each grinding operation by brushing or using a fine, high-velocity spray of solvent or water to remove grit and loose particles of concrete. The surface may be considered satisfactory for the microscopical traverse when surface, as viewed in strong light incident as a low angle appears essentially plane. Exceptions would include air voids or voids within particles of aggregate, where edges of sections of air voids are sharp and not rounded or crumbled; areas where sand grains are plucked from surface or areas where surface is irregular as a result of incomplete grinding, gouging, or scratching of cement paste and constitute less than about 5 percent of total area; and where any air-void sections as small as 10 µm in diameter are distinquishable or would be distinquishable if present.

NOTE 3.–If difficulty is encountered in preparing a satisfactory surface, the following method is helpful: (1) heat partially prepared slab of concrete to 302 °F (150 °C) in an oven; (2) remove specimen from oven and immediately brush melted carnauba wax heated to 302 °F onto surface, repeating application as wax is absorbed by concrete so that when temperature of concrete falls below melting point of wax, a perceptible film of wax remains on surface; and (3) after specimen has cooled to about room temperature, repeat grinding operation as outlined in section 7.2. After completion of grinding, remove wax residue from air voids by heating concrete to 302 °F and immersing specimen in xylene in a metal can. Perform this operation under a hood, avoid breathing the xylene fumes, and place lid on can after specimen has been immersed. Gentle agitation of can will facilitate dissolution of wax. Repeat this operation if examination of surface indicates incomplete removal of wax. Exceptionally fragile concrete may require two or more applications of wax and cycles of grinding before a satisfactory surface is obtained.

7.3 Parameters of the air-void system in the near-surface portion of the concrete should be determined by grinding portions of finished or formed surfaces in accordance with procedures described in section 7.2. Individual sections should be as large as can be ground and traversed satisfactorily with available equipment. The required area may be traversed on one or more prepared sections, and the traverse length spread uniformly over maximum of available prepared section. Because parameters of air-void system may vary greatly with distance from finished or formed surface, the distance separating the section to be traversed from the finished or formed surface should be measured as accurately as possible, at least to nearest 0.05 inch (1.3 mm). The following method may be used to establish the variation of parameters of air-void system with depth from a finished or formed surface: (1) prepare a specimen that includes a portion of finished or formed surface to be investigated and of convenient thickness, such as about 1 inch (25 mm), by sawing perpendicular and parallel to finished or formed surface; (2) grind surface using the No. 100 or 220 (150- or 63-µm) abrasive grit until last portion of surface is just removed, then complete grinding operation as described in section 7.2–this initially produced surface shall be reference plane to which depth measurements are referred; (3) grind back surface of specimen to produce a plane section as described in section 7.2; (4) measure thickness of specimen, using a micrometer caliper, to nearest 0.05 inch (1.3 mm) for at least four points uniformly spaced around periphery of specimen, averaging results and recording this average to nearest 0.05 inch; (5) determine parameters of system at both surfaces of specimen as described in section 10 or 14; and (6) again grind section near exposed surface to any desired depth, repeat traversing of prepared section, and measure thickness as before so that parameters can be correlated with distance of traversed surface from finished or formed suface. Repeat the grinding and traversing operations as required.

7.4 If the parameters of air-void system near the finished or formed surface are being determined to establish possible effects of surface treatments, finishing practices, admixtures, or other variables, the relationship of such parameters and the distance from finished or formed surface should be established for both the test concrete and reference concrete. For specimens having rough surfaces, it may be desirable to establish two reference planes on the surface, at the highest and lowest projections on surface. This would permit determining the air-void characteristics between the two reference planes and comparison of results with the depth below each plane. Specimen should be capped with high-strength gypsum plaster or plaster of paris by placing a conical pile of capping material on a capping plate and pressing concrete surface into material until highest point on surface contacts the plate. After capping material has hardened, measure thickness to back surface prepared in step (3) of section

7.3 using the micrometer caliper, step (4) of section 7.3. Grind the top (capped) surface to desired depth for microscopical observation. For observations between the two reference planes, the distance traversed over capping material should be subtracted from results. A thickness measurement should be taken when surface has been ground to lowest point in original surface to establish that reference plane.

7.5 The cement paste content of the near-surface zone differs from that of the concrete as a whole; therefore, for calculation of spacing factor, the proportional volume of cement paste in prepared sections shall be determined by microscopical traversing (see [9, 10] for applicable methods) or calculated from air-paste ratio in near-surface zone determined by methods of this procedure.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

LINEAR TRAVERSE (ROSIWAL) METHOD

9. Apparatus for Measurement of Specimens

9.1 The equipment listed in sections 9.1.1 through 9.1.5 is a recommended minimum selection permitting application of the linear traverse method to determine the air-void content and the specific surface and spacing factor of the air-void system in hardened concrete. However, equipment other than that listed has been used satisfactorily.

9.1.1 *Linear Traverse Device.*-This device, either hand- or motor-driven (note 4), consists of a stage or platform mounted on a carriage, and shall be so constructed that a specimen of concrete placed on the stage can be moved smoothly and uniformly: (1) at least 4.0 inches (102 mm) by turning a main lead screw to which carriage is connected, (2) at least 3.0 inches (76 mm) in a direction at right angles to main lead screw (note 5), and (3) at least 2.5 inches (64 mm) parallel to main lead screw using an upper lead screw, and to which stage is attached and supported by carriage (note 6). The pitch of the upper lead screw should not exceed 0.0105 inch (0.267 mm) per revolution. The pitch of both lead screws should be determined to nearest 0.0001 inch (0.003 mm) per revolution. Rotation counters should be attached to main lead screw and upper lead screw, and each counter should be supplemented by an indicator such that number of revolutions can be read to nearest 0.01. A manually operated tally counter should also be provided. If calculations are to be based on air-paste ratio, either a third lead screw (installed on upper stage) equipped with a revolution counter must be included, in which case main lead screw need not be equipped with a counter, or it must be possible to disengage counter from main lead screw. A photograph of a satisfactory linear traverse device is shown on figure 1.

NOTE 4.-If linear traverse device is motor-driven, a speed sufficiently low to permit satisfactory inspection of surface of specimen should be available.

NOTE 5.-It is convenient to have lateral movement of specimen accomplished by using a calibrated cross-feed screw to which upper lead screw and stage assembly are attached.

NOTE 6.-A satisfactory linear traverse device can be constructed by suitable modification of a machinist's lathe. The stage and upper lead screw assembly can be constructed on the carriage, which normally has a calibrated cross-feed arrangement. A manually operated clutch must be installed to permit control of movement of carriage by operator without disengaging carriage from lead screw. Vibration is minimized when motor is mounted separately from lathe chassis. A rotation counter should be affixed to main lead screw.

9.1.2 *Stereoscopic Microscope and Support.*-This microscope shall have objectives and oculars to give final magnifications from about 30X to at least 125X, and be so arranged as to permit continuous observations of surface of a concrete specimen mounted on stage of linear traverse device. One ocular should include cross-hairs or some other reticle device to serve as an index point.

9.1.3 *Microscope Lamp.*-This lamp should be a spotlight-type, arranged to provide illumination sufficient for close scrutiny of surface of a concrete specimen at a magnification of about 125X.

9.1.4 *Spirit Level.*-A 4- to 6-inch (102- to 152-mm) long level.

9.1.5 *Modeling Clay.*-Required to support and level section or other leveling-support device.

10. Procedure

10.1 Place prepared slab of concrete on stage of linear traverse device with prepared surface upward and such that a formed or finished surface, if present, is parallel to main lead screw of device. Using the spirit level, carefully level prepared surface by placing pedestals of modeling clay under slab so that surface may be traversed with a minimum of focusing of microscope (note 7). Adjust microscope lamp so that beam is focused in field of view of microscope at a magnification of at least 50X, and is incident upon surface at a low angle so that air voids are clearly delineated by a shadow.

10.2 By means appropriate to device being used, superimpose selected index point in reticle of one eyepiece of microscope, near one corner of specimen, ensuring that drives for carriage and stage are engaged and adjusted to remove all play from gear system. The preselected index point should be used throughout the entire traverse, and should be essentially dimensionless; that is, without perceptible area or length. If intersection of crosshairs is used, index point should be selected as the intersection of one pair of edges of the crosshairs. Initiate each segment of traverse at edge of satisfactory plane surface of slab rather than at edge of slab itself. Length of segments of traverse may vary. Extreme care must be used to determine whether a section of an air void is intersected by apparent

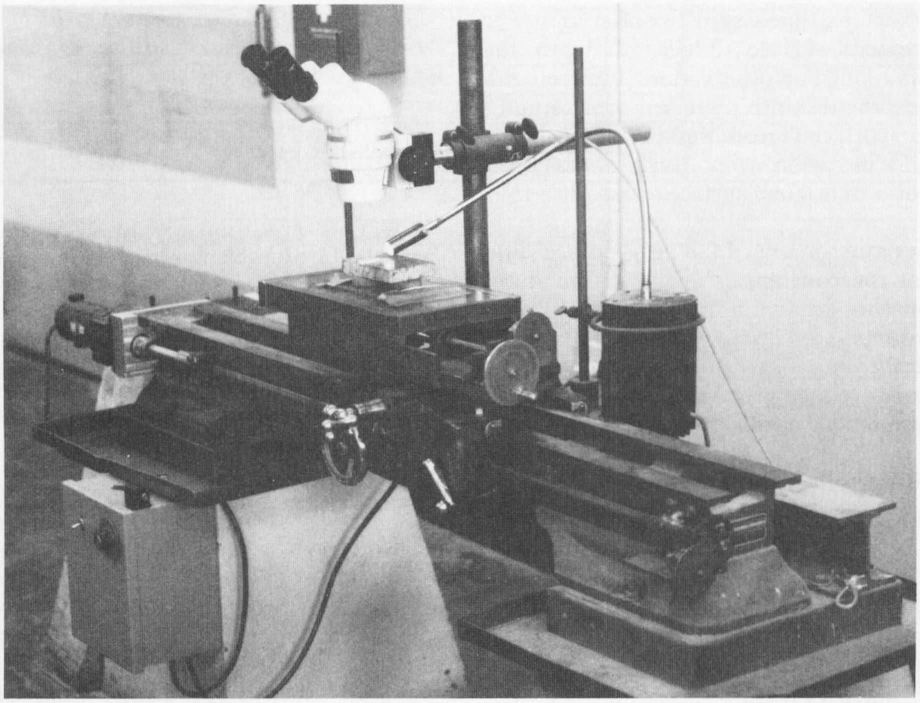


Figure 1. – Linear traverse device that meets the requirements of this designation.

movement of index point when line of traverse is nearly tangential to void section. Results can be affected significantly by consistent error in this respect. If periphery of an air void is crumbled or rounded, the position of true periphery in plane of surface must be estimated by extrapolation of surface contour of air void. Care must be used to distinguish depressions produced by plucking of sand grains from air voids. If a chipped or otherwise broken portion of ground surface is traversed, air voids revealed in depressions should be counted and measured as though they were projected into the plane of the surface. Read and record settings of counters affixed to main lead screw and upper lead screw. Set the manually operated tally counter at zero. Using main lead screw, cause movement of entire carriage assembly while simultaneously scrutinizing surface of slab as concrete moves beneath microscope. When index point is exactly superimposed upon periphery of a section of an air void in surface of slab, stop movement of carriage, actuate tally counter once and, using upper lead screw, move concrete under microscope until index point is again exactly superimposed upon periphery of same air-void section. Stop rotation of upper lead screw and resume movement of entire carriage using main lead screw as before (note 8). Proceed in this manner and traverse all portions of surface, except sections of air voids, using main lead screw, and traversing all chords across sections of air voids on line of traverse using upper lead screw, until index point is superimposed on end of prepared surface. Terminate each segment of traverse at edge of plane, prepared surface rather than at edge of slab. If calculations are to be based on air-paste ratio, either traverse all sections of cement paste with third lead screw or disengage counter from main lead screw while traversing aggregate particles. All air-void sections intersected by line of traverse are counted on tally counter. Read and record settings of all three counters.

NOTE 7.–A three-point adjustable stage has been found to be most convenient.

NOTE 8.–A pushbutton-actuated electronic counter, that counts the teeth on a gear on main lead screw or driving-motor shaft, greatly facilitates the counting process.

10.3 By means appropriate to device being used, shift concrete slab, at right angles to direction of traverse, an appropriate distance. Space segments of traverse to achieve at least the minimum total traverse length over the specified minimum area of prepared surface, see section 11. Superimpose index point at end of new line of traverse, and perform linear traverse as before. Repeat this process for all segments of total traverse. If more than one slab has been prepared from sample of concrete, repeat procedure described in 10.1 on each such slab to comply with this procedure or with such other requirements as may be necessary.

11. Length of Linear Traverse

11.1 The minimum length of the traverse shall be as specified in table 2.

12. Calculations

12.1 Calculate air-void content, specific surface, and spacing factor of air-void system from results of linear

Table 2. – Minimum length of traverse for the linear traverse method.

Nominal or observed maximum size of aggregate in concrete	Minimum length of traverse for determination of air-void content,[1] specific surface, or spacing factor	
	inches	(mm)
6 inches (150 mm)	160	(4064)
3 inches (75 mm)	120	(3048)
1-1/2 inches (37.5 mm)	100	(2540)
1 inch (25.0 mm)	95	(2413)
3/4 inch (19.0 mm)	90	(2286)
1/2 inch (12.5 mm)	80	(2032)
3/8 inch (9.5 mm)	75	(1905)
No. 4 (4.75 mm)	55	(1397)

[1] The limits of uncertainty of results obtained for air-void content depend upon length of traverse and air-void content of concrete. Based on experience, recommended minimum length of traverse shown should produce limits of uncertainty such that, up to 3 percent air-void content, the standard deviation is not greater than 0.5 percent which, at 3 percent air-void content, corresponds to a coefficient of variation of 17 percent. For traverse lengths greater than 55 inches (1397 mm) and air-void contents greater than 3 percent, the coefficient of variation is correspondingly reduced. The data obtained can be analyzed by statistical methods to determine limits of uncertainty to be applied.

traverse measurements using the following equation as a basis:

$$C = \frac{P_u R_u}{N} \qquad (1)$$

where:

C = average chord intercept of air-void sections on line of traverse, in inches (millimeters);
N = total number of air voids intersected in entire traverse;
P_u = pitch of upper lead screw used for traversing air voids, in inches (millimeters) per revolution; and
R_u = total number of revolutions of upper lead screw.

NOTE 9.–The product P_u R_u is equal to the total length of traverses across voids.

12.1.1 *Specific Surface.*–Calculate the specific surface from the following equation [8]:

$$\alpha = \frac{4}{C} \qquad (2)$$

where:

α = specific surface, in inches^{-1} (or in^2/in^3), (millimeters^{-1}) (or mm^2/mm^3), and
C = as previously defined.

12.1.2 *Air-Void Content.*–When air-paste ratio is not determined, calculate air-void content as follows:

$$T = P_u R_u + P_m R_m, \qquad (3)$$

$$n = \frac{N}{T}, \text{ and}$$

$$A = 100nC. \qquad (4)$$

where:

A = air-void content of hardened concrete, in percent;
T = total length of traverse, in inches (millimeters);
P_m = pitch of main lead screw, in inches (millimeters) per revolution;
R_m = total number of revolutions of main lead screw;
n = average number of air-void sections intercepted per inch or per millimeter of traverse; and
Other terms as previously defined.

NOTE 10.–It may be more convenient to calculate:

$$A = \frac{100\, P_u R_u}{P_u R_u + P_m R_m} \qquad (5)$$

where:

$P_m R_m$ = total length of traverses minus total length of traverses across voids (note 9).

12.1.3 *Spacing Factor.*–When paste content of concrete is known, calculate the spacing factor [8]:

When $\frac{p}{A} \leq 4.342$,

$$L = \frac{p}{400\, n} \quad \text{or} \quad L = \frac{p}{A\alpha} \qquad (6)$$

When $\frac{p}{A} > 4.342$,

$$L = \frac{3}{\alpha}\left[1.4\left(\frac{p}{A} + 1\right)^{1/3} - 1\right] \qquad (7)$$

where:

p/A = paste-air ratio;
L = spacing factor, in inches (millimeters);
p = paste content, in volume percent of concrete; and
Other terms as previously defined.

NOTE 11.–When calculating spacing factor for near-surface sections prepared and analyzed in accordance with 7.3, use the value for p that was determined microscopically by traversing the respective sections. Whenever determined by microscopical traverses of a section, use p, as determined experimentally, in calculating the paste-air ratio or spacing factor for that section.

12.1.3.1 If desired, the spacing factor may be estimated graphically using figure 2 or 3 rather than using equation (6) or (7).

12.2 When calculations are to be based on the air-paste ratio, proceed as follows:

12.2.1 *Air-Paste Ratio.*-Calculate the air-paste ratio as follows:

$$n_p = \frac{N}{P_p R_p} \qquad (8)$$

$$\frac{A}{p} = n_p C \qquad (9)$$

where:

A/p = air-paste ratio,
n_p = average number of air-void sections intersected per inch or per millimeter of traverse in paste,
P_p = pitch of lead screw used for traversing sections of cement paste in inches (millimeters),
R_p = total number of revolutions of lead screw used for traversing sections of cement paste, and
Other terms as previously defined.

12.2.2 *Spacing Factor.*-Calculate spacing factor, L, as follows:

When $\frac{p}{A} \leq 4.342$,

$$L = \frac{1}{4n_p} \quad \text{or} \quad L = \frac{p}{A\alpha} \qquad (10)$$

When $\frac{p}{A} > 4.342$, use equation (7), section 12.1.3.

where:

p/A = the reciprocal of A/p calculated in 12.2.1.

12.2.2.1 If desired, the spacing factor may be estimated graphically using figure 2 or 3 rather than using equation (7) or (10).

12.2.3 *Air-Void Content.*-The air-void content of the hardened concrete can be calculated using the air-paste ratio as follows:

$$A = \frac{\frac{A}{p}\,(100)}{\frac{A}{p} + 1 + \frac{G}{P_1}} \qquad (11)$$

where:

P_1 = percent by volume of air-free paste in mixture proportions as batched,
G = percent by volume of total aggregate in mixture proportions as batched, and
Other terms as previously defined.

12.3 Calculate the values for air-void content, air-paste ratio (when determined), specific surface, and spacing factor to three significant digits and report results to nearest two significant digits.

12.4 The Bureau does not determine the air-void content, specific surface, and spacing factor by the air-paste ratio as described in section 12.2.

12.5 Figure 4 shows a typical data sheet and figure 5 shows a calculation form for the linear traverse method. Figure 5 does not include data by the air-paste ratio method.

MODIFIED POINT-COUNT METHOD

13. Apparatus for Measurement of Specimens

13.1 The equipment listed in sections 13.1.1 through 13.1.5 is a recommended minimum selection permitting application of the modified point-count method to determine the air-void content and the specific surface and spacing factor of the air-void system in hardened concrete. However, equipment other than that listed has been used satisfactorily.

13.1.1 *Point-Count Device.*-This device consists of a stage or platform connected to the lead screw, and designed such that a specimen of concrete placed on the stage can be moved smoothly and uniformly through equal distances by turning the lead screw. The total possible translation of the stage should be not less than 4.0 inches (102 mm). The lead screw should be fitted with a notched wheel and stopping device such that, with rotation of lead screw, a click is easily audible to operator when a stop position is reached. Intervals between stops should correspond to a translation of the stage from 0.025 to 0.200 inch (0.64 to 5.08 mm); magnitude of average translation of stage between clicks should be determined to nearest 0.0001 inch (0.003 mm). The device should be designed so that concrete specimen mounted on stage can be moved at right angles to main lead screw by at least 3.0 inches (76 mm) (note 5). At least three digital counters shall be provided, either affixed to point-count device or mounted separately (note 12). If calculations are to be based on the air-paste ratio, a counter shall also be provided for determining paste content.

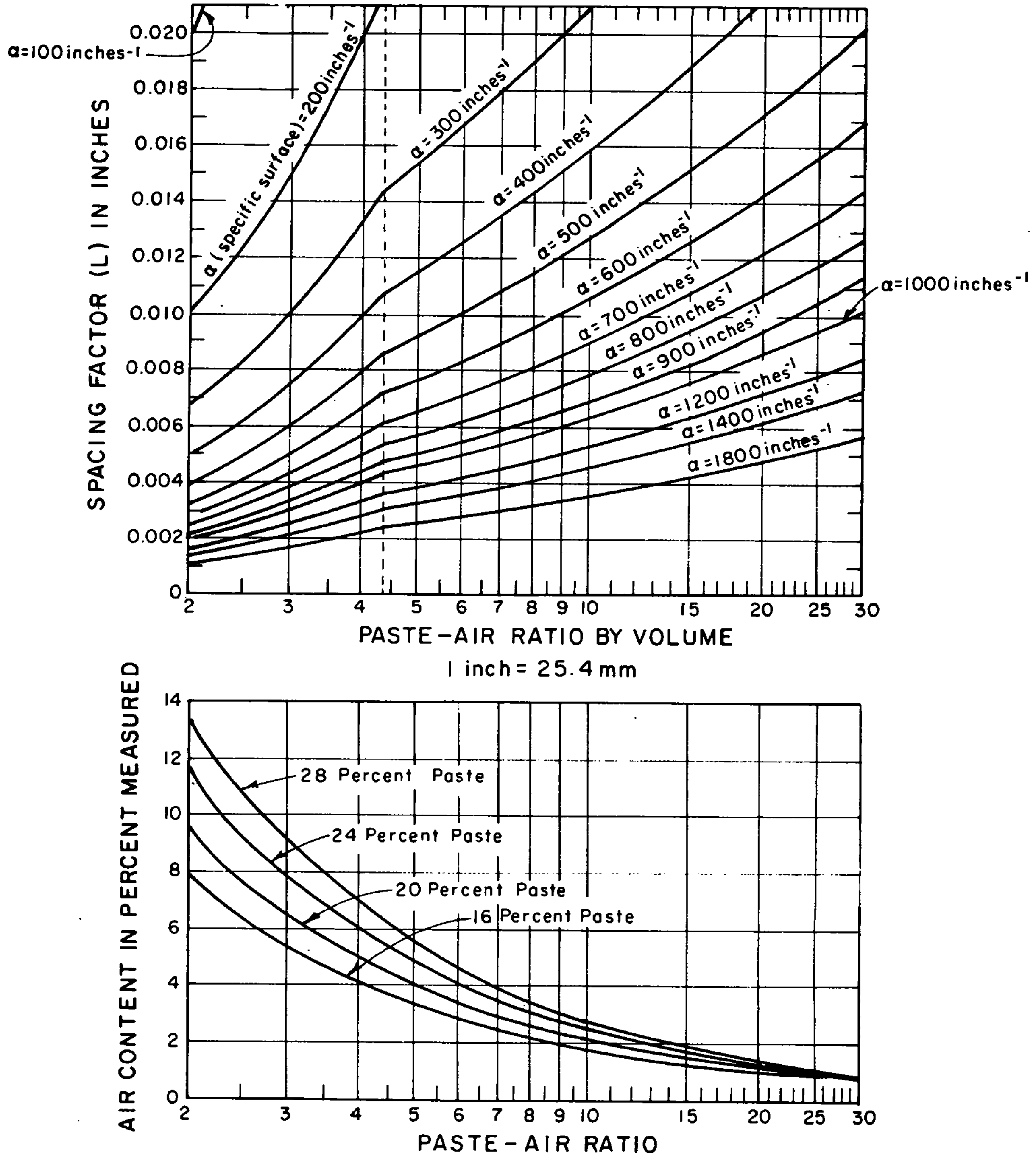
NOTE 12.-A counter may conveniently be attached to stopping device so as to register automatically the number of stops corresponding to any traverse across a specimen..

13.1.2 *Stereoscopic Microscope and Support.*-Refer to section 9.1.2.

13.1.3 *Microscope Lamp.*-Refer to section 9.1.3.

13.1.4 *Spirit Level.*-Refer to section 9.1.4.

13.1.5 *Modeling Clay.*-Refer to section 9.1.5.

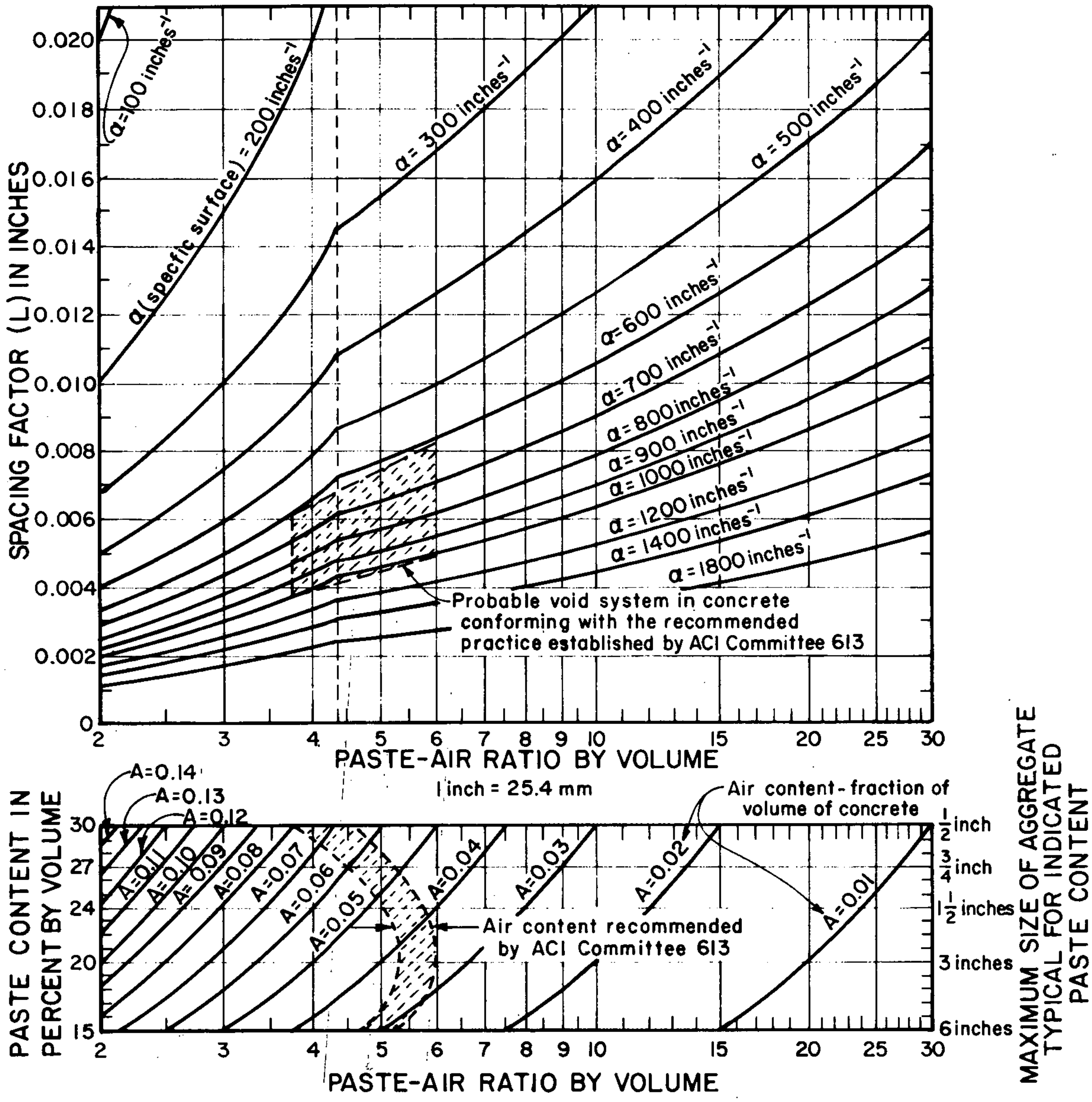


Estimate the spacing factor as follows:

(1) If air content was measured, select appropriate value in lower diagram and follow horizontally to calculated or estimated paste content. Then, move vertically to upper diagram to calculated specific surface and then horizontally to corresponding spacing factor, or

(2) If paste-air ratio was measured, select the appropriate value in the upper diagram, move vertically upward to calculated specific surface, and then horizontally to corresponding spacing factor.

Figure 2. – Graphs for estimating spacing factor.



Note: To determine spacing factor for a void system in a concrete from microscopically determined parameters, select calculated or estimated paste content on the ordinate of lower diagram and follow horizontally to proper air content or paste-air ratio of the concrete. Then move vertically to upper diagram, which correlates the specific surface of the voids and the spacing factor. If specific surface has been measured or is estimated, the value of the spacing factor is indicated at the ordinate. Conversely, specific surface is indicated on the curves at any selected values for the spacing factor and paste-air ratio.

Figure 3. – Probable void system in air-entrained concrete conforming with ACI 613-54. From [11].

14. Procedure

14.1 Place prepared slab of concrete on stage of point-count device with prepared surface upward and such that a formed or finished surface, if present, is parallel to main lead screw of device. Using the spirit level, carefully level prepared surface by placing pedestals of modeling clay under slab so that surface may be traversed with a minimum of focusing of microscope (note 7). Adjust microscope lamp so that beam is focused in field of view of microscope at a magnification of at least 50X, and is incident upon surface at a low angle so that air voids are clearly delineated by a shadow.

14.2 By means appropriate to device being used, superimpose selected index point in reticle of one eyepiece of microscope, near one corner of specimen, ensuring that drives for carriage are engaged and adjusted to remove all play from gear system. The stopping device shall be at a stop or click position at beginning of traverse. The preselected index point should be used throughout the entire traverse, and should be essentially dimensionless; that is, without perceptible area or length. If intersection of crosshairs is used, index point should be selected as the intersection of one pair of edges of the crosshairs. Initiate each segment of traverse at edge of satisfactory plane surface of slab rather than at edge of slab itself. Length of segments of traverse may vary. Read and record settings on all appropriate counters. Using main lead screw, cause movement of stage assembly and specimen while simultaneously scrutinizing surface of slab. Each time an air-void section passes beneath index point in reticle of one eyepiece, tally a count on appropriate counter. Extreme care must be used to determine whether a section of an air void is intersected by apparent movement of index point when line of traverse is nearly tangential to void section. Results can be affected significantly by consistent error in this respect. If periphery of an air void is crumbled or rounded, the position of true periphery in plane of surface must be estimated by extrapolation of surface contour of air void. Care must be used to distinguish depressions produced by plucking of sand grains from air voids. If a chipped or otherwise broken portion of ground surface is traversed, air voids revealed in depression should be counted and measured as though they were projected into the plane of the surface. When a stop or click position is reached, mark a tally on appropriate counter. If index point is superimposed on a section of an air void at the stop position, mark a tally on appropriate counter. If the air-paste ratio is to be computed, a fourth counter is required. Mark a tally on counter if index point is superimposed on a section of cement paste. Proceed in this manner to the last stop position on line of traverse. Mark a tally for each air void intercepted by line of traverse, a tally for each stop position, a tally for each stop position where index point is superimposed on a section of an air void and, when appropriate, a tally for each stop position where index point is superimposed on a section of cement paste. At the end of line of traverse, read and record the tally shown by each counter. Terminate each segment of traverse at edge of plane, prepared surface rather than at edge of slab. If traverse is being made to determine only the air-void content, the number of air voids intersected by line of traverse need not be determined. If lines of traverse are shorter than 1 inch (25 mm), do not tally a count for an air void that corresponds with point of observation at beginning of each line of traverse.

NOTE 13.–Some operators have found it preferable from the standpoint of enhanced precision, reduced error of tallying, and reduced operator fatigue to accomplish the operations by traversing each traverse line twice, once to record what is found at each stop and once to record number of voids intercepted by line of traverse.

14.3 By means appropriate to device being used, shift concrete slab, at right angles to direction of traverse, an appropriate distance. Space segments of traverse to achieve at least the minimum total traverse length over the specified minimum area of prepared surface, see section 15. Proceed along new line of traverse as before for all segments of total traverse and for all sections prepared from a sample of concrete so as to comply with requirements of this procedure or with such other requirements as may be necessary.

15. Length of Traverse and Number of Points

15.1 When total air content is desired, the minimum length of traverse and the minimum number of points shall be as shown in table 3.

15.2 When calculations are to be based on air-paste ratio, the minimum length of traverse shall be as shown in table 3; however, the minimum number of points shall comply with the following approximate equation:

$$S_v = \frac{1}{V^2} \tag{12}$$

where:

S_v = total number of stops where index point is superimposed on a section of an air void, and
V = desired coefficient of variation of air-void content expressed as a fractional value.

The required minimum total number of points depends on air-paste ratio. Points measured should be uniformly distributed over concrete surface.

16. Calculations

16.1 When calculations are to be based on total air content, proceed as follows:

16.1.1 *Air-Void Content.*–Calculate the air-void content from results of point-count analysis as follows:

$$A = \frac{100\, S_v}{S_t} \tag{13}$$

where:

A = air-void content of hardened concrete, in percent;
S_t = total number of stops during traverse; and
S_v = as defined in equation (12).

16.1.2 *Specific Surface.*–Calculate the specific surface [8] as follows:

Initially, determine total length of traverse and number of air-void sections per inch or per millimeter:

$$T = L_s\,(S_t - T_\lambda) \tag{14}$$

$$n = \frac{N}{T}$$

Table 3. - Minimum length of traverse and minimum number of points for the modified point-count method[1].

Nominal or observed maximum size of aggregate in concrete	Minimum length of traverse for determination of air-void content, specific surface, or spacing factor		Minimum number of points for determination of air-void content, specific surface, or spacing factor
	inches	(mm)	
6 inches (150 mm)	160	(4064)	2400
3 inches (75 mm)	120	(3048)	1800
1-1/2 inches (37.5 mm)	100	(2540)	1500
1 inch (25.0 mm)	95	(2413)	1425
3/4 inch (19.0 mm)	90	(2286)	1350
1/2 inch (12.5 mm)	80	(2032)	1200
3/8 inch (9.5 mm)	75	(1905)	1125
No. 4 (4.75 mm)	55	(1397)	1000

[1] The limits of uncertainty of results obtained for air-void content depend upon number of points and air-void content of concrete. The recommended minimum number of points shown should produce limits of uncertainty such that, up to 3 percent air-void content, the standard deviation of not greater than 0.5 percent which, at 3 percent air-void content, corresponds to a coefficient of variation of 17 percent. For number of points greater than 1000 and air-void contents greater than 3 percent, the coefficient of variation is correspondingly reduced. The data obtained can be analyzed by statistical methods to determine limits of uncertainty to be applied.

Determine average chord intercept:

$$C = \frac{A}{100\,n} \qquad (15)$$

Then, calculate specific surface:

$$\alpha = \frac{4}{C} \qquad (16)$$

where:

T = total length of traverse, in inches (millimeters);
n = average number of air-void sections intersected per inch or per millimeter of traverse;
T_λ = number of lines of traverse included in total traverse;
L_s = length of traverse between stops, in inches (millimeters);
N = total number of air voids intersected in entire traverse;
C = average chord intercept of air-void sections on line of traverse, in inches (millimeters);
α = specific surface; and
S_t = as previously defined in equation (13).

16.1.3 *Spacing Factor.*-If the paste content of the concrete is known, calculate the spacing factor, L, as follows:

When $\frac{p}{A} \leq 4.342$,

$$L = \frac{p}{400\,n} \qquad (17)$$

When $\frac{p}{A} > 4.342$,

$$L = \frac{3}{\alpha}\left[1.4\left(\frac{p}{A} + 1\right)^{1/3} - 1\right] \qquad (18)$$

where:

p/A = paste-air ratio, or the reciprocal of A/p;
L = spacing factor, in inches (millimeters);
p = paste content, in volume percent of concrete; and
Other terms as previously defined.

16.2 When calculations are to be based on air-paste ratio, proceed as follows:

16.2.1 *Air-Paste Ratio.*-Calculate the air-paste ratio from results of point-count analysis as follows:

$$\frac{A}{p} = \frac{S_v}{S_p} \qquad (19)$$

where:

A/p = air-paste ratio,
S_p = total number of stops where index point is superimposed on a section of cement paste (counter No. 4), and
S_v = as defined in equation (12).

16.2.2 *Specific Surface.*-Calculate the specific surface as follows:

Initially, determine total length of traverse through paste and number of air-void sections per inch or per millimeter:

$$T_p = (S_t - T_\lambda)\left(\frac{S_p}{S_t}\right) L_s \qquad (20)$$

$$n_p = \frac{N}{T_p}$$

Determine average chord intercept:

$$C = \frac{\left(\frac{A}{P}\right)}{n_p} \qquad (21)$$

Then, calculate specific surface using equation (16).

where:

T_p = total length of traverse through paste, in inches (millimeters);
n_p = average number of air-void sections intersected per inch or per millimeter of traverse in paste; and
Other terms as previously defined.

16.2.3 *Spacing Factor.*–Calculate the spacing factor, L, as follows:

When $\frac{P}{A} \leq 4.342$,

$$L = \frac{1}{4n_p} \qquad (22)$$

When $\frac{P}{A} > 4.342$, use equation (18).

All terms as previously defined.

16.2.3.1 If desired, the spacing factor may be estimated graphically using figure 2 or 3.

16.2.4 *Air-Void Content.*–Calculate the air-void content as follows:

$$A = \frac{\left(\frac{A}{P}\right)(100)}{\left(\frac{A}{P}\right) + 1 + \left(\frac{G}{P_1}\right)} \qquad (23)$$

where:

P_1 = percent by volume of air-free paste in mixture proportions as batched,
G = percent by volume of total aggregate in mixture proportions as batched,
A/p = air-paste ratio as calculated in section 16.2.1, and
A = as previously defined.

16.3 The Bureau does not use the modified point-count method; therefore, no typical forms or data are included with this procedure.

17. Report

17.1 A typical reporting form showing the results of the linear traverse (Rosiwal) method and the modified point-count method is shown on figure 6. The report should include:

- Identification of source of samples.
- Location from which samples were taken and samples orientation with respect to sources.
- Orientation and position of slabs cut from samples for traversing.
- Length of traverse and, if modified point-count method is used, the number of stops.
- Determined values of air-void content, specific surface, spacing factor, and air-paste ratio (if measured). If parameters of air-void system have been determined on one or more near-surface sections, relationship of such parameters to depth from finished or formed surface for test concrete and reference concrete, respectively, should be included.
- A comparison between determined values of air-void content, specific surface, spacing factor, and air-paste ratio with the values recommended by the American Concrete Institute Committee 613 for freeze-thaw resistant portland cement concrete, see figure 3.

18. Precision and Bias of Air-Content Results

18.1 Precision criteria for judging air-content results obtained by the point-count method are given in table 4.

18.2 A bias statement has not been established at this time.

Table 4. – Single operator standard deviation (1S) for indicated air content using the modified point-count method.[1]

Nominal or observed maximum size aggregate in concrete	Number of points	Air content, percent				
		1	3	5	7	9
6 inches (150 mm)	2400	0.20	0.35	0.45	0.52	0.59
3 inches (75 mm)	1800	.23	.40	.52	.60	.67
1-1/2 inches (37.5 mm)	1500	.26	.44	.56	.66	.74
1 inch (25.0 mm)	1425	.26	.45	.58	.68	.76
3/4 inch (19.0 mm)	1350	.27	.46	.59	.69	.78
1/2 inch (12.5 mm)	1200	.29	.49	.63	.74	.83
3/8 inch (9.5 mm)	1125	.30	.51	.65	.76	.85
No. 4 (4.75 mm)	1000	.31	.54	.69	.81	.91

[1] Values shown are the theoretical maximum standard deviations when number of points counted is the minimum shown in table 3. The difference between the results of two properly conducted tests (D2S) should not exceed 2.83 times the standard deviations shown. The precision for the linear traverse method has not been determined.

19. References

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Spec. or Solic. No. NA	Structure NA	Tested by G. SHELDON Date 9-4-84
Project CONCRETE RESEARCH	Item SPECIMEN No. MEF-1 Location ~	Computed by G. SHELDON Date 9-4-84
Feature DR-428	Station ~ Offset ~ Depth ~ to ~	Checked by NOT CHECKED Date

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF THE AIR-VOID SYSTEM IN HARDENED CONCRETE—LINEAR TRAVERSE METHOD

Reading No.	Cumulative Voids	Void "Zero"	Void "End"	Total "Zero"	Total "End"	Reading No.	Cumulative Voids	Void "Zero"	Void "End"	Total "Zero"	Total "End"
1	28	0	27.77	82,000.00	82,203.52	16	531		399.38		85,228.86
2	73		58.52		82,403.30	17	577		430.10		85,428.47
3	108		79.95		82,606.06	18	613	0	20.76		85,630.10
4	130		103.63		82,808.10	19	657		45.78		85,832.04
5	161		121.40		83,012.32	20	685		67.88		86,034.47
6	185		135.66		83,217.22	21	719		100.30		86,233.33
7	212		153.31		83,421.50	22					
8	242		171.81		83,624.87	23					
9	274		203.44		83,824.55	24					
10	297		219.30		84,028.89	25					
11	336		251.14		84,228.42	26					
12	376		280.05		84,428.83	27					
13	399		295.51		84,633.79	28					
14	439		323.20		84,834.38	29					
15	481		356.52		85,033.33	30					

NOTES:

On this apparatus, the void counter only reads to 50c. For this test, the counter was reset to zero after reading No. 17. The Void "End" column and readings 17 thru 21 are cumulative to give total length of traverse across voids.

Figure 4. – Typical data sheet for determination of air-void distribution.

Spec. or Solic. No. NA	Structure NA	Tested by G. SHELDON — Date 9-4-84
Project CONCRETE RESEARCH	Item SPECIMEN No. MEF-1 Location ~	Computed by G. SHELDON — Date 9-4-84
Feature DR-428	Station ~ Offset ~ Depth ~ to ~	Checked by NOT CHECKED — Date

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF THE AIR-VOID SYSTEM IN HARDENED CONCRETE—LINEAR TRAVERSE METHOD

N (Total Number of Air Voids Intersected in Entire Traverse), Reading = 719

P_u (Upper Level Screw Traversing Air Voids), Calibration Factor: 1/120.048 = 0.008330 inch/rev.

R_u (Total Number of Revolutions of Upper Lead Screw), Reading = 530.40 rev.

P_m (Main Lead Screw Traversing Entire Specimen), Calibration Factor: 1/40.007 = 0.02500 inch/rev.

R_m (Total Number of Revolutions of Main Lead Screw), Final Reading of Total "End" Column Minus Initial Reading of Total "Zero" Column: 86,233.33 - 82,000.00 = 4233.33 rev.

P_uR_u (Length of Traverse Across Voids), (0.008330)(530.40) = 4.42 inches

P_mR_m (Length of Traverse Across Non-Voids), (0.02500)(4233.33) = 105.83 inches

C (Average Chord Intercept of Air Voids) = P_uR_u/N = 4.42 / 719 = 0.00615 inches

α (Specific Surface) = $4/C$ = 4/0.00615 = 650 inch^{-1}

A (Air-Void Content), Air-Paste Ratio Not Determined:
T (Total Length of Traverse) = $P_uR_u + P_mR_m$ = 4.42 + 105.83 = 110.25 inches
n (Average Number of Air-Void Sections Intercepted) = N/T = 719 /110.25 = 6.52 per inch
$A = 100\,nC$ = (100)(6.52)(0.00615) = 4.01 % or, Where P_mR_m Equals Total Length of Traverses Minus the Sum of Traverses Across Voids, $A = (100\,P_uR_u)/(P_uR_u + P_mR_m)$ = (100)(4.42)/(4.42 + 105.83) = 4.01 %

L (Spacing Factor), Paste Content of Concrete Known:
p (Paste Content, Volume Percent of Concrete) = (100)(Σ Cement Volume, Fly Ash, Water) Divided by Total Volume of Batch* = (100) (0.2456 + 0.1468 + 0.0367)/ 1.5 = 28.61 %
p/A = 28.61 / 4.01 = 7.13
When $p/A \leq 4.342$, $L = p/400n$ or $p/A\alpha$ = _____/(400)(   ) = _____ inch
= _____/(   )(   ) = _____ inch

When $p/A > 4.342$, $L = \frac{3}{\alpha}\left[1.4\left(\frac{p}{A}+1\right)^{1/3} - 1\right] = \frac{3}{650}\left[1.4\,(7.13+1)^{1/3} - 1\right]$ = 0.0084 inch

NOTES:
* These quantities obtained from mix design.

Figure 5a. - Typical calculations for air-void determination (inch-pound units).

Spec. or Solic. No. NA	Structure NA	Tested by Date G. SHELDON 9-4-84
Project CONCRETE RESEARCH	Item SPECIMEN No. MEF-1 Location ~	Computed by Date G. SHELDON 9-4-84
Feature DR-428	Station ~ Offset ~ Depth ~ to ~	Checked by Date NOT CHECKED

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF THE AIR-VOID SYSTEM IN HARDENED CONCRETE—LINEAR TRAVERSE METHOD

N (Total Number of Air Voids Intersected in Entire Traverse), Reading = 719

P_u (Upper Level Screw Traversing Air Voids), Calibration Factor: 1/4.725 = 0.2116 mm/rev.

R_u (Total Number of Revolutions of Upper Lead Screw), Reading = 530.40 rev.

P_m (Main Lead Screw Traversing Entire Specimen), Calibration Factor: 1/1.575 = 0.6350 mm/rev.

R_m (Total Number of Revolutions of Main Lead Screw), Final Reading of Total "End" Column Minus Initial Reading of Total "Zero" Column: 86,233.33 - 82,000.00 = 4233.33 rev.

P_uR_u (Length of Traverse Across Voids), (0.2116)(530.40) = 112.2 mm

P_mR_m (Length of Traverse Across Non-Voids), (0.6350)(4233.33) = 2688.1 mm

C (Average Chord Intercept of Air Voids) = P_uR_u/N = 112.2 / 719 = 0.156 mm

α (Specific Surface) = $4/C$ = 4/0.156 = 25.6 mm^{-1}

A (Air-Void Content), Air-Paste Ratio Not Determined:
T (Total Length of Traverse) = $P_uR_u + P_mR_m$ = 112.2 + 2688.1 = 2800.3 mm
n (Average Number of Air-Void Sections Intercepted) = N/T = 719 /2800.3 = 0.257 per mm
$A = 100\,nC$ = (100)(0.257)(0.156) = 4.01 % or, Where P_mR_m Equals Total Length of Traverses Minus the Sum of Traverses Across Voids, $A = (100\,P_uR_u)/(P_uR_u + P_mR_m)$ = (100) (112.2)/(112.2 + 2688.1) = 4.01 %

L (Spacing Factor), Paste Content of Concrete Known:
p (Paste Content, Volume Percent of Concrete) = (100)(Σ Cement Volume, Fly Ash, Water) Divided by Total Volume of Batch* = (100) (0.006955 + 0.004157 + 0.001039)/0.042475 = 28.61 %
p/A = 28.61 / 4.01 = 7.13
When $p/A \leq 4.342$, $L = p/400n$ or $p/A\alpha$ = ______ /(400)( ) = ______ mm
= ______ /( )( ) = ______ mm

When $p/A > 4.342$, $$L = \frac{3}{\alpha}\left[1.4\left(\frac{p}{A}+1\right)^{1/3} - 1\right] = \frac{3}{25.6}\left[1.4\,(7.13+1)^{1/3} - 1\right] = 0.213 \text{ mm}$$

NOTES:
* These quantities obtained from mix design.

Figure 5b. - Typical calculations for air-void determination (SI-metric).

Spec. or Solic. No. NA	Structure NA	Tested by G. SHELDON	Date 9-4-84
Project CONCRETE RESEARCH	Item SPECIMEN NOS. MEF & PF Location ~	Computed by G. SHELDON	Date 9-4-84
Feature DR-428	Station ~ Offset ~ Depth ~ to ~	Checked by NOT CHECKED	Date

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF THE AIR-VOID SYSTEM IN HARDENED CONCRETE—LINEAR TRAVERSE METHOD

Specimen No.	A Air Content, percent	C Average Chord Intercept, inch	α Specific Surface, inch^{-1}	n No. of Voids Intercepted, per inch	p Paste Content, percent	p/A Paste-Air Ratio	$\bar{L}$ Spacing Factor, inch
MEF-1	4.01	0.00615	650	6.52	28.61	7.13	0.0084
MEF-7	4.36	0.0066	603	6.57	28.61	6.56	0.0087
MEF-10	4.29	0.0063	635	6.81	28.61	6.67	0.0083
PF-1	4.33	0.0092	437	4.74	28.61	6.61	0.0120
PF-4	4.39	0.0103	387	4.25	28.61	6.52	0.0135
PF-10	4.32	0.0104	386	4.17	28.61	6.62	0.0136
PF-37	4.60	0.0035	1,158	13.31	28.61	6.22	0.0044
PF-43	5.38	0.0039	1,037	13.93	28.61	5.32	0.0046
PF-46	5.46	0.0040	997	13.62	28.61	5.24	0.0047

NOTES:

Figure 6a. – Summary of air-void parameters (inch-pound units).

Spec. or Solic. No. NA	Structure NA	Tested by G. SHELDON Date 9-4-84
Project CONCRETE RESEARCH	Item SPECIMEN NOS. MEF & PF Location ~	Computed by G. SHELDON Date 9-4-84
Feature DR-428	Station ~ Offset ~ Depth ~ to ~	Checked by NOT CHECKED Date

MICROSCOPICAL DETERMINATION OF AIR-VOID CONTENT AND PARAMETERS OF THE AIR-VOID SYSTEM IN HARDENED CONCRETE—LINEAR TRAVERSE METHOD

Specimen No.	A Air Content, percent	C Average Chord Intercept, mm	α Specific Surface, mm^{-1}	n No. of Voids Intercepted, per mm	p Paste Content, percent	p/A Paste-Air Ratio	L Spacing Factor, mm
MEF-1	4.01	0.156	25.6	0.257	28.6	7.13	0.213
MEF-7	4.36	0.168	23.7	0.259	28.6	6.56	0.221
MEF-10	4.29	0.160	25.0	0.268	28.6	6.67	0.211
PF-1	4.33	0.234	17.2	0.187	28.6	6.61	0.305
PF-4	4.39	0.262	15.2	0.167	28.6	6.52	0.343
PF-10	4.32	0.264	15.2	0.164	28.6	6.62	0.345
PF-37	4.60	0.089	45.6	0.524	28.6	6.22	0.112
PF-43	5.38	0.099	40.8	0.548	28.6	5.32	0.117
PF-46	5.46	0.102	39.3	0.536	28.6	5.24	0.119

NOTES:

Normally, the air content and spacing factor should be reported to only two significant digits; however, these values are shown to three significant digits here to reduce rounding variations for checking calculation procedures.

Figure 6b. – Summary of air-void parameters (SI-metric).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4469-92

PROCEDURE FOR

STATIC MODULUS OF ELASTICITY AND POISSON'S RATIO OF CONCRETE IN COMPRESSION

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, Code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4469; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 469-83.

1. Scope

1.1 This designation covers the procedures for determination of: (1) Young's chord modulus of elasticity, and (2) Poisson's ratio of molded concrete cylinders and diamond-drilled concrete cores under longitudinal compressive stress.

2. Applicable Documents

2.1 *USBR Procedures*:
1104 Load Verification of Testing Machines
4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4172 Sampling Freshly Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory
4617 Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:
C 174 Standard Method of Measuring Length of Drilled Concrete Cores[1]
C 469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression[1]
E 6 Standard Definitions of Terms Relating to Methods of Mechanical Testing[2]
E 83 Standard Method of Verification and Classification of Extensometers[2]

3. Summary of Procedure

3.1 A cylindrical concrete specimen is loaded in compression at a prescribed rate. Longitudinal and, if desired, transverse strains are measured at two stipulated stress levels. The modulus of elasticity is computed as the ratio of change in stress to change in longitudinal strain. Poisson's ratio is computed as ratio of change in transverse strain to change in longitudinal strain.

4. Significance and Use

4.1 This test procedure provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete at designated age and curing conditions.

4.2 The modulus of elasticity and Poisson's ratio values, applicable within the customary working stress range of 0 to 40 percent of ultimate concrete strength, may be used in sizing reinforced and nonreinforced structural members, establishing quantity of reinforcement, and computing stress for observed strains.

NOTE 1.-This method of calculating elasticity and Poisson's ratio should be limited to cylinders or cores with concrete strengths less than 6,000 lbf/in^2 (41.4 MPa) because the working stress range is increased above 1,000 lbf/in^2 (6.9 MPa) with the current high-strength concrete being used in some construction.

4.3 The modulus of elasticity values obtained will usually be less than values derived under rapid load application, e.g. dynamic or seismic rates, and will usually be greater than values obtained under slow load application or extended load duration, other test conditions being the same.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM E 6.

6. Interferences

6.1 The upper loading value is a function of the strength and elasticity of the concrete at time of testing. Care must be taken during preliminary loading to ensure that overloading does not occur.

7. Apparatus

7.1 *Testing Machine*.-Any type of testing machine capable of imposing a load at the rate and magnitude prescribed in section 13.3 may be used. The machine shall

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 03.01

conform to requirements of USBR 1104, and spherical head and bearing blocks shall conform to section 5 of USBR 4039.

7.2 *Compressometer.*-For determining modulus of elasticity, a bonded or unbonded sensing device shall be provided for measuring, to nearest 10 millionths, the average deformation of two diametrically opposite gauge lines, each parallel to the axis, and each centered about midheight of specimen. The effective length of each gauge line shall be not less than three times the maximum size of aggregate in concrete nor more than two-thirds height of specimen. The preferred length of gauge line is one-half height of specimen. Gauge points may be embedded in or cemented to specimen, and deformation of the two lines read independently; or a compressometer may be used consisting of two yokes, one of which is rigidly attached to specimen and the other attached at two diametrically opposite points so that it is free to rotate. At one point on rotating yoke, midway between two support points, a long pivot rod shall be used to maintain a constant distance between yokes so that at the opposite point on circumference the change in distance between yokes is equal to the sum of deformations of the two diametrically opposite gauge lines. Deformation may be measured by a dial gauge (used directly), with a lever multiplying system, a wire strain gauge, or by a linear variable differential transformer.

7.3 *Extensometer.*-If Poisson's ratio is desired, transverse strain shall be determined by: (1) an unbonded extensometer capable of measuring to nearest 25μinch (0.635μm) the change in diameter at midheight of specimen, or (2) two bonded strain gauges mounted circumferentially at diametrically opposite points at midheight of specimen and capable of measuring circumferential strain to nearest 10 millionths. A combined compressometer and extensometer is a convenient unbonded device. Figure 1 shows such a device. This apparatus shall contain a third yoke, consisting of two equal segments, located halfway between the two compressometer yokes and attached to specimen at two diametrically opposite points. Midway between these points a short pivot rod, adjacent to long pivot rod, shall be used to maintain a constant distance between bottom and middle yokes. The middle yoke shall be hinged at pivot point to permit rotation of the two yoke segments in the horizontal plane. At opposite point on circumference, the two segments shall be connected through a dial gauge or other sensing device capable of measuring transverse deformation to nearest 50μinch (1.27μm) so that this deformation is twice (or more if eccentricity of gauge exceeds that of hinge) the transverse deformation of specimen diameter.

7.4 Instruments for compression testing of cylinders larger than 6 by 12 inches (152 by 305 mm) are of same basic design as compressometer, except that the two sets of instruments are separate.

7.5 A balance or scale, accurate to 0.1 lb (0.045 kg), shall be provided if necessary.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

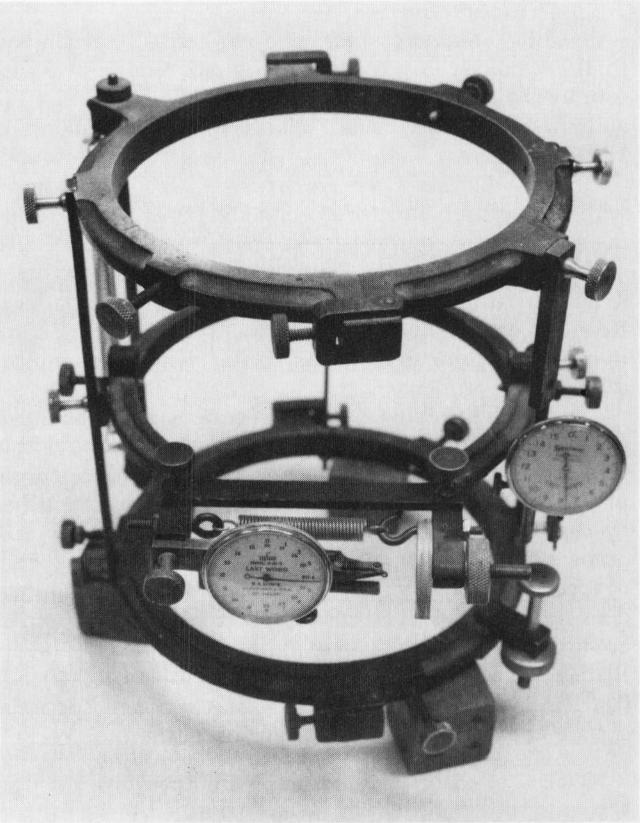


Figure 1. - Suitable combined compressometer-extensometer.

8.2 In all compression tests, the main precaution to be observed, particularly in the case of concrete or masonry specimens, is to prevent impact loading. Accordingly, after specimens have been properly positioned on lower platen, the cross head should be moved by the electric motor to within about 0.5 inch (13 mm) of specimen. Then, the hydraulic pump is turned on and the power ram brought into contact *very slowly* with the specimens. Other precautions would be to avoid eccentric loadings; use only a safe procedure in handling of all specimens, large or small, and avoid backing up to "pick up" any readings that might have been missed. If, on the contrary, significant readings must be picked up, load should be relieved to a considerable point (as long as maximum peak load has not exceeded yield point) below desired reading, then slowly work back up to the desired load.

9. Sampling, Test Specimens, and Test Units

9.1 Freshly mixed concrete shall be sampled in accordance with the provisions of USBR 4172.

9.2 Hardened concrete shall be sampled in accordance with the provisions of USBR 4042.

9.3 *Test Specimens*:

9.3.1 *Molded Cylindrical Specimens*.–Test cylinders shall be molded in accordance with the requirements for compression test specimens of USBR 4192, or USBR 4031, and shall be capped in accordance with requirements of USBR 4617.

9.3.2 *Drilled Core Specimens*.–Cores shall comply with the requirements for drilling and moisture conditioning applicable to compressive strength specimens of USBR 4042, except that only diamond-drilled cores having a length-to-diameter ratio greater than 1.50 shall be used. Requirements relative to storage and to ambient conditions immediately prior to test shall be the same as for molded cylindrical specimens (12.1).

9.3.3 The ends of test specimens shall be made perpendicular to the axis within ±0.5°, and plane within 0.002 inch (0.05 mm). If specimen as cast does not meet planeness requirements, planeness shall be accomplished by capping in accordance with USBR 4617, by lapping, or by grinding. Aggregate popouts which occur at ends of specimens may be repaired provided total area of popouts does not exceed 10 percent of specimen area and repairs are made before capping or grinding is completed (note 2). Planeness will be considered within tolerance when a 0.002-inch feeler gauge will not pass between specimen surface and a straightedge held against surface.

NOTE 2.–Repairs may be made by epoxying dislodged aggregate back in place or by filling void with capping material and allowing adequate time for it to harden.

9.3.4 The diameter of test specimen shall be measured by caliper to nearest 0.01 inch (0.25 mm) by averaging two diameters measured at right angles to each other near center of length of specimen. This average diameter shall be used for calculating cross-sectional area. The length of a molded specimen, including caps, shall be measured and reported to nearest 0.1 inch (2.5 mm). The length of a drilled specimen, including caps, shall be measured in accordance with ASTM C 174, and shall also be reported to nearest 0.1 inch.

9.3.5 If there are no companion specimens available for determination of compressive strength, and if approximate density of specimen is not known, the mass shall be determined immediately prior to test and recorded to nearest 0.1 lbm (0.045 kg). The density shall be calculated by dividing the mass of the specimen by its volume as calculated from the dimensions obtained in 9.3.4. The result shall be expressed to the nearest 1 lbm/ft^3 or 1 kg/m^3.

10. Preparation of Apparatus

10.1 The method for mounting the compressometer-extensometer, the instrument normally used for measuring strains, on the specimen is described in this section. First, set the capped cylinder on a flat surface and place two wooden blocks on opposite sides of the specimen. Lower the compressometer-extensometer into position on top of the blocks; this operation automatically elevates the compressometer one-sixth of the height above the base of the specimen. Center the upper yoke and tighten firmly against the cylinder the two pointed screws that hold the ring in place. Remove the wooden blocks, and tighten the three screws in the center ring with the specimen centered in the frame. Tighten the two screws in the center ring against the the cylinder, and loosen the spacer bars connecting the three yokes. Install dials between upper and lower yokes and on center yoke. Figure 2 shows a 6- by 12-inch (152- by 305-mm) concrete cylinder with a compressometer-extensometer mounted and ready for use.

NOTE 3.–After dials have been installed on compressometer-extensometer, it is not necessary that they be removed until the day's test schedule has been completed.

NOTE 4.–On larger specimens, longitudinal deformation rods and lateral ring may be held in place by fittings installed in inserts placed in mold prior to casting, or installed by drilling into specimen and cementing insert or tab in place after receipt of specimen. On these larger specimens, three dials may be used to measure longitudinal deformation, and six dials to measure lateral deformation.

10.2 When measurements are to be made using bonded strain gauges, smooth the area to receive the gauges by wire brushing or sanding. Remove loose dust from surface

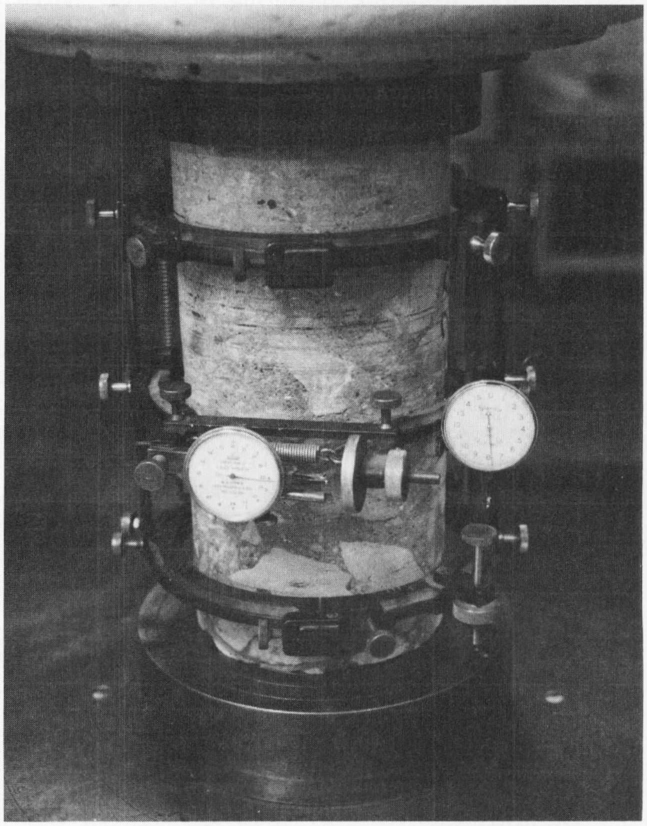


Figure 2. – A 6- by 12-inch (152- by 305-mm) concrete cylinder with a compressometer-extensometer mounted and ready for use.

by air jet or light brushing. Dry surface of concrete to receive gauge. Apply a leveling and precoat of epoxy adhesive to concrete. After sealing coat has hardened, abrade surface with silicon-carbide paper. Bond gauge to specimens using a high-strength epoxy adhesive.

11. Calibration and Standardization

11.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

11.2 Procedures for calibrating strain measuring devices are given in ASTM E 83.

11.3 A frame constant must be determined for each compressometer-extensometer frame. This constant is determined from gauge length, eccentricity of gauge, and the hinge from the axis of specimen (sec. 14).

12. Conditioning

12.1 Specimens shall be subject to the specific curing conditions, and tested at the age for which elasticity information is desired. Specimens shall be tested within 1 hour after removal from curing or storage room when using unbonded strain measuring devices. Specimens removed from a moist room for testing shall be kept moist by a wet cloth covering during interval between removal and test.

12.2 Adhesives do not adhere well to wet surfaces. When using bonded strain measuring devices, area of surface to which gauges must be bonded needs to be surface dried with a minimum of drying occurring to test specimens as a whole. On removal of specimen from moist room, wrap specimen in plastic. Cut windows in the plastic where strain gauges are to be applied. Seal plastic around the windows to the specimen when sealant adhesive is applied to specimen as described in 10.2. If significant drying occurs, waterproof gauges and return specimen to moist room before testing.

12.3 Maintain ambient temperature and humidity as constant as possible throughout test. Record any unusual fluctuation in temperature or humidity in the report (sec. 15).

13. Procedure

13.1 If companion specimens are available, determine compressive strength in accordance with USBR 4039 prior to test for modulus of elasticity.

13.2 Place the specimen, with strain-measuring equipment attached, on lower platen or bearing block of testing machine. Carefully align axis of specimen with center of thrust of spherically seated upper bearing block. Note reading on strain indicators. As bearing block is brought slowly to bear upon specimen, rotate movable portion of block gently by hand so that uniform seating is obtained.

13.3 Compression loads are applied at the rate of 2,000 lbf/in² (13.9 MPa) per minute unless otherwise specified. Briefly, the procedure for routine compression testing by hydraulic machine is as follows: First, rotate dial knob to proper dial range and turn on air supply; then adjust rate-of-loading device to proper range for dial to be used. When the rate-of-loading device is adjusted, the load-pacing disk moves at a uniform clockwise rate. The load-indicating hand is controlled manually to follow one of the dots on the rate-of-loading disk. The compression specimen should then be placed directly on lower platen of machine or on an elevated block which rests on lower platen. The specimen should be centered under spherical bearing head and the cross head moved down to between 0.5 and 1 inch (13 and 25 mm) of the top of specimen. For the Bureau's 5-million-pound force (22 241-kN) testing machine, the adjustable platen on the bottom of the sensitive cross head is adjusted by electric motors which rotate a disk cam. The hydraulic pump is started, release valve (left hand) is closed, and the control valve (right hand) is opened. Thus, the compression loading is initiated.

13.4 *Load Specimen Twice.*-If a companion specimen has been tested for strength and strength exceeds 3,000 lbf/in² (20.7 MPa), extend the first loading, on which no readings are taken, to 1,000 lbf/in² (6.9 MPa). If strength is unknown, load until either a stress of 1,000 lbf/in² or strain given in table 1, whichever comes first, is attained. Use this value for upper load on second loading when readings are taken. On both loadings, apply load continuously and without shock at a constant rate within the range of 35±5 lbf/in² (241±34.5 kPa) per second. On first loading, observe performance of gauges and correct any unusual behavior prior to second loading. On second loading, record (without interruption of loading) the longitudinal strain at the point (1) when compressive stress is zero, (2) 100 lbf/in² (689 kPa), and (3) maximum load as previously determined. If Poisson's ratio is to be determined, record transverse strain at the same points. Record results on test record form, figure 4. If specimen is to be tested to destruction, remove the load and compressometer-extensometer prior to reloading for strength test. When measuring with expandable bonded strain measuring devices, continue the second loading to failure without interruption of loading.

Table 1. - Maximum strain values.

Density at time of test,		Max. strain at age indicated, $\times 10^{-6}$	
lbm/ft³	kg/m³	7 Days or more	Less than 7 days
≥ 205	≥ 3284	300	200
165-204	2643-3268	375	250
135-164	2162-2627	450	300
115-134	1842-2146	525	350
105-114	1682-1826	600	400
95-104	1522-1666	675	450
85-94	1362-1506	750	500
75-84	1201-1346	825	550

14. Calculations

14.1 When bonded gauges are used as measuring devices, the longitudinal and lateral deformations for calculating the modulus of elasticity and Poisson's ratio are obtained directly. When a compressometer-extensometer frame is used, the deformations need to be adjusted for the frame constants. If hinge of frame is same distance from center of specimen as dial gauge, the measured readings are amplified by a factor of 2 over the actual deformation and the measured readings should be multiplied by a factor of 0.5. If distances are not the same, correction can be calculated as follows:

$$FR_{LO} \text{ or } FR_{LA} = \frac{e_r}{e_r + e_g} \tag{1}$$

where:

FR_{LO} = longitudinal frame ratio,
FR_{LA} = lateral frame ratio,
e_r = longitudinal or lateral eccentricity of rod measured to nearest 0.01 inch, and
e_g = longitudinal or lateral eccentricity of gauge measured to nearest 0.01 inch from axis of specimen.

$$FC_{LO} = \frac{FR_{LO}}{GL} \tag{2}$$

where:

FC_{LO} = longitudinal frame constant, and
GL = gauge length in inches (millimeters)

$$E = \frac{S}{(FC_{LO})\,(SR_{LO})} \tag{3}$$

where:

E = modulus of elasticity in pound force per square inch (gigapascals),
S = stress in pound force per square inch (megapascals), and
SR_{LO} = measured longitudinal strain, inch per inch (millimeter per millimeter).

$$D_{LO} = (FC_{LO})\,(SR_{LO}) \tag{4}$$

$$D_{LA} = \frac{(FR_{LA})\,(SR_{LA})}{d_a} \tag{5}$$

$$\mu = \frac{D_{LA}}{D_{LO}} \tag{6}$$

where:

D_{LO} = longitudinal deformation in inches (millimeters),
D_{LA} = unit lateral deformation in inches (millimeters),
SR_{LA} = measured lateral strain, inch per inch (millimeter per millimeter),
d_a = specimen diameter in inches (millimeters), and
μ = Poisson's ratio.

$$\mu = \frac{D_{LA}}{D_{LO}} = \frac{\dfrac{FR_{LA}\,(SR_{LA})}{d_a}}{(FC_{LO})\,(SR_{LO})}$$

$$= \frac{(FR_{LA})\,(SR_{LA})}{(FC_{LO})\,(SR_{LO})\,(d_a)} \tag{7}$$

Example (using inch-pound units):

If frame measurements are:

GL = 8.00 inches
e_r = 4.656 inches longitudinal and 3.503 inches lateral,
e_g = 4.641 inches longitudinal and 4.856 inches lateral, and from specimen No. 9 on figure 4:
S = 900 lbf/in^2,
d_a = 6.00 inches,
SR_{LO} = 35.25×10^{-4} inch, and
SR_{LA} = 4.85×10^{-4} inch, then:

Using equation (1):

$$FR_{LO} = \frac{4.656}{4.656 + 4.641} = 0.5008$$

Using equation (2):

$$FC_{LO} = \frac{0.5008}{8.00} = 0.0626$$

Using equation (3):

$$E = \frac{900}{(0.0626)(0.003525)}$$

$$= 4.08 \times 10^6 \text{ lbf/in}^2$$

Using equation (1):

$$FR_{LA} = \frac{3.503}{3.503 + 4.856} = 0.4191$$

Using equation (7):

$$\mu = \frac{(0.4191)(0.000485)}{(0.0626)(0.003525)(6.00)} = 0.154$$

14.1.1 Figure 3 shows a typical form for determining the frame ratios and frame constant.

14.2 This section describes the method of obtaining the modulus of elasticity and Poisson's ratio from bonded gauges with equipment currently being used at the Bureau's Denver Office. Other readout equipment could also be used without changing the test procedure. A printout of the data is shown on figure 5, and a plot of the data is shown on figure 6. The present program is in inch-pound units; figures are not presented using metric terminology.

14.2.1 After strain gauges have been installed on concrete cylinder, they must be connected to a readout device. The readout device currently in use is a system consisting of a multiplexer and analog-to-digital converter that is interfaced to a digital computer. The two axial strain gauges and two precision resistors are connected in a full-bridge configuration for sensitive detection of strain in the strain gauges. The two strain gauges are positioned in opposite legs of the bridge so that their outputs are averaged. The bridge is excited using a 5-volt, d-c power supply, and output of bridge is connected to multiplexer. The lateral pair of strain gauges is connected in a similar bridge and its output is connected to another channel of the multiplexer as are the electrical load output of the testing machine and the bridge excitation voltage. The digital computer is programmed to read voltages using the multiplexer and analog-to-digital converter at the rate of about two times per second and then to calculate the strains and stresses which it then plots on its CRT display and saves for hardcopy plotting and printer after the test.

14.2.2 The computer program for calculating strain is based on the strain gauge equations for an unbalanced bridge. This calculation requires that the output of the bridge and excitation voltage be read initially with specimen in an unstrained state and then again as specimen is being strained. Using this information and the gauge factor of the strain gauges, the strain can be computed using the following equations:

$$\text{Strain} = \frac{-2\,V_r}{GF\,(1 + V_r)} \qquad (8)$$

$$V_r = \frac{V_o}{V_i}\,(\text{strained}) - \frac{V_o}{V_i}\,(\text{unstrained}) \qquad (9)$$

where:

V_o = bridge output voltage,
V_i = bridge excitation voltage, and
GF = gauge factor of strain gauges.

14.2.3 The gauge factor of the strain gauges is entered by the operator before the test and the strain is calculated each time bridge output and excitation voltage is read for both the axial and lateral strain gauges. The load voltage output from testing machine is read at same time bridge outputs are read. By using area of cylinder entered by operator at beginning of test, the stress on the cylinder is also computed.

14.2.4 After test has been completed, the computer program gives the operator the options of plotting and/or printing the test data. Plotting of the data is done on a digital plotter which gives a plot of stress versus strain with both axial and lateral strains plotted on same set of axes. Printout of the data gives stress, axial strain, lateral strain, modulus of elasticity, and Poisson's ratio. Calculation of modulus of elasticity is performed by dividing stress at each point by strain at that point. This calculation is equivalent to calculating a chord modulus from zero. Calculation of the modulus for other chords can be done manually using data provided on printout. Poisson's ratio is calculated by dividing lateral strain at each point by axial strain at that point.

14.2.5 Because the automatic recording is on a timed interval rather than on a load interval, it is not possible to determine a chord modulus between 100 and 1,000 lbf/in^2 (0.00069 and 0.00690 GPa) exactly.

15. Report

15.1 Figure 4 shows a typical report, and it shall include:

- Specimen identification number
- Dimensions of specimen in inches (millimeters)
- Curing and environmental histories of specimen
- Age of specimen
- Strength of concrete (if determined)
- Density of concrete (if determined)
- Stress-strain curves (if plotted)
- Chord modulus of elasticity
- Poisson's ratio (if determined)

16. Precision and Bias

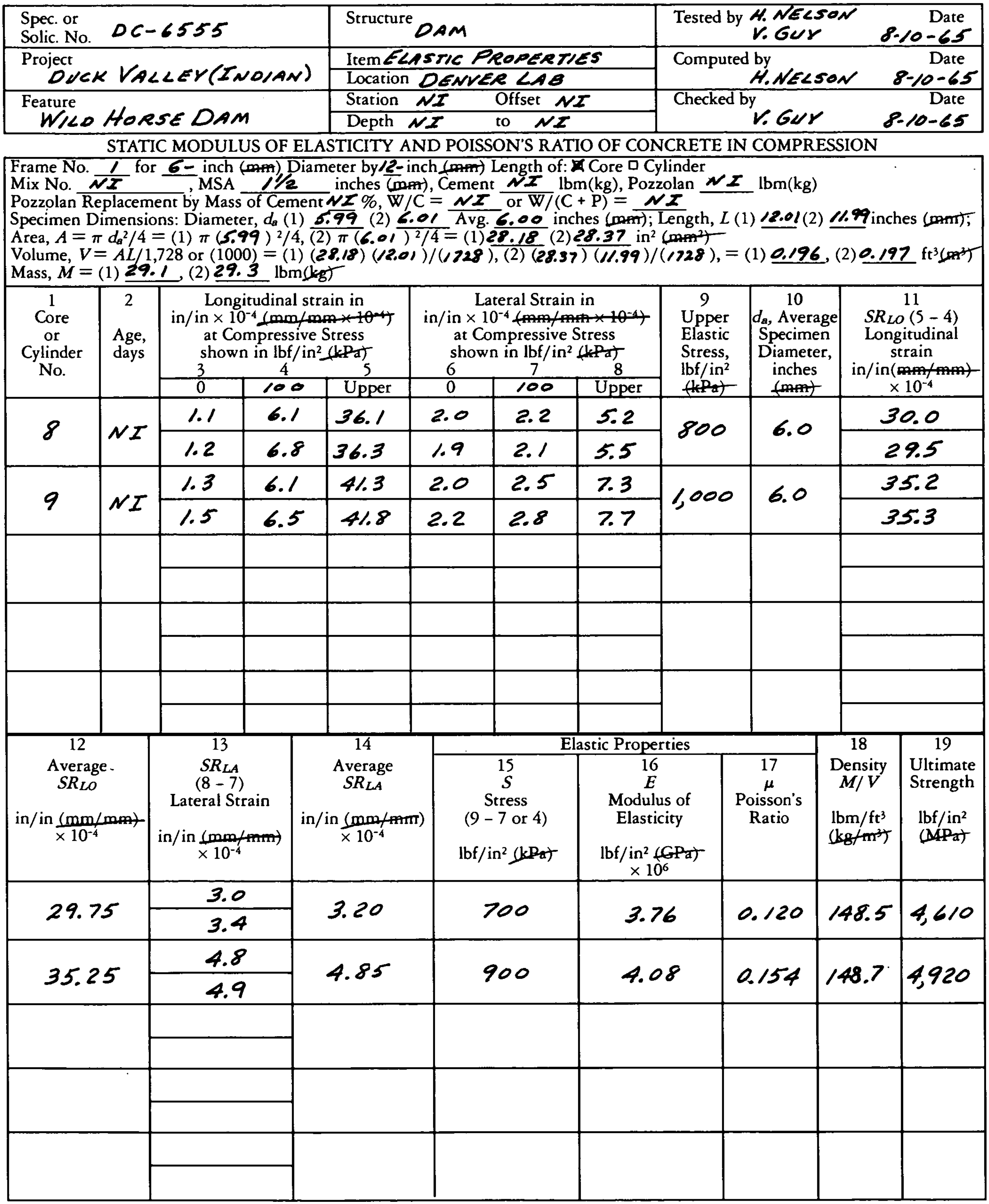
16.1 The precision and bias for this procedure have not been established.

Compressometer-Extensometer Deformation Data and Computations	Measured by H. NELSON	Date 8-10-65
	Computed by H. NELSON	Date 8-10-65
	Checked by V. GUY	Date 8-10-65

STATIC MODULUS OF ELASTICITY AND POISSON'S RATIO OF CONCRETE IN COMPRESSION

Frame ID	☒Core ☐ Cylinder Dia., inches ~~(mm)~~	Length, inches ~~(mm)~~	GL Gauge Length, inches ~~(mm)~~	e_r Eccentricity of Rod Long., inches ~~(mm)~~	Lat., inches ~~(mm)~~	e_g Eccentricity of Gauge Long., inches ~~(mm)~~	Lat., inches ~~(mm)~~	FR_{LO} Longitudinal Frame Ratio $\frac{e_r}{e_r + e_g}$	FR_{LA} Lateral Frame Ratio $\frac{e_r}{e_r + e_g}$	FC_{LO} Longitudinal Frame Constant $\frac{FR_{LO}}{G_L}$
1	6	12	8.00	4.656	3.503	4.641	4.856	0.5008	0.4191	0.0626

Figure 3.–Determination of longitudinal and lateral frame ratios and longitudinal frame constant.



Spec. or Solic. No. DC-6555	Structure DAM	Tested by H. NELSON V. GUY Date 8-10-65
Project DUCK VALLEY(INDIAN)	Item ELASTIC PROPERTIES Location DENVER LAB	Computed by H. NELSON Date 8-10-65
Feature WILD HORSE DAM	Station NI Offset NI Depth NI to NI	Checked by V. GUY Date 8-10-65

STATIC MODULUS OF ELASTICITY AND POISSON'S RATIO OF CONCRETE IN COMPRESSION

Frame No. 1 for 6- inch ~~(mm)~~ Diameter by 12- inch ~~(mm)~~ Length of: ☒ Core ☐ Cylinder

Mix No. NI, MSA 1½ inches ~~(mm)~~, Cement NI lbm(kg), Pozzolan NI lbm(kg)

Pozzolan Replacement by Mass of Cement NI %, W/C = NI or W/(C + P) = NI

Specimen Dimensions: Diameter, d_a (1) 5.99 (2) 6.01 Avg. 6.00 inches ~~(mm)~~; Length, L (1) 12.01 (2) 11.99 inches ~~(mm)~~;

Area, $A = \pi d_a^2/4$ = (1) π (5.99)^2/4, (2) π (6.01)^2/4 = (1) 28.18 (2) 28.37 in^2 ~~(mm^2)~~

Volume, $V = AL/1{,}728$ or (1000) = (1) (28.18) (12.01)/(1728), (2) (28.37) (11.99)/(1728), = (1) 0.196, (2) 0.197 ft^3 ~~(m^3)~~

Mass, M = (1) 29.1, (2) 29.3 lbm~~(kg)~~

1 Core or Cylinder No.	2 Age, days	Longitudinal strain in in/in × 10^{-4} ~~(mm/mm × 10^{-4})~~ at Compressive Stress shown in lbf/in^2 ~~(kPa)~~			Lateral Strain in in/in × 10^{-4} ~~(mm/mm × 10^{-4})~~ at Compressive Stress shown in lbf/in^2 ~~(kPa)~~			9 Upper Elastic Stress, lbf/in^2 ~~(kPa)~~	10 d_a, Average Specimen Diameter, inches ~~(mm)~~	11 SR_{LO} (5 – 4) Longitudinal strain in/in~~(mm/mm)~~ × 10^{-4}
		3 0	4 100	5 Upper	6 0	7 100	8 Upper			
8	NI	1.1	6.1	36.1	2.0	2.2	5.2	800	6.0	30.0
		1.2	6.8	36.3	1.9	2.1	5.5			29.5
9	NI	1.3	6.1	41.3	2.0	2.5	7.3	1,000	6.0	35.2
		1.5	6.5	41.8	2.2	2.8	7.7			35.3

12 Average SR_{LO} in/in ~~(mm/mm)~~ × 10^{-4}	13 SR_{LA} (8 – 7) Lateral Strain in/in ~~(mm/mm)~~ × 10^{-4}	14 Average SR_{LA} in/in ~~(mm/mm)~~ × 10^{-4}	Elastic Properties 15 S Stress (9 – 7 or 4) lbf/in^2 ~~(kPa)~~	Elastic Properties 16 E Modulus of Elasticity lbf/in^2 ~~(GPa)~~ × 10^6	Elastic Properties 17 μ Poisson's Ratio	18 Density M/V lbm/ft^3 ~~(kg/m^3)~~	19 Ultimate Strength lbf/in^2 ~~(MPa)~~
29.75	3.0	3.20	700	3.76	0.120	148.5	4,610
	3.4						
35.25	4.8	4.85	900	4.08	0.154	148.7	4,920
	4.9						

NI = NOT IDENTIFIED

Figure 4. – Typical data and reporting form.

USBR Concrete Laboratory
Elastic Properties Testing
Test: Arrowrock Dam, 6- by 12-inch
Spec: DH-2A/55.3 Compression
Date and Time: 10/08/87, 13:05

Stress, lbf/in^2	Axial Strain, ϵ_A	Lateral Strain, ϵ_L
22	5	2
37	10	3
199	44	9
317	69	14
436	95	18
554	122	23
672	149	28
790	176	32
908	203	37
1,025	231	42
1,143	259	47
1,260	287	52
1,378	315	57
1,495	345	62
1,613	374	67
1,730	404	72
1,850	434	77
1,967	466	82
2,081	497	88
2,194	528	93
2,308	561	98
2,425	597	104
2,543	633	110
2,661	676	118
2,779	727	130
2,896	777	141
3,015	835	152
3,133	905	163
3,251	981	177
3,368	1,066	198
3,482	1,174	245
3,512	1,214	271
3,540	1,264	304
3,566	1,330	351
3,593	1,429	424
3,615	1,607	572
3,625	1,934	1,297

Maximum Load = 3,625 lbf/in^2

Area to 70% = 0.853

Area 70% to ultimate = 4.403

Stress, lbf/in^2	Axial Strain, ϵ_A	Lateral Strain, ϵ_L
100	27	6
1,000	225	41

USBR Calculations
$E = 4.54 \times 10^6$, $\mu = 0.176$

Stress, lbf/in^2	Axial Strain, ϵ_A	Lateral Strain, ϵ_L
228	50	10
1,450	333	60

ASTM Calculations
$E = 4.31 \times 10^6$, $\mu = 0.176$

Figure 5. - Typical printout data.

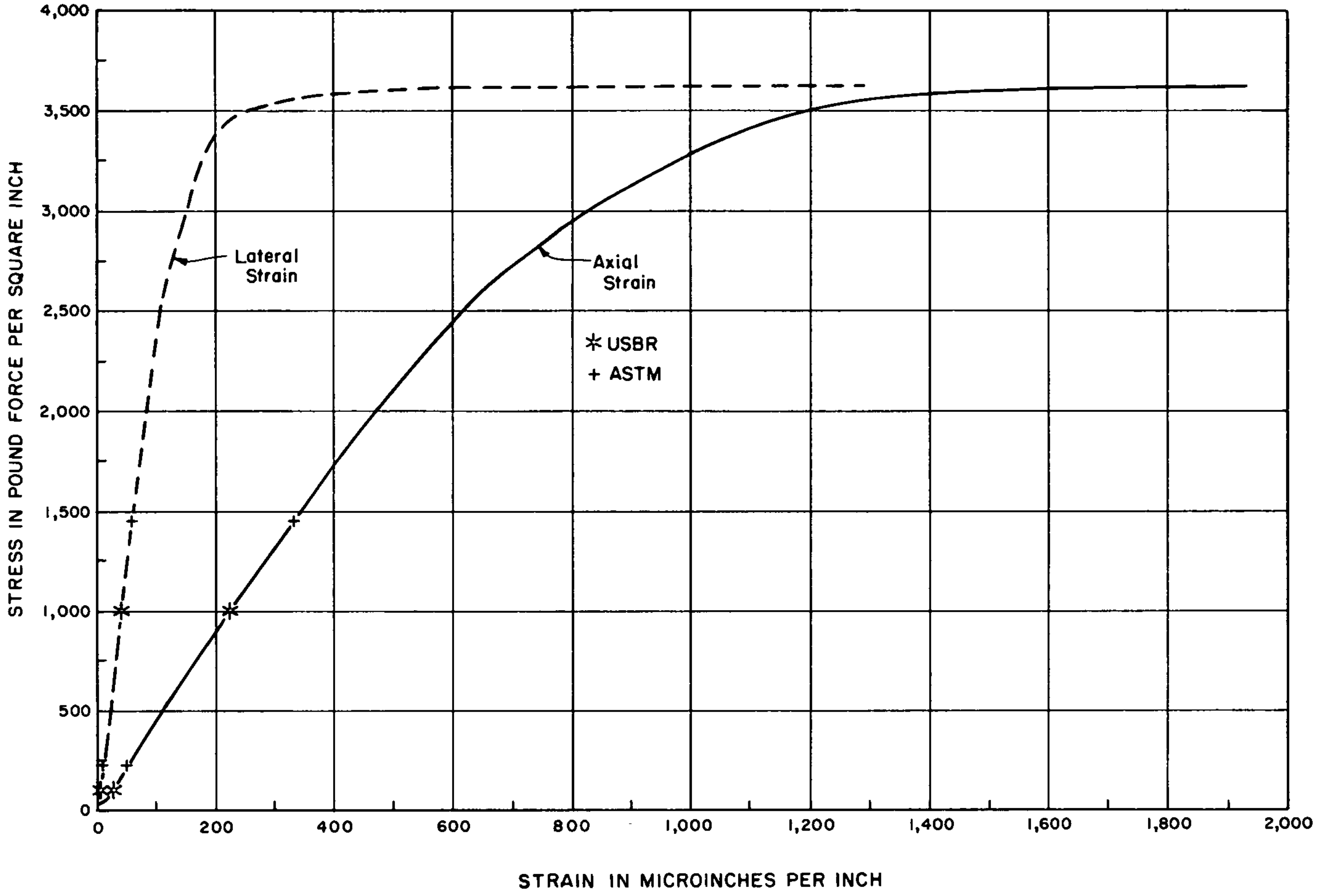


Figure 6. – Plot of data shown on figure 5.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4496-92

PROCEDURE FOR

SPLITTING TENSILE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4496; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 496-71 (Reapproved 1979).

1. Scope

1.1 This designation covers the procedure for determination of the splitting tensile strength of cylindrical concrete specimens such as molded cylinders and drilled cores.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1104 Load Verification of Testing Machines
4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standard*:
C 496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens[1]

2.3 *ACI Standard*:
213R Guide for Structural Lightweight Aggregate Concrete[2]

3. Apparatus

3.1 *Testing Machine*.–The testing machine shall conform to requirements of USBR 4039, and may be of any type of sufficient capacity that will provide rate of loading prescribed in section 7.5.

3.2 *Supplementary Bearing Bar or Plate*.–If diameter or largest dimension of upper bearing face or lower bearing block is less than length of cylinder to be tested, a supplementary bearing bar or plate made of machined steel shall be used. Surfaces of bar or plate shall be machined to within ±0.001 inch (0.025 mm) of planeness, as measured on any line of contact of bearing area. Bar or plate shall have a width of at least 2 inches (51 mm) and a thickness not less than distance from edge of spherical or rectangular bearing block to end of cylinder. The bar or plate shall be used in such manner that load will be applied over entire length of specimen.

3.3 *Bearing Strips*.–Two bearing strips of nominal 1/8-inch (3-mm) thick balsa wood, free of imperfections, about 1 inch (25 mm) wide, and of a length equal to or slightly longer than that of specimen shall be provided for each specimen. Strips shall be placed between specimen and both the upper and lower bearing blocks of testing machine, or between specimen and supplemental bars or plates, if used (see sec. 3.2). Bearing strips shall not be reused.

4. Precautions

4.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Test Specimens

5.1 The test specimens shall conform to the size, molding, and curing requirements set forth in either USBR 4031 or 4192. Drilled cores shall conform to the size and curing requirements set forth in USBR 4042. Moist-cured specimens, during the period between their removal from curing environment and testing, shall be kept moist by a wet burlap or blanket covering, and shall be tested in a moist condition as soon as practicable.

5.2 When evaluating lightweight aggregate concrete, the effects of curing and moisture condition on the tensile splitting strength discussed in section 4.10 of ACI 213R must be considered.

6. Calibration and Standardization

6.1 Calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *American Concrete Institute 1985 ACI Manual of Concrete Practice*, part 1.

under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

6.2 The testing machine shall meet requirements of section 7.5 by being calibrated in accordance with USBR 1104.

6.3 The supplementary bearing bar or plate shall be checked for compliance with section 3.2 by using linear measurement devices complying with standards of USBR 1000.

7. Procedure

7.1 *Marking.*–Draw diametral lines on each end of specimen using a suitable device that will ensure that lines are in same axial plane, see figures 1 and 2 (note 1). As an alternative, use aligning jig as shown on figure 3 (note 2).

NOTE 1.–Figures 1 and 2 show a suitable device for drawing diametral lines on each end of specimen in same axial plane. The device consists of three parts: (1) a 4-inch (102-mm) steel channel, flanges of which have been machined flat, (2) a section of a tee bar, *B*, that is grooved to fit smoothly over flanges of channel and includes a rectangular notch for positioning vertical member of tee bar assembly, and (3) a vertical bar, *C*, containing a longitudinal aperture (cleft), *A*, for guiding a pencil. The tee bar assembly is not fastened to channel, it is positioned at either end of channel without disturbing position of specimen when marking diametral lines.

NOTE 2.–Figure 4 is a detailed drawing of the aligning jig shown on figure 3 that achieves same purpose as marking diametral lines. The device consists of: (1) a base for holding lower bearing strip and cylinder, (2) a supplementary bearing bar conforming to requirements of section 3.2 as to critical dimensions and planeness, and (3) two uprights for positioning test cylinder, bearing strips, and supplementary bearing bar.

7.2 *Measurements*:

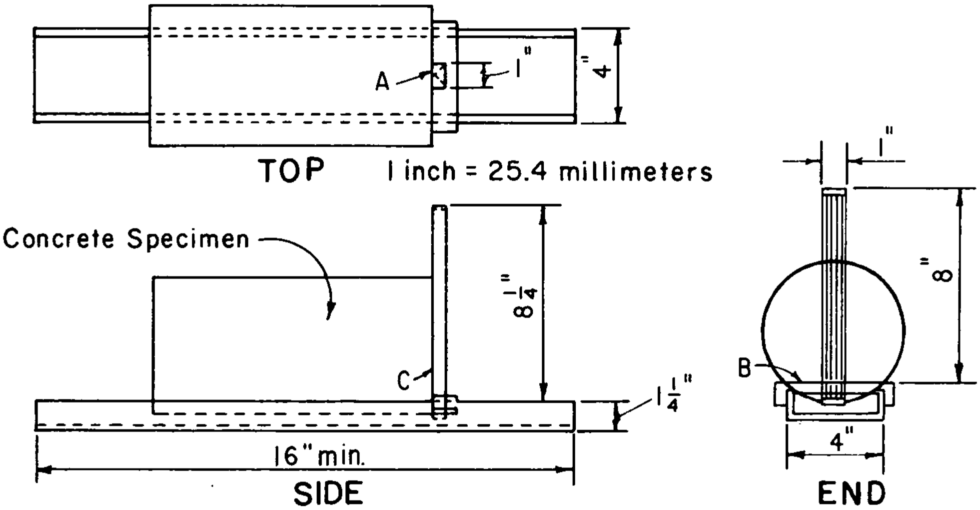
7.2.1 Determine diameter of test specimen to nearest 0.01 inch (0.25 mm) by averaging three diameters measured near ends and middle of specimen and lying in plane containing diametral lines marked on the two ends. Determine length of specimen to nearest 0.1 inch (2.5 mm) by averaging at least two length measurements taken in plane containing diametral lines.

7.3 *Positioning Using Marked Diametral Lines.*–Center one of the balsa wood strips along center of lower bearing block. Place specimen on balsa wood strip and align such that diametral lines marked on ends of specimen are vertical and centered over strip. Place a second balsa wood strip lengthwise on cylinder, centered on diametral lines. Position assembly to ensure following two conditions:

(1) The projection of the plane of the two diametral lines marked on ends of specimen intersects center of upper bearing plate.

(2) Supplementary bearing bar or plate, when used, and the center of specimen are directly beneath center of thrust of spherical bearing block (fig. 5).

7.4 *Positioning Using Aligning Jig.*–Position bearing strips, test cylinder, and supplementary bearing bar using aligning jig as shown on figure 3, and center jig so that supplementary bearing bar and center of specimen are directly beneath center of thrust of spherical bearing block.



A = Longitudinal aperture (cleft) in vertical bar, C.

B = Section of T-bar grooved to fit over flanges of 4-inch steel channel.

C = Vertical bar.

Figure 1. – General views of a suitable apparatus for marking end diameters used for alignment of specimen in testing machine.

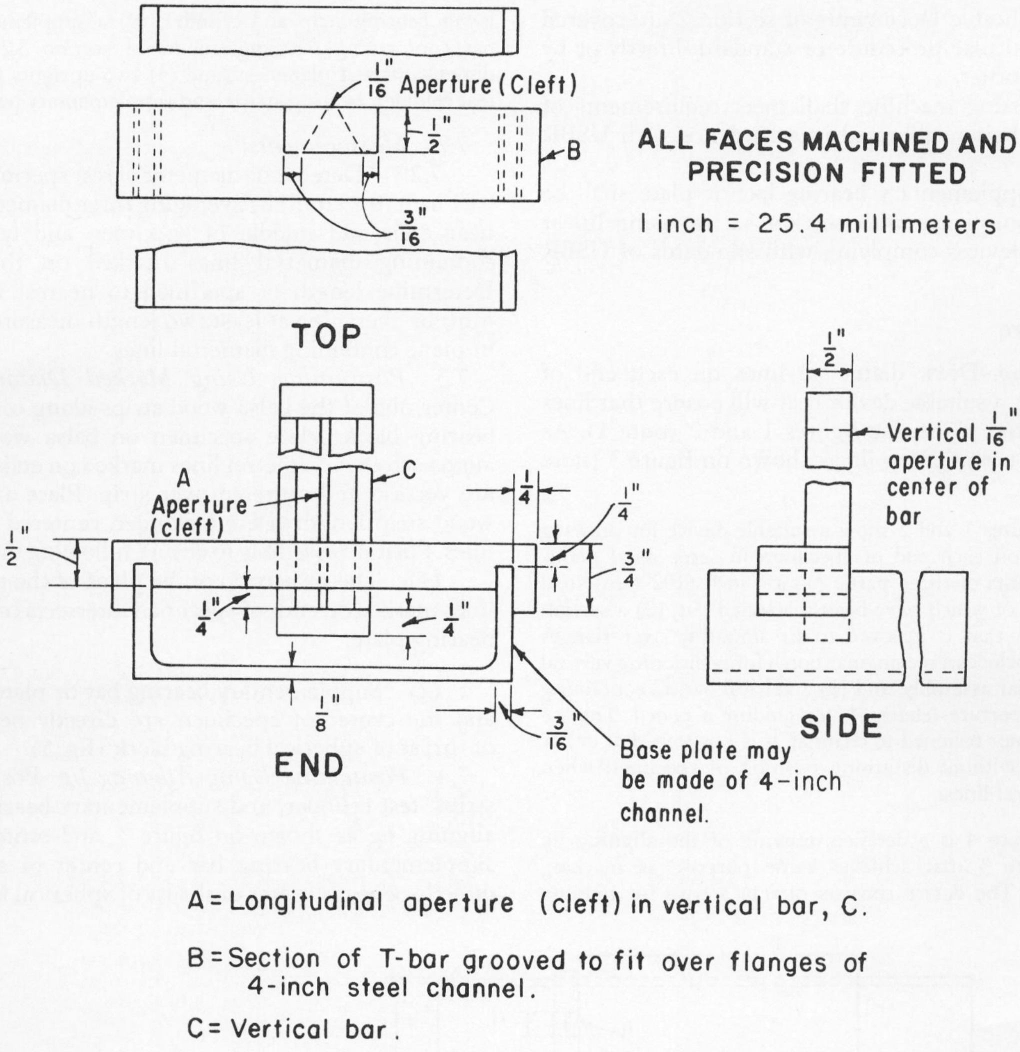


Figure 2. – Details of a suitable apparatus for marking end diameters used for aligning specimen.

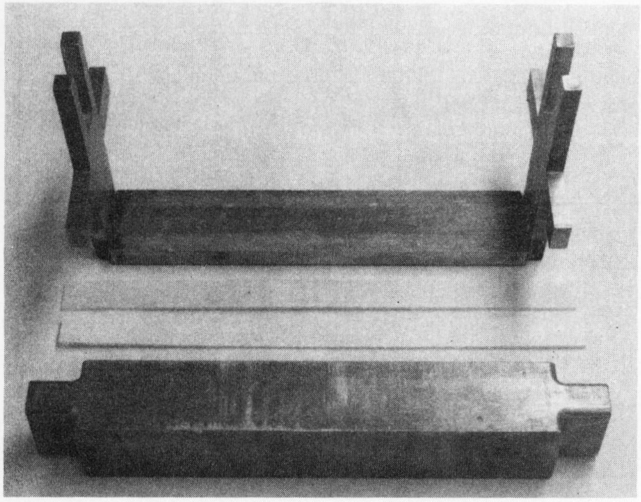


Figure 3. – Jig for aligning concrete cylinder and bearing strips.

7.5 *Loading Rate*:

7.5.1 Apply load continuously and without shock at a constant rate within the range of 100 to 200 lbf/in^2 (689 to 1379 kPa) per minute splitting tensile stress until failure occurs (note 3). Record maximum applied load indicated by testing machine at failure, and note type of failure and appearance of concrete.

NOTE 3.–The relationship between splitting tensile stress and applied load is shown in section 8. The required loading range in splitting tensile stress corresponds to an applied total load in the range of 11,300 to 22,600 lbf (50.3 to 100.5 kN) per minute for 6- by 12-inch (152- by 305-mm) cylinders.

8. Calculations

8.1 Calculate splitting tensile strength of specimen as follows:

$$T = \frac{2P}{\pi LD} \qquad (1)$$

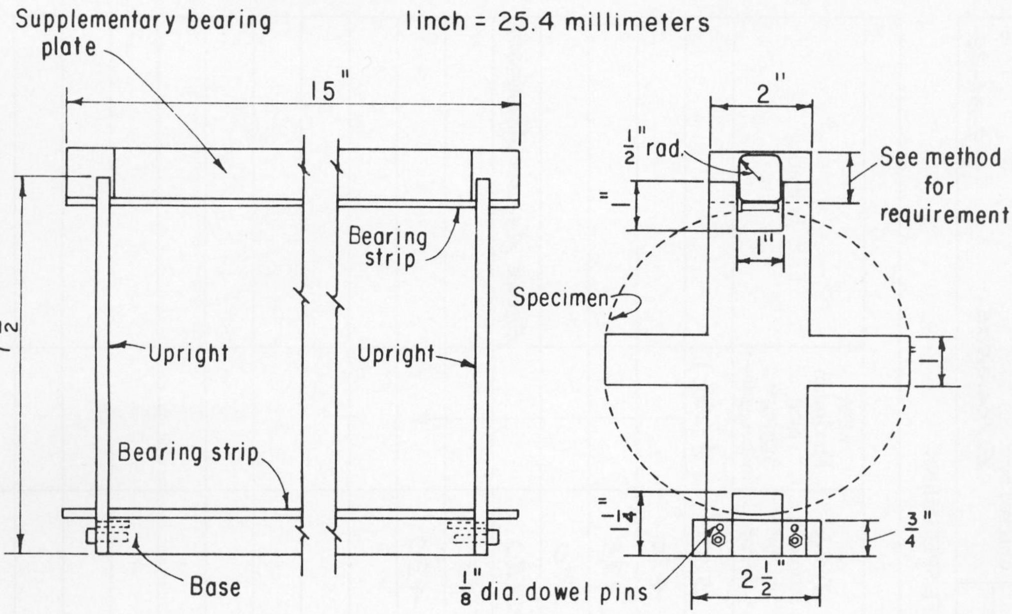


Figure 4. – Details of a suitable aligning jig.

where:

T = splitting tensile strength in pound force per square inch (megapascals),
P = maximum applied load indicated by testing machine in pound force (kilonewtons),
L = length in inches (meters), and
D = diameter in inches (meters).

8.2 A typical calculation form is shown on figure 6.

9. Report

9.1 Figure 6 may also serve as a reporting form. The report shall include:

- Identification number
- Diameter and length in inches (meters)
- Maximum load in pound force (kilonewtons)
- Splitting tensile strength calculated to nearest 5 lbf/in^2 or 0.05 MPa
- Estimated proportion of coarse aggregate fractured during test
- Age of specimen
- Curing history
- Defects in specimen
- Type of fracture
- Type of specimen

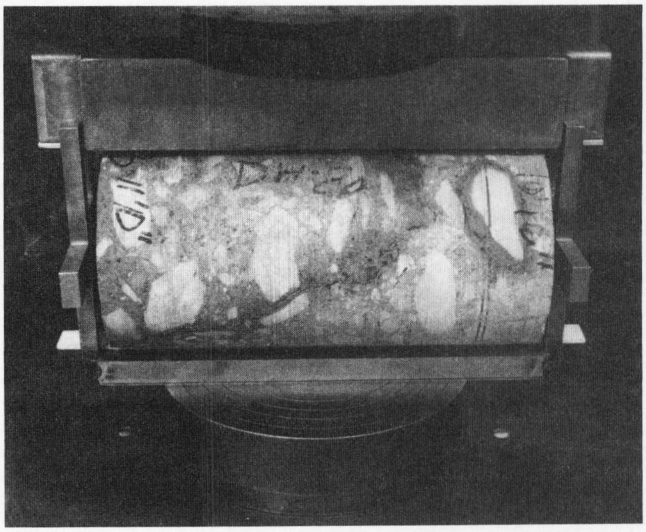


Figure 5. – Specimen positioned in a testing machine for determination of splitting tensile strength.

10. Precision and Bias

10.1 The precision and bias for this procedure have not been established.

Spec. or Solic. No. INVESTIGATIONS	Structure DAM	Tested by D. PARADY K. FORBES Date 9-24-82
Project SALT RIVER	Item 6- BY 12-INCH CORE Location DENVER LAB	Computed by K. FORBES Date 9-24-82
Feature STEWART MOUNTAIN DAM	Station NOT IDENT. Offset NOT IDENT. Depth REFER TO SPECIMEN No IDENTIFICATION	Checked by E. HARBOE Date 9-24-82

SPLITTING TENSILE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

Curing Conditions Prior To Testing :

Specimen No.	Age	Specimen Length in inches ~~(m)~~			Specimen Diameter in inches ~~(m)~~				*P* Load, lbf ~~(kN)~~	*T* Tensile Strength, lbf/in² ~~(MPa)~~	MSA Maximum Size Aggregate, inches ~~(mm)~~	Remarks
		L_1	L_2	Avg.	D_1	D_2	D_3	Avg.				
102-2.5	53 YEARS	12.0	12.1	12.1	6.00	5.98	6.01	6.00	57,980	510	4 (EST.)	
-7.3		12.0	12.0	12.0	6.01	6.00	6.00	6.00	53,270	470		
-13.9		12.0	12.0	12.0	6.00	5.99	6.00	6.00	44,390	395		
-20.3		11.8	11.7	11.8	6.01	6.00	5.98	6.00	56,290	510		
-24.6		11.1	11.2	11.2	6.00	6.00	6.00	6.00	29,660	280		BROKE AROUND AGGREGATE
-31.5		12.0	12.0	12.0	6.01	5.98	6.00	6.00	48,420	430		
-30.8		12.0	12.0	12.0	5.98	6.01	6.00	6.00	48,420	430		

Figure 6. – Typical data, calculation, and reporting form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4497-92

PROCEDURE FOR

TESTING CONCRETE PIPE, SECTIONS, OR TILE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4497; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 497-85b.

1. Scope

1.1 This designation covers procedures for the testing of concrete pipe, sections, or tile. The tests described are used in production and acceptance testing to evaluate properties provided for in the specifications.

1.2 The tests appear in this procedure in the following order:

	Section
External Load Crushing Strength	7
Flat Slab Tops	8
Core Strength	9
Absorption	10
Hydrostatic	11
Permeability	12
Manhole Step	13

1.3 The test specimens shall not have been exposed to temperatures below 40 °F (4.4 °C) for the 24 hours immediately preceding the test, and shall be free of all visible moisture.

1.4 If any test specimen fails because of mechanical reasons, such as failure of testing equipment or improper specimen preparation, specimen may be discarded and another taken.

1.5 Specimens shall be selected in accordance with the specifications for type of pipe or tile being tested.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1040 Calibrating Pressure Gauges
1104 Load Verification of Testing Machines
4039 Compressive Strength of Cylindrical Concrete Specimens
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4617 Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:

C 497 Standard Methods of Testing Concrete Pipe, Sections, or Tile[1]
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[2]
C 822 Standard Definitions of Terms Relating to Concrete Pipe and Related Products[1]

3. Terminology

3.1 For definitions of terms relating to concrete pipe, see ASTM C 822.

4. Precautions

4.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Calibration and Standardization

5.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

5.2 The calibration of equipment for the three-edge bearing method is covered under section 7.4 and USBR 1104.

5.3 Linear measuring devices shall be calibrated in accordance with USBR 1000.

5.4 Ovens shall be calibrated in accordance with USBR 1020.

5.5 Balances or scales are covered under section 10.4.5 and shall be calibrated in accordance with USBR 1012.

5.6 The pressure gauge referenced in section 11.3.3 shall be calibrated in accordance with USBR 1040.

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[1] *Annual Book of ASTM Standards*, vol. 04.05.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, and 04.08.

6. Conditioning

6.1 The conditioning of specimens for the tests is covered under each test individually.

7. External Load Crushing Strength Test by Three-Edge Bearing Method

7.1 *Summary of Method.*-Specimen is tested in a machine designed to apply a crushing force upon specimen in a plane through vertical axis extending along length of specimen.

7.2 *Significance and Use.*-The crushing test can be either a quality control test performed to establish that finished pipe has sufficient strength to withstand crushing loads stated in specifications, or a proof-of-design test performed to prove adequacy of design.

7.3 *Apparatus*:

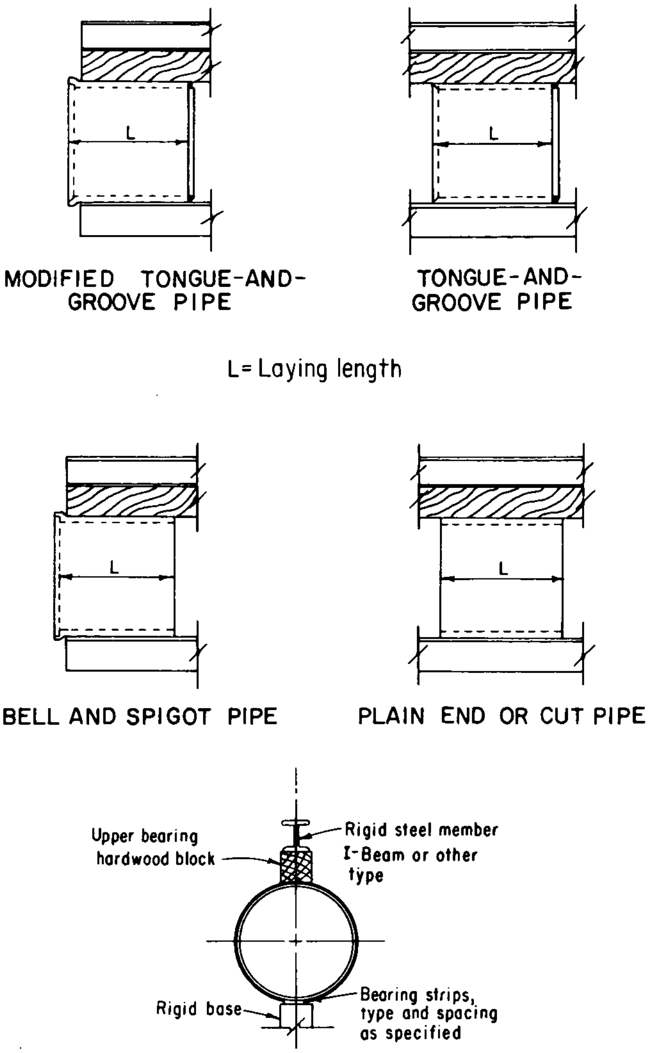
7.3.1 In making any test, any mechanical or hand-powered device may be used in which the test head moves at such a speed that load is applied at a minimum uniform rate of 3,000 lbf/lin ft (43.9 kN/lin m) of pipe per minute and a maximum uniform rate of 7,500 lbf/lin ft (109.4 kN/lin m) of pipe per minute.

7.3.2 The testing machine shall be substantial and rigid throughout so that distribution of load will not be affected appreciably by the deformation or yielding of any part.

7.3.3 The three-edge bearing method of loading shall be used. The test specimen shall be supported on two parallel longitudinal strips, and the load applied through a top bearing beam, see figures 1, 2, 3, and 4. At option of manufacturer, the two parallel strips or the top bearing beam may extend the full length or any portion of length of specimen.

7.3.4 The lower bearings shall consist of hardwood or hard rubber strips. Hardwood strips shall be straight, have a cross section of not less than 2 inches (51 mm) in width and not less than 1 inch (25 mm) nor more than 1-1/2 inches (38 mm) in height, and shall have the top inside corners rounded to a radius of 1/2 inch (13 mm). Hard rubber strips shall have a durometer hardness of not less than 45 nor more than 60; be rectangular in cross section having a width of not less than 2 inches, a thickness not less than 1 inch nor more than 1-1/2 inches; and shall have the top inside corners rounded to a radius of 1/2 inch.

7.3.5 The bottom bearing strips shall be fastened to a wooden or steel beam, or directly to a concrete base, any of which shall provide sufficient rigidity to permit application of maximum load without a deflection greater than 1/720 of specimen length. The interior vertical sides of strips shall be parallel and spaced apart not more than 1 in/ft (83 mm/m) of specimen diameter, but in no case less than 1 inch (25 mm) apart. The bearing faces of the bottom strips shall not vary from a straight line vertically or horizontally by more than 1/32 in/ft (2.6 mm/m) of length under no load.

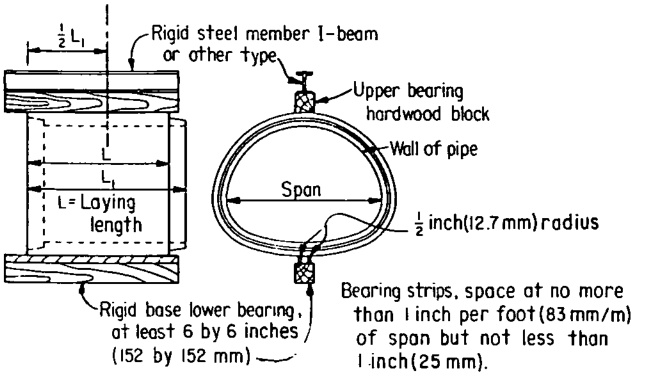


NOTE: The above sketches illustrate methods for applying load to pipe.

Figure 1. - Three-edge bearing test for circular pipe.

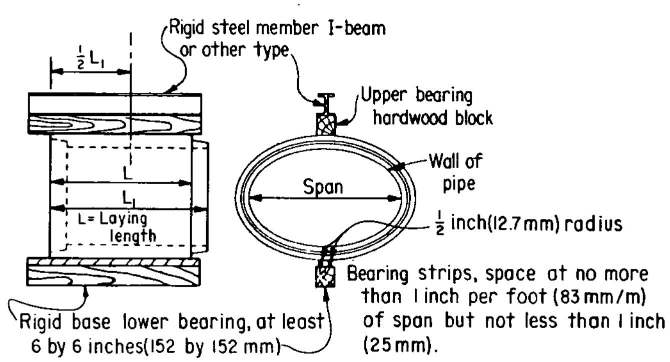
7.3.6 The upper bearing shall be a rigid hardwood beam with or without an attached hard rubber strip. The hardwood beam shall be sound, free of knots, and straight and true from end to end. It shall be fastened to a steel or wood-faced steel beam of such dimensions that deflections under maximum load will not be greater than 1/720 of specimen length. The bearing face of the hardwood beam shall not deviate from a straight line by more than 1/32 in/ft (2.6 mm/m) of length. When a hard rubber strip is used on bearing face, it shall have a durometer hardness not less than 45 nor more than 60, a width of not less than 2 inches (51 mm) and a thickness of not less than 1 inch (25 mm) nor more than 1-1/2 inches (38 mm), and shall be secured to the hardwood beam.

7.3.7 If mutually agreed between manufacturer and client prior to test and before specimen is placed, a fillet of plaster of paris not exceeding 1 inch (25 mm) in thickness



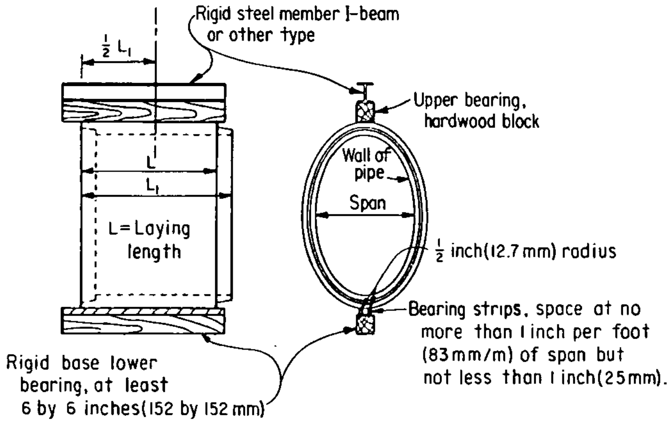
Note: This figure illustrates a method of applying the load to the pipe.

Figure 2. - Three-edge bearing test for arch pipe.



Note: This figure illustrates a method of applying the load to the pipe.

Figure 3. - Three-edge bearing test for horizontal elliptical pipe.



Note: This figure illustrates a method of applying the load to the pipe.

Figure 4. - Three-edge bearing test for vertical elliptical pipe.

may be cast on surface of upper and lower bearings. The width of the fillet cap, top or bottom, shall be not more than 1 in/ft (83 mm/m) of specimen diameter, but in no case less than 1 inch.

7.3.8 The equipment shall be so designed that load will be distributed about center of overall length of specimen (figs. 1, 2, 3, and 4). At option of manufacturer, center of load may be applied at any point on the overall length of specimen. The load may be applied either at a single point or at multiple points dependent on length of specimen being tested and rigidity of test frame. Multiple points of load applications to top bearing will permit use of lighter beams without appreciable deflection.

7.4 *Calibration.*-The loading device shall be one that provides an accuracy of ±2 percent at specified test loads. A calibration curve may be used. Machines used for performing the three-edge bearing tests shall be verified in accordance with USBR 1104.

7.5 *Procedure*:

7.5.1 Place specimen on two bottom bearing strips in such a manner that the pipe or tile rests firmly and with the most uniform possible bearing on each strip.

7.5.2 Mark the two ends of specimen at a point midway between bearing strips and then establish diametrically opposite points on each end.

7.5.3 Place top bearing beam so that it is aligned with the marks established in 7.5.2. After placing specimen in machine on bottom strips, align the top bearings symmetrically in testing machine. Apply load at rate indicated in 7.3.1 until either the formulation of a 0.01-inch (0.25-mm) crack width or the ultimate strength load, as may be specified, is reached. If both the 0.01-inch crack and the ultimate load are required, the specified rate of loading need not be maintained after the load of the 0.01-inch crack has been determined.

7.5.4 The 0.01-inch crack load is the maximum load applied to the pipe before a crack having a width of 0.01 inch (0.25 mm) occurs throughout a continuous length of 1 foot (305 mm) or more, measured parallel to longitudinal axis of pipe barrel. Consider the crack to be 0.01 inch in width when point of measuring gauge will, without forcing, penetrate 1/16 inch (1.6 mm) at close intervals throughout the specified distance of 1 foot. Measure width of crack using a gauge made from a leaf 0.01 inch thick (as in a set of standard machinist gauges), ground to a point of 1/16 inch in width with corners rounded, and with a taper of 1/4 in/in (0.25 mm/mm), as shown on figure 5. The ultimate load is reached when the pipe will support no more load.

NOTE 1.-As used in this procedure, the 0.01-inch (0.25-mm) crack is a test criterion for pipe tested in the three-edge bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

7.6 *Calculations*:

7.6.1 Strength test results shall be calculated in terms of pounds force per linear foot (kilonewtons per linear meter) to produce a 0.01-inch (0.25-mm) crack, or pounds force per linear foot at ultimate load, or both, as required by specifications. The laying length used in calculating the strength values shall be that as indicated by an *L* on figures 1, 2, 3, and 4, except that for tongue-and-groove pipe, the

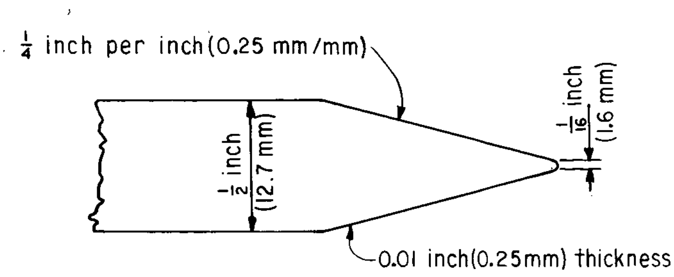


Figure 5. - Gauge leaf for measuring cracks.

laying length L shall include either the tongue or the groove, whichever is longer.

7.6.2 The load in pounds force per linear foot required to produce the 0.01-inch crack shall be calculated by dividing total load on specimen, at time crack occurs, by laying length of pipe.

7.6.3 The crushing strength, or ultimate load, in pounds per linear foot shall be calculated by dividing maximum load applied to specimen by laying length.

7.6.4 Figure 7 shows a typical calculation form.

7.7 *Precision and Bias*:

7.7.1. The true value for the strength of a concrete pipe cannot be determined because the specimen is tested to destruction and an exact duplicate specimen cannot be obtained. Therefore, no calculations of precision and bias are presently possible. Specifications that include this test method for various types of concrete pipe should include a provision for additional tests of one or more specimens.

8. Test for Flat Slab Tops

8.1 *Summary of Method.*-A load is applied to flat slab top and supporting capacity of top is measured.

8.2 *Significance and Use.*-The method is a proof-of-design test performed to prove the adequacy of design.

8.3 *Procedure.*-Place the section that has been designated to receive the flat slab top on a firm, even surface. Assemble flat slab top to this section. If a frame or riser has been designed to be fitted to access portion of flat slab top, assemble it to the slab top. Apply test load to riser or frame as assembled to the slab top. If no access opening has been provided to the flat slab top, apply test load to center of flat slab top by means of a 12- by 12- by 4-inch (305- by 305- by 102-mm) wood bearing block (fig. 6). Calculate the test load as follows:

$$P_u = 1.3\,D + 2.17\,P_L\,(1 + I) \qquad (1)$$

where:

Pu = applied minimum ultimate proof-of-design test load in pounds force (newtons),
D = total calculated field dead load on slab in pounds force (newtons),
P_L = calculated live load on flat slab top, and
I = impact factor, 30 percent minimum.

8.4 This test is not used by the Bureau; therefore, no typical calculations are included.

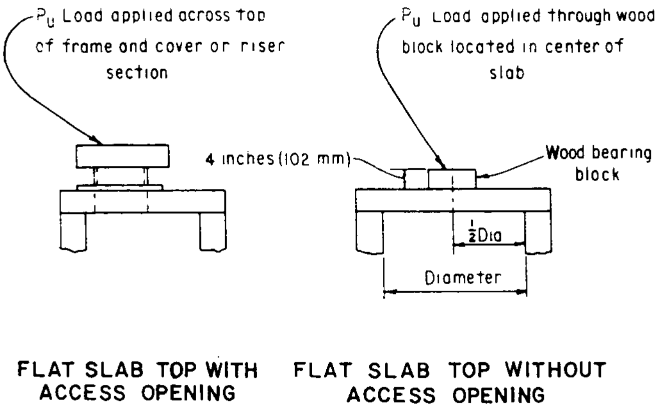


Figure 6. - Flat slab top test.

9. Core Strength Test

9.1 *Summary of Method.*-The compressive strength of the concrete in the pipe is determined by making crushing tests of cores cut from the pipe.

9.2 *Significance and Use.*-The core strength test is a quality control test performed to establish the fact that the finished, shippable, precast concrete product has sufficient concrete strength to meet the strengths stated in the specifications.

9.3 *Apparatus.*-A core drill shall be used for securing cylindrical core specimens from the wall of the pipe; a shot drill or a diamond drill may be used.

9.4 *Test Specimens*:

9.4.1 The core specimen taken for determination of compressive strength shall have a diameter at least three times the maximum size of the coarse aggregate used in the concrete. If cores are cut from wall of pipe and tested, the length to diameter ratio shall lie between 1 and 2 after the curved surfaces have been removed from the cut core.

9.4.2 *Moisture Conditioning.*-Unless the agency for which the testing is being done directs otherwise, the core test specimens shall be submerged in lime-saturated water in accordance with the provisions of USBR 4042.

9.5 *Procedure*:

9.5.1 *End Preparation and Capping.*-Core specimens to be tested in compression shall have ends that are essentially smooth, and perpendicular to the axis and of same diameter as body of specimen. Before making the compression test, cap ends of specimen to meet requirements of USBR 4617.

9.5.2 *Measurement.*-Prior to testing, measure length of capped specimen to nearest 0.1 inch (2.5 mm), and determine its average diameter to nearest 0.1 inch from two measurements taken at right angles near center of length.

9.5.3 Test the specimens as prescribed in section 9 of USBR 4039.

9.6 *Calculations*:

9.6.1 Calculate compressive strength of each specimen in pounds force per square inch (pascals) based on average diameter of specimen. If ratio of length to diameter is less than 2, make allowance for this ratio by multiplying the compressive strength by the applicable correction factor given in table 1; determine values not given in the table by interpolation.

9.6.2 A typical calculation form for the core strength test is shown on figure 5 of USBR 4039.

9.7 *Precision and Bias*:

9.7.1 This procedure for testing concrete pipe for strength is considered satisfactory for acceptance testing of commercial shipments because it has been used extensively for such testing. In cases of disagreement arising from differences in values reported by the Bureau and the supplier when using this procedure for acceptance testing, the statistical bias, if any, should be determined with each comparison being based on testing specimens randomly drawn from one pipe of the type being evaluated.

Table 1.-Strength correction factors for variations in *L/D*.

L/D	Factor, percent	*L/D*	Factor, percent
2.25	101.4	1.6	96.8
2.2	101.1	1.5	96.0
2.1	100.6	1.4	95.2
2.0	100.0	1.3	94.5
1.9	99.2	1.1	93.1
1.8	98.4	1.2	90.0
1.7	97.6	1.0	85.0

Note: Cylindrical specimens with an *L/D* less than 1.0 may be broken for informational purposes but are not considered as acceptable specimens for strength evaluation. Cylindrical specimens with an *L/D* greater than 2.25 should be sawed to an *L/D* of 2.0.

10. Absorption Test

10.1 *Summary of Method*.-This method covers testing of a specimen that is a sample or core from wall of pipe. Test specimen is first subjected to drying, then to immersion to determine specimen's absorption of water when tested by the described procedures. Two alternative procedures for conducting the test are presented. Method A is the standard test and referee, and requires 3 to 6 days to complete. Method B is intended as an accelerated test that requires about 1-1/2 days to complete.

10.2 *Significance and Use*.-The method is a quality control test performed to establish the fact that the finished, shippable pipe meets the absorption limits stated in the specifications.

10.3 *Test Specimens*:

10.3.1 *Method A Specimens*.-Method A absorption test specimens shall be in accordance with the requirements of the applicable pipe specification and shall be used for the absorption procedure that requires 5 hours for boiling, and a natural water cooling period of 14 to 24 hours.

10.3.2 *Method B Specimens*.-Method B absorption test specimens shall consist of three 1-1/2-inch (38-mm) diameter cores as taken from the two ends and the center area of each tile, pipe, or section.

10.4 *Procedure for Boiling Absorption Test*:

10.4.1 *Drying Specimens*.-Dry specimens in a ventilated, mechanical convection oven at 221 to 239 °F (105 to 115 °C).

10.4.1.1 *Method A*.-Dry specimens until two successive determinations of mass at intervals of not less than 6 hours show an increment of loss not greater than 0.10 percent of last oven-dry mass of specimen. Dry specimens with a wall thickness of 1.5 inches (38 mm) or less for a minimum of 24 hours, dry specimens with a wall thickness of 1.5 to 3 inches (38 to 76 mm) for a minimum of 48 hours, and dry specimens with a wall thickness exceeding 3 inches for a minimum of 72 hours. Use the last 6 hours of the minimum drying time to determine if sample has obtained proper dried mass.

10.4.1.2 *Method B*.-Dry all specimens for a minimum of 24 hours.

10.4.2 *Determining Mass of Dried Specimens*.-Determine mass of oven-dried specimens immediately upon removal from oven, where drying temperature was 221 to 239 °F (105 to 115 °C).

10.4.3 *Immersion and Boiling*:

10.4.3.1 *Method A Specimen*.-Within 24 hours, carefully place dried specimen, that mass has been determined for, in a suitable receptacle that contains clean water at 50 to 75 °F (10 to 24 °C). Use distilled water, rain water, or tap water that is known to have no effect on test results. Heat water to boiling point in not less than 1 hour nor more than 2 hours. Do not apply live steam to water to shorten preboil period until after 1 hour of heating by gas or electricity has been completed. Continue boiling for 5 hours. At end of 5-hour boiling period, turn off heat and allow specimen to cool in the water to room temperature by the natural loss of heat for not less than 14 hours nor more than 24 hours.

10.4.3.2 *Method B Specimen*.-Within 24 hours, carefully place dried specimen, that mass has been determined for, in a suitable receptacle that contains clean water at 50 to 75 °F (10 to 24 °C). Use distilled water, rain water, or tap water that is known to have no effect on test results. Heat water to boiling point in not less than 1 hour nor more than 2 hours. Do not apply live steam to water to shorten preboil period until after 1 hour of heating by gas or electricity has been completed. Continue boiling for 3 hours. At end of 3-hour boiling period, turn off heat and cool specimen for 3 hours by running cold tap water into boiler, or by placing specimen in a separate container of water. Temperature of the cooling water shall not exceed 65 °F (18 °C).

10.4.4 *Redetermining Mass of Wet Specimens*.-Remove water-cooled specimens from water, place on an open drain rack, and allow to drain for 1 minute. Remove remaining superficial water by quickly blotting specimen with a dry, absorbent cloth or paper. Determine mass of specimen immediately following blotting.

10.4.5 *Scale Sensitivity*.-Determine mass of specimens less than 2.2 lbm (1 kg) to an accuracy of 0.10 percent of specimen mass. Determine mass of specimens more than 2.2 lbm to an accuracy of 0.002 lbm (1 g).

10.5 *Calculations*:

10.5.1 *Method A Specimen*.-Divide increase in mass of boiled specimen by its dry mass and express as a percentage of dry mass; this is the absorption of the specimen. Report results separately for each specimen.

10.5.2 *Method B Specimen*.-Divide increase in mass of boiled specimen by its dry mass and express as a percentage of dry mass; this is the absorption of the specimen. Report the result as an average of the three 1-1/2-inch (38-mm) diameter cores as taken from one tile or pipe section. The absorption, as calculated by this method, shall be considered satisfactory when its value does not exceed a value that is 0.5 percent less than the absorption designated in the Method A procedure. When the absorption, as calculated by this method, does not meet the specified requirement, a retest may be done using Method A.

10.5.3 Figure 8 shows a typical calculation form.

10.6 *Procedure for 10-Minute Soaking Absorption Test*.-Test specimens for determination of the 10-minute water soaking absorption may be the same as those used later for the 5-hour boiling absorption test. After drying and determining mass as specified in sections 10.4.1 and 10.4.2, immerse specimens in clear water for 10 minutes at room temperature. Then, remove specimens and determine mass in accordance with 10.4.4 and calculate percentage absorption in accordance with 10.5. Figure 8 shows a typical calculation form.

10.7 *Precision and Bias*:

10.7.1 *Single-Operator Precision*:

10.7.1.1 *Method A*.-The single-operator standard deviation has been found to be 0.143 percent; therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.40 percent.

10.7.1.2 *Method B*.-The single-operator standard deviation has been found to be 0.157 percent; therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.44 percent.

NOTE 2.-The values shown in 10.7.1.1 and 10.7.1.2 represent, respectively, the (IS) and (D2S) limits described in ASTM C 670.

10.7.1.3 *The 10-Minute Soak Method*.-Precision for this method has not been determined, a statement will be included when proper data have been collected and analyzed.

10.7.2 *Multilaboratory Precision*.-The multilaboratory precision for the three methods discussed in 10.7.1 have not been determined; however, they are being investigated. Precision statements will be included when the proper data have been obtained and anlyzed..

10.7.3 *Bias*.-The bias for the three methods discussed in 10.7.1 cannot be determined because the true value for the absorption is not known and cannot be determined except by application of tests for which the bias is not known.

11. Hydrostatic Test

11.1 *Summary of Method*.-A section of pipe is subjected to hydrostatic pressure and observed for leakage at joint or on surface of pipe section.

11.2 *Significance and Use*.-This is a quality control test performed to establish the fact that the finished, shippable pipe meets the leakage requirements stated in the specifications for installed pipe wall or pipe joint or both.

11.3 *Procedure*:

11.3.1 The equipment for making the test shall be such that the specimen under test can be filled with water to the exclusion of air and subjected to the required hydrostatic pressure without the presence of enough leakage from the ends of the pipe to interfere with the test, and that no appreciable circumferential compression is placed on outside of specimen wall.

11.3.2 Do not test when temperature of specimen, air around specimen, or water within specimen is below 33 °F (1 °C).

11.3.3 Connect a standardized pressure gauge close to specimen. Raise pressure of water in about 1 minute to required level and hold for specified time. The water pressure or time of holding pressure, or both, may be increased when so specified.

11.3.4 A data worksheet is not included for the hydrostatic test because it is strictly an observance test.

11.4 *Precision and Bias*:

11.4.1 No justifiable statement can be made on either the precision or on the bias of this method of testing for leakage under hydrostatic pressure because the test result merely states whether there is conformance to the criteria for success specified.

12. Permeability Test

12.1 *Summary of Method*.-A section of pipe is kept filled with water for a specified time and the outer surface is tested for moisture.

12.2 *Significance and Use*.-This is a quality control test performed to establish the fact that the finished, shippable pipe meets the leakage limits stated in the specifications.

12.3 *Procedure*.-Perform tests by placing a section of pipe, with spigot end down, on a soft rubber mat or its equivalent, weighted if necessary, and kept filled with water to a level of the base of the socket during the test period. Make initial inspection about 15 minutes after test has begun. If pipe shows moist or damp spots on outer surface of pipe at that time, continue tests for a period not to exceed 24 hours at option of manufacturer. Examine pipe during extended period for existence of moist or damp spots.

12.3.1 A data worksheet is not inlcuded for the permeability test because it is strictly an observance test.

12.4 *Precision and Bias*:

12.4.1 No justifiable statement can be made on either the precision or on the bias of this method of testing for leakage because the test result merely states whether there is conformance to the criteria for success specified.

13. Manhole Step Test

13.1 *Summary of Method.*-This method covers the testing of an installed manhole step. The step shall be installed so that distance from wall of riser or cone, measured from point of embedment to outside face of rung, is 5.5 inches (140 mm). The step shall be initially subjected to a horizontal pull-out load and then a vertical load. The loads shall be applied over a width of 3.5 inches (89 mm) and centered on rung. Load shall be applied at a uniform rate until required test load is reached.

13.2 This test is not used by the Bureau; therefore, no typical calculations are included.

13.3 *Precision and Bias*:

13.3.1 No justifiable statements can be made on the precision and bias for this test because the test result merely states whether there is conformance to the criteria for the success specified.

14. Report

14.1 This designation includes several test procedures; therefore, no single reporting form would be appropraite. Figure 9 shows a typical reporting form for the more common pipe tests. Results of a test such as permeability would be more appropriately described in a memorandum type report.

Spec. or Solic. No. DC-3942	Structure PIPELINE	Tested by H. RIFFLE Date 11-3-53
Project FRENCHMAN-CAMBRIDGE	Item PRECAST CONCRETE PIPE Location CONCRETE & STRUCTURAL LAB	Computed by H. RIFFLE Date 11-3-53
Feature CAMBRIDGE DISTRIBUTION SYSTEM	Station ~ Offset ~ Depth ~ to ~	Checked by C. GORE Date 11-3-53

TESTING CONCRTE PIPE, SECTIONS, OR TILE

Pipe ID No.	Type of Pipe	Class of Pipe	Age, Days	Test Section Length				Inside Diameter		Shell Thickness		Three-Edge Bearing Test Results						Remarks
				L		L_1						Initial Crack		0.01-inch (0.025-mm) Crack		Ultimate Load		
				ft	m	ft	m	inch	mm	inch	mm	lbf/ft	kN/m	lbf/ft	kN/m	lbf/ft	kN/m	
DX -7	CIRCULAR BELL & SPIGOT	30-A-25	22	10				30		2.75		3,000		5,350		7,200		REPORT No. RC-11
DX -11	ARCH BELL & SPIGOT .	30-B-25	19				3		762		70		61.28		103.6		116.6	

Figure 7. - Sample data form for the external load crushing strength test by the three-edge bearing method.

Spec. or Solic. No. DC-7578	Structure PIPELINE	Tested by K. MITCHELL Date 3-26-86
Project CENTRAL VALLEY	Item MORTAR COATING-PRESTRESS OF ~~Location~~ EMBEDDED CYL, CONCRETE PIPE	Computed by K. MITCHELL Date 3-26-86
Feature SANTA CLARA CONDUIT	Station ~ Offset ~ Depth ~ to ~	Checked by E. HARBOE Date 3-27-86

TESTING CONCRETE PIPE, SECTIONS, OR TILE

Spec. ID No.	A Mass of Oven-Dry Sample, [✓ lbm] grams	B Mass of SSD Sample in Air, [✓ lbm] grams	C Mass of Sample in Water, [✓ lbm] grams	D_x Method A Mass After 5-Hour Boil, [✓ lbm] grams	Method B Mass After 3-Hour Boil, lbm grams	10-Min. Mass After 10-Min Soak, lbm grams	Absorption Standard $\frac{B-A}{A}(100)$ percent	5-Hour Boil $\frac{D_1-A}{A}(100)$ percent	3-Hour Boil $\frac{D_2-A}{A}(100)$ percent	10-Min. Soak $\frac{D_3-A}{A}(100)$ percent	Specific Gravity Bulk Dry $\frac{A}{B-C}$	Bulk SSD $\frac{B}{B-C}$	Apparent $\frac{A}{A-C}$
SC-1	1.230	1.309	0.742	1.337			6.4	8.7			2.17	2.31	2.52

Concrete Density = Specific Gravity times 62.4 for units of pound mass per cubic foot, or times 1,000 for units of kilograms per cubic meter.

$D_x = D_1$, D_2, or D_3 where D_1 = mass after 5-hour boil
D_2 = mass after 3-hour boil
D_3 = mass after 10-minute soak

DENSITY = 2.31(62.4) = 144.1 lbm/ft^3

Figure 8. – Sample data form for absorption and density of concrete.

Spec. or Solic. No. DC-3942	Structure PIPELINE	Compiled by H. RIFFLE Date 4-4-54
Project FRENCHMAN-CAMBRIDGE	Item PRECAST CONCRETE PIPE Location CONC. & STRUCT. LAB	Computed by ~ Date
Feature CAMBRIDGE DISTRIBUTION SYSTEM	Station ~ Offset ~ Depth ~ to ~	Checked by ~ Date

TESTING CONCRETE PIPE, SECTIONS, OR TILE

Pipe ID No.	Type of Pipe	Class of Pipe	Age, days	Three-Edge Bearing Test		Core Strength, [✓ lbf/in²] (MPa)	Absorption		Hydrostatic Pressure Test at 40 lbf/in² ____ (MPa)	Permea-ability
				0.01-inch (0.25-mm) Crack, [✓ lbf/ft] (kN/m)	Ultimate Load, [✓ lbf/ft] (kN/m)		Standard, percent	Method A, percent		
DX-7	CIRC. BELL & SPIGOT	30-A-25	22	5,350	7,200	8,110	4.1	6.8	NO LEAKS	NOT RUN

Remarks:

Figure 9. - Sample reporting form for various tests on concrete pipe, sections, or tile.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4500-92

PROCEDURE FOR

TESTING ASBESTOS-CEMENT PIPE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4500; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 500-83.

1. Scope

1.1 This designation covers the procedure for testing of asbestos-cement pipe for hydrostatic strength, flexural strength, crushing strength, straightness, and uncombined calcium hydroxide. This procedure is for use in conjunction with the individual specifications for asbestos-cement pipe.

1.2 Guidelines for internal and external corrosion are included in section 11, and serve as an aid in determining the type of pipe which should be specified to maximize service life for a particular application.

2. Applicable Documents

2.1 *USBR Procedures*:

1025 Checking Sieves
1040 Calibrating Pressure Gauges
1104 Load Verification of Testing Machines
3100 Sampling of Water
3105 Hydrogen Ion Activity (pH) of Water and Water-Based Fluids
5450 Determining Water Soluble Solids in Soils

2.2 *ASTM Standards*:

C 500 Standard Test Methods for Asbestos-Cement Pipe[1]
D 1125 Standard Test Methods for Electrical Conductivity and Resistivity of Water[2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Apparatus

3.1 *Hydrostatic Pressure Testing Machine*.-This machine shall be capable of applying water pressure at a uniform rate of not less than 100 lbf/in² (689.5 kPa) per second to a specified pressure, and maintaining this pressure level for a minimum of 5 seconds.

3.2 *Flexural Testing Machine*.-This machine shall be capable of applying a load at a uniform rate of at least 250 lbf/s (1112 N/s) to a specified load, and maintaining this load for a minimum of 5 seconds for the flexure proof test. Machine shall also be capable of applying a load at a uniform rate of 2,000±500 lbf/min per linear foot (29.2±7.3 kN/min per linear meter) for the crushing test.

3.3 *Glass and Reference Electrodes, and pH Meter*.-This equipment, which is used for determining the pH of the solution, shall conform to requirements of USBR 3105.

3.4 *Conductivity Bridge and Cell*.-The conductivity bridge and cell shall be capable of providing the data outlined in USBR 5450 and ASTM D 1125.

3.5 *Sieves*.-Sieves shall comply with requirements of ASTM E 11.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Calibration and Standardization

5.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

5.2 The pressure gauge for the hydrostatic pressure testing machine shall be calibrated in accordance with USBR 1040.

5.3 The flexural testing machine shall conform to requirements of section 3.2 by calibration procedures of USBR 1104.

5.4 The conductivity bridge and cell and pH meter shall be calibrated in accordance with manufacturer's instructions.

5.5 Sieves shall meet requirements of ASTM E 11 by calibration in accordance with USBR 1025.

6. Hydrostatic Pressure Test

6.1 *Significance*.-The hydrostatic pressure test establishes the fact that pipe has sufficient strength to withstand hydrostatic pressure loads stated in specifications. The strength level required by the specifications ensures that a minimum strength is maintained; that pipe will not leak

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[1] *Annual Book of ASTM Standards*, vol. 04.05
[2] *Annual Book of ASTM Standards*, vol. 11.01.
[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02

or weep in service; and that pipe will accommodate stresses simultaneously induced by internal pressure, earth loads, and surge pressures.

6.2 *Terminology*:

6.2.1 *Hydrostatic Strength*.–The ability of the pipe and coupling sleeve to withstand forces resulting from internal pressure.

6.3 *Procedure*.–Place pipe and coupling sleeve, or pipe and coupling sleeve with factory-assembled joint, in a hydrostatic pressure testing machine with gaskets that seal the ends but exert no end pressure. Expel all air and apply internal water pressure at a minimum uniform rate of 100 lbf/in^2 (689.5 kPa) per second to specified pressure, and maintain that pressure level for a minimum of 5 seconds.

6.3.1 Coupling sleeves may be tested with a rubber bladder inside sleeves.

6.3.2 Consider hydrostatic pressure test to have failed when pipe or coupling sleeve fails to sustain test pressure for the 5-second period.

7. Flexural Test

7.1 *Significance*.–The flexural test establishes the fact that the pipe has sufficient strength to withstand the flexural bending loads stated in the specifications. These test loads provide adequate strengths to resist transverse bending loads normally encountered in field service when good bedding methods are employed by the installer.

7.2 *Terminology*:

7.2.1 *Flexural Strength*.–The ability of a standard pipe section to withstand external loads bearing on the pipe transversely to its longitudinal axis that induce bending.

7.3 *Procedure*.–Support pipe in a flexural testing machine over a clear span of 9 feet (2.74 m). Unless otherwise specified, it shall be optional, with pipe lengths in excess of 12.5 feet (3.81 m), to test at 75 percent of specified loads on supports 12 feet (3.66 m) apart. Apply load at a minimum uniform rate of 250 lbf/s (1112 N/s) until load reaches proof load specified; maintain proof load for a minimum of 5 seconds. Distribute load equally and apply at third points of clear span, as shown on figure 1.

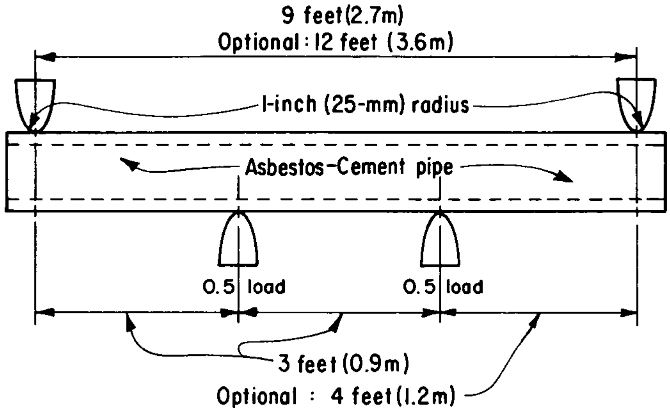

Figure 1. –Assembly for flexural strength test.

7.3.1. Consider the flexural test to have failed when a break occurs in pipe as a result of flexural load being applied to pipe during test prior to reaching minimum flexural load, or while holding at this minimum load.

8. Crushing Test

8.1 *Significance*.–The crushing test establishes the fact that pipe has sufficient strength to withstand crushing loads stated in the specifications. The strength level required by the specifications ensures minimum strengths that will satisfactorily withstand magnitude of loads normally encountered in service with a reasonable margin of safety.

8.2 *Terminology*:

8.2.1 *Crushing Strength*.–The ability of pipe to withstand external loads that tend to collapse pipe.

8.2.2 Consider the crushing test (fig. 2) to have failed when a break occurs in pipe as a result of crushing load being applied to pipe during test prior to reaching minimum crushing load designated in specifications.

8.3 *Procedure for V-Shaped, Three Edge Bearing Method*.–The assembly for this method is shown on figure 3.

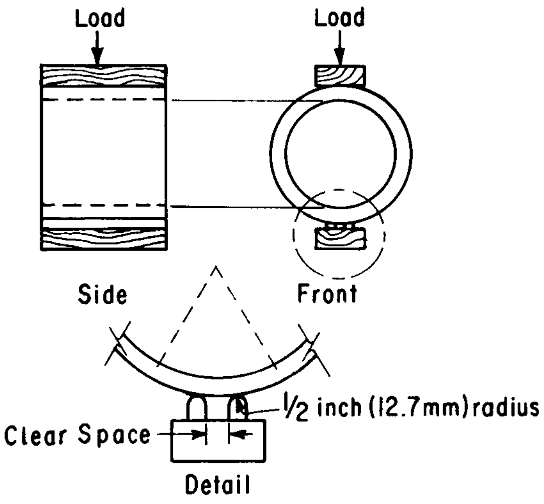

Figure 2. – Assembly for crushing strength test.

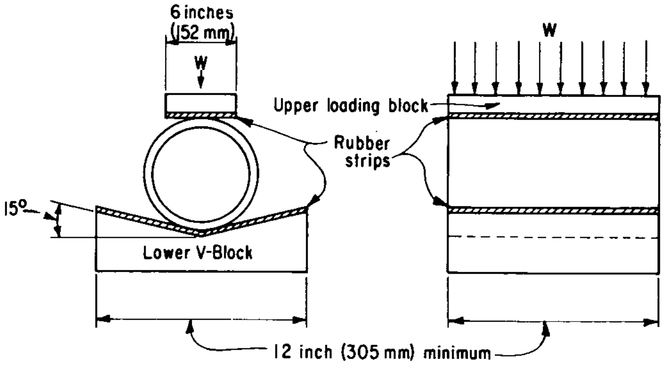

Figure 3. – Assembly for V-shaped crushing strength test.

8.3.1 The lower press-block consists of a V-shaped support having an included angle of 150°; support is made of metal or hardwood. Insert strips of rubber of suitable width and length between press-block and test specimen. These rubber strips shall be 0.625±0.125 inch (15.9±3.2 mm) thick, and have a hardness between 45 and 65 Shore A durometer.

8.3.2 The flat upper press-block, made of same material as lower press-block, shall have a minimum width of 6 inches (152 mm). Insert a strip of rubber that is the same size as rubber strips in lower press-block (sec. 8.3.1) between press-block and test specimen.

8.3.3 Apply load at a uniform rate so that failure will occur in not less than 15 seconds and in not more than 30 seconds.

9. Straightness Test

9.1 *Significance.*–The straightness test covers measurement of the maximum deviation from straightness of a standard length of asbestos-cement pipe.

9.2 *Procedure.*–Measure maximum ordinate from exterior surface of pipe by placing a straightedge, that exceeds pipe length, against exterior surface; or by placing pipe on a plane surface, upon which the pipe can be rolled, and measuring maximum distance from exterior pipe surface to the plane surface.

10. Uncombined Calcium Hydroxide Test

10.1 *Significance.*–This test covers measurement of amount of uncombined calcium hydroxide in asbestos-cement pipe to establish the fact that pipe has required chemical resistance. Criteria for resistance to environmental aggressiveness is given in section 11.

10.2 *Terminology*:

10.2.1 *Uncombined Calcium Hydroxide.*–The chemical resistance of the pipe as related to the uncombined calcium hydroxide content.

10.3 *Reagents*:

10.3.1 *Ammonium Acetate, Standard Solution* (1 mL = 0.0066 gram of $Ca(OH)_2$).–Dissolve 16.0 grams of dry crystalline ammonium acetate in 1 liter of absolute or anhydrous ethanol (note 1). Standardize the solution against calcium oxide (CaO) in accordance with sections 10.4.3 and 10.4.4. Calculate the calcium hydroxide equivalent as follows:

$Ca(OH)_2$ equivalent, in grams per milliliter,

$$= \frac{1.32A}{B} \qquad (1)$$

where:

A = grams of CaO used, and
B = milliliters of ammonium acetate required for titration.

NOTE 1.–Specially denatured alcohol conforming with Formula No. 30, 3a, or 2b of the U.S. Bureau of Internal Revenue Service (Alcohol and Tobacco Tax Division), or alcohol consisting of 95 percent specially denatured alcohol conforming to, Formula No. 3a plus 5 percent isopropanol may be substituted.

10.3.2 *Phenolphthalein Indicator Solution.*–Dissolve 1.0 gram of phenolphthalein in 100 mL of absolute ethanol (note 1).

10.3.3 *Glycerol-Ethanol Solvent* (1+2).–Mix 1 volume of glycerol with 2 volumes of anhydrous or absolute ethanol (note 1). To each liter of this solution, add 2.0 mL of phenolphthalein indicator solution. Adjust the solvent to slightly basic with either dilute sodium hydroxide (NaOH) in absolute ethanol (note 1) or standard ammonium acetate solution, depending on original pH.

10.3.4 *Strontium Nitrate*, $Sr(NO_3)_2$.

10.4 *Procedure*:

10.4.1 Prepare representative samples of pipe and coupling sleeves, and immediately sieve them through a No. 20 (850-µm) sieve. Place material passing sieve immediately into a bottle and cover with bottle's ground-glass top.

10.4.2 Place bottle, with top removed, in a drying oven at 220 °F (104.4 °C) for 2 hours; then cool in a desiccator to room temperature.

10.4.3 Obtain a mass of 1±0.010 gram of dried sample to nearest 0.001 gram, and place this mass in a dry 250-mL Erlenmeyer flask. Using a Teflon-fluorocarbon encapsulated stirring bar, add 60 mL of the glycerol-ethanol solvent and 2.0 grams of $Sr(NO_3)_2$. Attach flask to a watercooled condenser with a standard-taper 24/40 glass joint and place on a hotplate with a magnetic stirrer.

10.4.4 Boil solution gently for 30 minutes, while stirring gently. Then, remove flask and filter mixture through a Buchner funnel under vacuum. Bring filtrate to a boil and titrate with ammonium acetate solution until mixture is colorless. Compare with a similar mixture containing no phenolphthalein indicator.

10.5 *Calculations.*–Calculate the percentage of uncombined $Ca(OH)_2$ in the sample as follows:

$$Ca(OH)_2 \text{ (percent)} = \frac{CD}{E} (100) \qquad (2)$$

where:

C = $Ca(OH)_2$ equivalent of ammonium acetate solution, in grams per milliliter;
D = milliliters of ammonium acetate required for titration of solution; and
E = grams of sample used.

10.5.1 Figure 4 shows a typical calculation form.

11. Guidelines for Internal and External Corrosion

11.1 *Scope.*–This procedure establishes guidelines for the definition and classification of aggressive water and soil environments. The guidelines are based on exposure within the temperature range of 40 to 80 °F (4.4 to 26.7 °C). For pipe exposures to temperatures beyond these limits, consult manufacturer.

11.2 *Significance and Use.*–Guidelines for internal and external corrosion of asbestos-cement pipe are included in this procedure solely for the purpose of helping users evaluate the economic service life of asbestos-cement pipe under various soil and water conditions. If either water or soil corrosion guidelines are not adhered to, some decrease in economic service life can be expected; when guidelines are followed, experience has shown that an indefinite life can be expected for the pipe.

11.3 *Summary of Method.*–Factors that cause aggressive environments, internal and external waters, external soil conditions, and soluble sulfate contents of waters and soils should be considered separately even though they may exist in combination.

11.4 *Corrosion Guidelines for Water Transported Through Asbestos-Cement Pipe*:

11.4.1 The aggressiveness of water is classified as shown in table 1. The aggressive index is defined as:

$$AI = \text{pH} + \log(FH) \qquad (3)$$

where:

AI = aggressive index,
pH = index of acidity or alkalinity of the water in standard pH units,
F = total alkalinity in milligrams per liter as $CaCO_3$, and
H = calcium hardness in milligrams per liter as $CaCO_3$.

Table 1. – Aggressiveness of water.

Water	Value of AI
Highly aggressive	< 10.0
Moderately aggressive	10.0 to 11.9
Nonaggressive	≥ 12.0

11.4.2 Table 2 shows the type of asbestos-cement pipe to be used with aggressive waters.

Table 2. – Type of pipe for aggressive waters.

Water	Recommended pipe
Highly aggressive	See Note
Moderately aggressive	Type II
Nonaggressive	Types I and II

Note: The serviceability of asbestos-cement pipe for such applications should be established by the Government in conjunction with manufacturer.

11.5 *Corrosion Guidelines for Acidic Soils External to Asbestos-Cement Pipe.*–Table 3 shows guidelines, based upon minimum pH factors alone, for the use of asbestos-cement pipe in acidic soils. The pipe may or may not perform satisfactorily in acidic soil environments that have pH values below those listed in the table. To determine suitability of pipe in soils that have lower pH values, evaluate each situation individually, taking into consideration all aspects of soil environment that affect its corrosiveness to asbestos-cement pipe.

Table 3. – Minimum pH in nonsulfate acidic soils.

Water conditions within soil environment	Minimum pH of acidic soils when using asbestos-cement pipe	
	Type I	Type II
Essentially quiescent	5.0	4.0
Mildly fluctuating	5.5	5.0
Rapidly moving or grossly cyclic	6.3	5.5

11.6 *Corrosion Guidelines for Soluble Sulfate in Water and Soils*:

11.6.1 Table 4 classifies the relative degree of sulfate attack on concrete products by various concentrations of soluble sulfates in soils and ground water.

Table 4. – Attack on concrete by soils and waters containing various sulfate concentrations.

Relative degree of sulfate attack	SO_4 in water, mg/L	SO_4 in soil, percent
Very Severe[1]	1500 to 10 000	0.20 to 2.00
Negligible	0 to 150	0 to 0.10
Positive[1]	150 to 1500	0.10 to 0.20
Severe[1]	1500 to 10 000	0.20 to 2.00
Very Severe[1]	$\geq$ 10 000	$\geq$ 2.00

[1] Use Type II asbestos-cement pipe.

12. Calculations

12.1 The pH determinations shall be entered on the forms shown in USBR 3100.

12.2 The SO_4 determinations shall be entered on a form that is shown on figure 1 of USBR 5450.

12.3 The $Ca(OH)_2$ equivalent and the percentage of $Ca(OH)_2$ shall be determined in accordance with sections 10.3.1 and 10.5, as demonstrated on figure 4.

13. Report

13.1 Figure 5 shows a typical reporting form.

14. Precision and Bias

14.1 The precision and bias for this procedure are not known at this time.

Spec. or Solic. No. RESEARCH	Structure PIPE	Tested by B. BRINK Date 6-14-61
Project NA	Item ASBESTOS-CEMENT UNCOMBINED $Ca(OH_2)$ Location DENVER LAB	Computed by B. BRINK Date 6-15-61
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by G. BRIGGS Date 7-15-61

TESTING ASBESTOS-CEMENT PIPE

Specimen No.	Type of Specimen	Method of Curing	Silica-Cement Ratio	C $Ca(OH)_2$ Equivalent of Standard Solution, g/mL	D Standard Solution Required for Titration, mL	E Mass of Sample, grams	Uncombined $Ca(OH)_2$, percent
M-3868A	AC SHEET	2 HOURS STEAM	0.4	0.0066	8.20	1.002	5.4
M-3868B	do	12 HOURS STEAM	0.4	do	1.51	1.008	0.9
M-3868C	do	22 HOURS STEAM	0.4	do	0.91	1.004	0.6
M-3869	do	16 HOURS STEAM	0	do	16.48	0.998	10.9
M-3870	do	16 HOURS STEAM	0.6	do	1.21	1.001	0.8
M-3871	do	FOG	0	do	19.39	1.000	12.8
M-3872	do	FOG	0.6	do	13.88	1.007	9.1
M-3909	AC PIPE	STEAM	0.6	do	1.22	1.007	0.8
M-3910	do	FOG	0	do	21.34	1.006	14.0

Figure 4. - Typical calculation form for determination of uncombined calcium hydroxide.

Spec. or Solic. No. RESEARCH	Structure PIPE	Tested by M. PEABODY Date 1-5-82
Project NA	Item ASBESTOS-CEMENT PROP. Location DENVER LAB	Computed by M. PEABODY Date 1-6-82
Feature NA	Station ∼ Offset ∼ Depth ∼ to ∼	Checked by C. NELSON Date 1-13-82

TESTING ASBESTOS-CEMENT PIPE

Specimen No.	Hydrostatic Pressure Test	Bursting Pressure, lbf/in^2 ~~(kPa)~~	Flexural Strength, lbf/in^2 (kPa)	Three-Edge Bearing Crushing Strength, lbf/ft ~~(kN/m)~~	V-Block Crushing Strength, lbf/ft ~~(kN/m)~~	Straightness Test	Uncombined Ca(OH)$_2$, percent
24-A-50 AC-30-1	PASSED-NO LEAKAGE AT 225 lbf/in^2	360					0.3
24-A-50 AC-30-2					5,290		
24-A-50 AC-30-3				4,800			
24-D-50 AC-50-1	PASSED-NO LEAKAGE AT 375 lbf/in^2	550					0.4
24-D-50 AC-50-2					11,560		
24-D-50 AC-50-3				9,970			

Figure 5. – Typical form for reporting properties of asbestos-cement pipe.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4512-92

PROCEDURE FOR

CREEP OF CONCRETE IN COMPRESSION

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4512; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 512-82 (Reapproved 1983).

1. Scope

1.1 This designation covers a procedure for the determination of creep of molded concrete cylinders subjected to a sustained longitudinal compressive load. Two methods may be used in performing the test.

1.1.1 *Method A*.-This method essentially follows the procedure outlined in ASTM C 512, and is limited to concrete in which the maximum aggregate size does not exceed 1-1/2 inches (37.5 mm).

1.1.2 *Method B*.-This method is used by the Bureau of Reclamation, and was developed primarily to study creep of concrete containing aggregates larger than 1-1/2 inches (37.5 mm). Interior mass concrete in dams frequently contains aggregate up to a maximum size of 6 inches (150 mm), and a test cylinder must also be of relatively large size to be representative. Usually, 18- by 36-inch (457 by 914-mm) test cylinders are used by the Bureau.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1040 Calibrating Pressure Gauges
4039 Compressive Strength of Cylindrical Concrete Specimens
4192 Making and Curing Concrete Test Specimens in Laboratory
4617 Capping Cylindrical Concrete Specimens
4901 Drying Shrinkage of Hardened Concrete

2.2 *ASTM Standards*:

C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically[1]
C 512 Standard Test Method for Creep of Concrete in Compression[1]
E 177 Standard Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[1,2]

2.3 *ACI Standard*:

SP-9 Symposium on Creep of Concrete[3]

3. Significance and Use

3.1 This procedure measures the load-induced, time-dependent compressive strain at selected ages for concrete under an arbitrary set of controlled environmental conditions.

3.2 This procedure can be used to compare creep potentials of different concretes. A method is available, using a developed equation or graphical plot, for calculating stress from strain data within massive nonreinforced concrete structures. For most specific design applications, the test conditions set forth herein must be modified to more closely simulate the anticipated curing, thermal, exposure, and loading age conditions for the prototype structure. Current theories and effects of material and environmental parameters are presented in ACI SP-9.

3.3 In the absence of a satisfactory hypothesis governing creep phenomena, a number of assumptions have been developed that have been generally substantiated by testing and experience.

3.3.1 Creep is proportional to stress in the stress range from 0 to 40 percent of the concrete compressive strength.

3.3.2 Creep has been shown to be directly proportional to paste content throughout the range of paste contents normally used in concrete. Thus, creep characteristics of concrete mixtures containing aggregate of a maximum size greater than 1-1/2 inches (37.5 mm) may be determined from creep characteristics of the minus 1-1/2-inch (−37.5 mm) fraction obtained by wet sieving. Multiply value of characteristic by ratio of cement paste content (proportion by volume) in full concrete mixture to paste content of sieved sample.

3.4 The use of the logarithmic expression in section 10 does not imply that the creep strain-time relationship is necessarily an exact logarithmic function; however, for the period of 1 year, the expression approximates normal creep behavior with sufficient accuracy to make possible the calculation of parameters that are useful for the purpose of comparing concretes.

3.5 There are no data that would support extrapolation of the results of this test procedure to tension or torsion.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 14.02.

[3] Available from American Concrete Institute, PO Box 19150, Detroit, Michigan 48219.

4. Apparatus

4.1 *Molds*.–The molds shall be cylindrical, conforming to general provisions of section 3.1 and to specific provisions of section 3.2.1 or 3.2.2 of USBR 4192, whichever is applicable; or to provisions of ASTM C 470. If required, provisions shall be made for attaching gauge studs and inserts and for affixing integral bearing plates to ends of specimen as it is cast.

4.1.1 Horizontal molds shall conform to general requirements of section 3.1 and to specific provisions of section 3.2.2 of USBR 4192. A horizontal mold that has proven satisfactory is shown on figure 1.

4.2 *Loading Frame*.–The loading frame shall be capable of applying and maintaining required load on specimen, regardless of any change in dimension of specimen. The loading frame basically consists of header plates bearing on ends of loaded specimen, a load-maintaining element that may be a spring or hydraulic capsule or ram, and threaded rods to take reaction of loaded system. Bearing surfaces of header plates shall not depart from plane by more than 0.001 inch (0.025 mm). Only one specimen may be loaded per loading frame. When a hydraulic load-maintaining element is used, several frames may be loaded simultaneously through a central hydraulic pressure-regulating unit consisting of an accumulator, regulator, indicating gauges, and a source of high pressure such as a cylinder of nitrogen or a high-pressure pump. Springs, such as railroad car springs, may be used to maintain load in frames. The initial compression shall be applied using a portable jack or testing machine. When springs are used, care should be taken to provide a spherical head or ball joint and end plates rigid enough to ensure uniform loading of cylinders. Figure 2 shows an acceptable spring-loaded frame. Means shall be provided for measuring and maintaining load to nearest 2 percent of total applied load. This may be accomplished by a permanently installed hydraulic pressure gauge, or a hydraulic jack and a load cell inserted in frame when load is applied or adjusted.

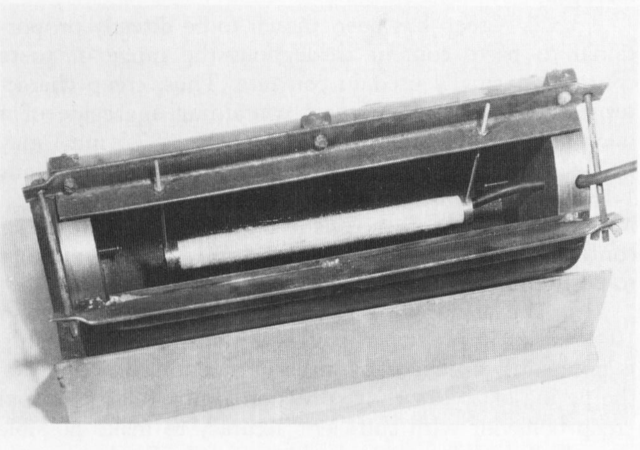


Figure 1. – Horizontal mold for creep specimens. Mold shown contains internal elastic wire strain gauge and integrally cast-in-place end plates.

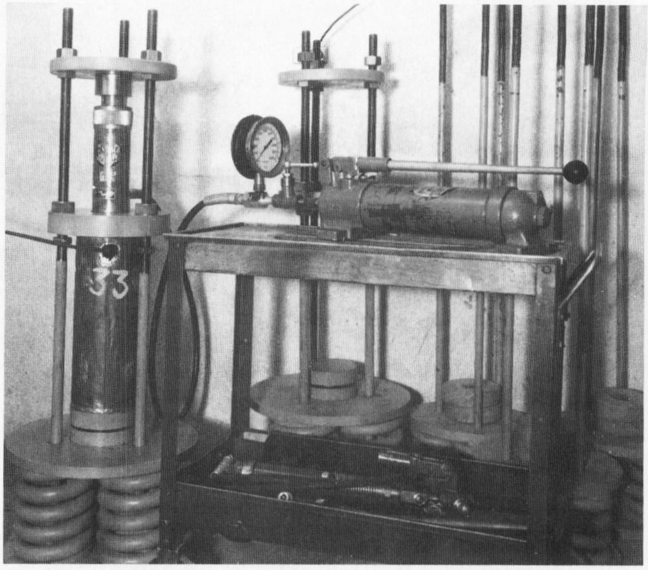


Figure 2. – Spring-loaded creep frame.

4.3 *Strain-Measuring Device*.–A suitable apparatus shall be provided for measurement of longitudinal strain in specimen to nearest 10 millionths. The apparatus may be embedded, attached, or portable. If a portable apparatus is used, gauge points shall be attached to specimen in a positive manner. Attached gauges relying on friction contact are not permissible. If an embedded device is used, it shall be situated so that its strain movement occurs along longitudinal axis of cylinder. If external devices are used, strains shall be measured on not less than two gauge lines spaced uniformly around periphery of specimen. The gauges may be instrumented so that average strain on all gauge lines can be read directly. The effective gauge length shall be at least three times the maximum size of aggregate in the concrete. The strain-measuring device shall be capable of measuring strains for at least 1 year without change in calibration.

NOTE 1.–Systems in which the varying strains are compared with a constant-length standard bar are considered most reliable; however, unbonded electrical strain gauges are satisfactory.

5. Precautions

5.1 This test method may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Test Specimens

6.1 *Specimen Size*.–The diameter of each specimen shall be 6±1/16 inches (152.4±1.6 mm), and the length shall be at least 11-1/2 inches (292 mm). When ends of specimen are in contact with steel bearing plates, specimen length shall be at least equal to gauge length of strain-measuring apparatus plus diameter of specimen.

6.2 *Fabricating Specimens.*-The maximum size of aggregate shall not exceed 1-1/2 inches (37.5 mm). Vertically cast cylinders shall be fabricated in accordance with provisions of section 8 of USBR 4192. The ends of each cylinder shall meet the planeness requirements of section 1.2 and note 1 of USBR 4617. Horizontally cast specimens shall be consolidated by the method appropriate to the consistency of the concrete as indicated in section 8.5.1 of USBR 4192. Care must be taken to ensure that rod or vibrator does not strike the strain meter. When vibration is used, concrete shall be placed in one layer and vibrating element shall not exceed 1-1/4 inches (32 mm) in diameter. When rodding is used, concrete shall be placed in two approximately equal layers with each layer being rodded 25 times evenly along each side of strain meter. After consolidation, concrete shall be struck off with trowel or float, then trowelled the minimum amount to form the concrete in the opening concentrically with rest of specimen. A template curved in the radius of the specimen may be used as a strikeoff to shape and finish concrete more precisely in the opening.

NOTE 2.-Requirements for planeness may be met by capping, lapping, or, at time of casting, fitting ends with bearing plates normal to axis of cylinder.

6.3 *Number of Specimens.*-No less than six specimens shall be made from a given batch of concrete for each test condition: two specimens shall be tested for compressive strength, two shall be loaded and observed for total deformation, and two shall remain unloaded for use as control specimens to indicate deformations due to causes other than load. Each strength and control specimen shall undergo same curing and storage treatment as loaded specimen.

7. Conditioning

7.1 *Curing and Storage of Specimens*:

7.1.1 *Standard Curing.*-Before removal from molds, specimens shall be stored at 73.4±3.0 °F (23.0±1.7 °C) and covered to prevent evaporation. Specimens shall be removed from molds not less than 20 nor more than 48 hours after molding, and stored in a moist condition at 73.4±3.0 °F until the age of 7 days. A moist condition is that in which free water is maintained on surfaces of specimens at all times. Specimens shall not be exposed to a stream of running water nor be stored in water. After completion of moist curing, the specimens shall be stored at 73.4±2.0 °F (23.0±1.1 °C) and at a relative humidity of 50±4 percent until completion of test.

7.1.2 *Basic Creep Curing.*-If it is desired to prevent gain or loss of water during storage and test period, specimens shall, at time of fabrication or stripping, be enclosed and sealed in moistureproof jackets, such as thin copper, to prevent loss of moisture by evaporation, and shall remain sealed throughout storage and testing period.

7.1.3 *Variable Curing Temperature Regimen.*-When it is desired to introduce effect of temperature on elastic and inelastic properties of a concrete, such as the adiabatic temperature conditions existing in massive concrete or temperature conditions to which concrete is subjected during accelerated curing, temperatures within specimen storage facility shall be controlled to correspond to desired temperature history. The user shall be responsible for establishing the time-temperature history and the permissible range of deviation.

7.1.4 *Other Curing Conditions.*-Other test ages and ambient storage conditions may be substituted when information is required for specific applications. The storage conditions shall be carefully detailed in the report.

7.2 *Embedded Gauges.*-Figure 1 shows a mold for horizontally casting a specimen to contain an elastic wire strain gauge for measuring strain. The strain meter is secured rigidly in center of mold with two threaded rods attached to an angle iron at top of mold. When this or a similar system is used, the support rods shall be removed after mold is filled and concrete has taken initial set so that gauge is free to respond to movements of the concrete. Unthread the rods from the gauge and remove from specimen. This will leave two long voids in the concrete which are considered negligible in volume.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

8.2 Molds shall be calibrated to meet requirements of section 3 in USBR 4192 by using linear measuring devices meeting requirements of USBR 1000.

8.3 Loading frames shall be checked for compliance with section 4.2 using loading jacks equipped with certified pressure gauges or by hydraulic load-maintaining devices equipped with certified gauges. These gauges may be checked for accuracy in accordance with USBR 1040.

8.4 Strain measuring devices of the mechanical type shall be checked for compliance by comparing with a constant-length standard reference bar made of invar steel. Elastic wire and vibrating wire-type strain measuring devices are calibrated using calibration jigs with optional micrometers. Although the manufacturer's calibrations are normally accurate, gauges should be checked to ensure they have not been damaged by being extended beyond their working range during handling.

9. Procedure

9.1 *Age at Loading.*-When purpose of test is to compare creep potential of different concretes, initially load specimens at 28-day's age. When complete creep behavior of a given concrete is desired, prepare specimens for initial loading at 2-, 7-, 28-, and 90-day's; and 1-year age. If information is desired for other ages of loading, include such in the report.

9.2 *Loading Details.*–Immediately prior to loading creep specimens, determine compressive strength of strength specimens in accordance with USBR 4039. When unsealed creep specimens are placed in loading frame, cover ends of control cylinders to prevent loss of moisture (note 3). Load specimens at an intensity of not more than 40 percent of the compressive strength at age of loading. Make strain readings immediately before and after loading, 2 to 6 hours after loading, daily for 1 week, weekly for 1 month, and monthly until end of 1 year. With higher concentrations of cement replacements by pozzolans and the slower strength gains, the early strain readings must be interpreted with caution. Before making each strain reading, measure the load. If load varies more than 2 percent from correct value, load must be adjusted (note 4). Make strain readings on control specimens on same schedule as loaded specimens.

NOTE 3.–When placing creep specimens in frame, take care in aligning specimens to avoid eccentric loading.

NOTE 4.–Where springs are used to maintain load, adjustment can be accomplished by applying correct load and tightening nuts on threaded reaction rods.

10. Calculations

10.1 Calculate total load-induced strain per pound force per square inch (or per kilopascal) as the difference between the average strain values of the loaded and control specimens divided by the average stress. To determine creep strain per pound force per square inch (or per kilopascal) for any age, subtract from the total load-induced strain, at that age, the strain immediately after loading. If desired, plot total strain on semilog coordinate paper, on which logarithmic axis represents time, to determine constants $1/E$ and $F(K)$ used in the following equation:

$$\epsilon = \frac{1}{E} + F(K)\ln(t+1) \qquad (1)$$

where:

ϵ = total strain in pound force per square inch (kilopascals),
E = instantaneous elastic modulus in pound force per square inch (kilopascals),
$F(K)$ = creep rate (calculated as slope of a straight line representing creep curve on semilog plot),
ln = natural logarithmic function, and
t = time after loading in days

The constant $1/E$ is the initial elastic strain, and is determined from the strain readings taken immediately before and after loading the specimen. If loading was not accomplished expeditiously, some creep may have occurred before the after-loading strain was observed, in which event extrapolation to zero time by method of least squares may be used to determine this quantity.

For example, to calculate the total strain at 133 and 126 days for 100 lbf/in^2 at 7 days loading age and for 400 lbf/in^2 at 14 days loading age, the constant initial elastic strain, $1/E$, is 0.29 and 0.23 × 10^{-6} inch per inch per pound force per square inch, respectively. The creep rate, $F(K)$, is determined by running a linear regression equation plotting the natural logarithm (base e = 2.7182818) of $(t+1)$ on the x-axis against the normalized creep in inch per inch per pound force per square inch for each age of reading on the y-axis. The correlation coefficient, intercept point where line crosses the y-axis, and the slope of the line are then determined:

100 lbf/in^2 at 7 days loading age:
Correlation coefficient = 0.8239902
Intercept = 0.330921
Slope = 0.0338368
$\epsilon = 0.29 + 0.0338 \ln (133 + 1)$
$= 0.29 + 0.0338 (4.8978)$
$= 0.46$ lbf/in^2
For comparison, figure 7 indicates $\epsilon = 0.49$ lbf/in^2

400 lbf/in^2 at 14 days loading age:
Correlation coefficient = 0.9740423
Intercept = 0.2428489
Slope = 0.0312123
$\epsilon = 0.23 + 0.0312 \ln (126 + 1)$
$= 0.23 + 0.0312 (4.8442)$
$= 0.38$ lbf/in^2
For comparison, figure 7 indicates $\epsilon = 0.38$ lbf/in^2

It should be noted that a correlation coefficient close to unity (1) indicates a highly positive relationship.

10.2 Figures 6 through 10 show typical calculation forms and plotted curves.

11. Report

11.1 A reporting form for this procedure is best represented by a cover letter in conjunction with figures 6 through 10. The report shall include:

- Cementitious content, water-cementitious ratio, maximum aggregate size, slump, and air content.
- Type and source of cement, aggregate, admixture, and mixing water (if other than fresh water is used).
- Position of cylinder when cast.
- Storage conditions before and after loading.
- Age of specimen at time of loading.
- Compressive strength of specimen.
- Type of strain measuring device.
- Magnitude of any preload.
- Intensity of applied load.
- Initial elastic strain.
- Creep strain at designated age up to 1 year.
- Creep rate $F(K)$, if determined.

12. Precision and Bias

12.1 The single-operator batch precision has been found to be ±4.0 percent, and the single-operator multibatch precision is ±9.0 percent over the range of creep strains from 250 to 2,000 millionths. These are the R1S percentages defined in ASTM E 177. Therefore, the results of properly conducted tests of duplicate cylinders from a single batch should agree within 6 percent of the average of the two cylinders, and the results of properly conducted tests of duplicate cylinders from different batches should agree within 13 percent of the average.

12.2 There is no known bias.

METHOD B

13. Apparatus

13.1 *Hydraulic Loading System*.–The loading piston consists of a 1-inch (25-mm) thick steel plate 18 inches (457 mm) in diameter. This piston plate moves in a cylinder machined into top plate of loading frame. A single Teflon "O" ring provides a seal between plate and cylinder wall. A constant sustained pressure is maintained on piston plate by a control system consisting of a pressure controller, a motor-driven metering pump, and an accumulator (fig. 3). Pressure is regulated by a vane-type controller sensitive to small changes in pressure. The loads maintained on the cylinders vary depending upon age of concrete when cylinders are loaded. A separate control system is necessary for each pressure being maintained. Suppressed ranges are used on all but the lowest pressure controller to gain greater sensitivity and accuracy. The pressure controller actuates a motor-driven, positive displacement, reciprocating plunger-type metering pump that has an adjustable stroke from 0 to 1-1/2 inches (0 to 38 mm). The maximum stroke is used to bring system under load, and then reduced to the shorter stroke for maintaining constant pressure.

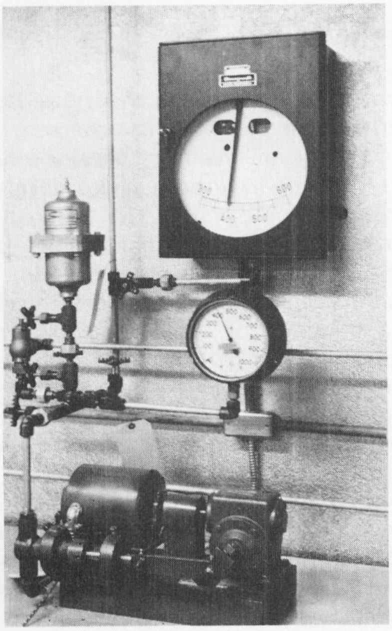


Figure 3. – Pressure regulator, metering pump, and accumulator for load control on creep tests.

13.1.1 Pressure fluctuations due to the positive displacement pump are absorbed in a hydropneumatic accumulator installed on the line. The accumulator is a metal shell separated into two chambers by a rubber hat or diaphragm. The upper chamber is charged with nitrogen, and lower chamber is connected to hydraulic fluid line. In addition to equalizing pressure fluctuations, accumulator serves to maintain pressure on system during periods of power failure. For economy, aluminum accumulators of 30-in^3 (0.0005-m^3) capacity are used on pressure systems of 400 lbf/in^2 (2758 kPa) or less. On the 600-lbf/in^2 (4137-kPa) pressure system, a 60-in^3 (0.001-m^3) steel accumulator is used to provide additional volume because of an anticipated greater number of specimens being connected to system.

13.1.2 A pressure gauge has been placed in hydraulic line as a check reading on control instrument. Should controller stick, causing pressure pump to run continuously, a safety relief valve in system would open before damaging pressures are reached.

13.1.3 Extra-strong seamless steel tubing and 3,000-lbf/in^2 (20 684-kPa) pipe fittings are used on all pressure lines, which permits any of the systems to be operated at a higher pressure if required.

13.2 *Loading Frames*.–The rods connecting the top and base plates are made of high strength, Max-El 2b steel to reduce number of rods necessary for higher loads. Stiffeners have been added to top end plate to avoid excessive deflection of plate. An equalizer cell is placed on bottom base plate when pressures over 400 lbf/in^2 (2758 kPa) are applied to avoid nonuniform stress distribution across specimen end due to base plate deflection. This equalizer cell is connected to same hydraulic pressure line as loading piston. Because equalizer cell carries mass of specimen in addition to load on specimen, a spacer wire is placed on top of the piston to ensure that hydraulic fluid enters entire cavity between piston and cylinder end.

14. Precautions

14.1 The general precautions are the same as for method A (sec. 5). Special precautions in case of power failure are discussed in section 13.1.1, and precautions in case of pressure buildup in section 13.1.2.

15. Test Specimens

15.1 *Specimen Mold*.–The mold for casting the 18- by 36-inch (457- by 914-mm) concrete cylinders is shown on figure 4. A sheet copper liner 0.01 inch (0.25 mm) thick, that remains on cylinder to seal concrete from

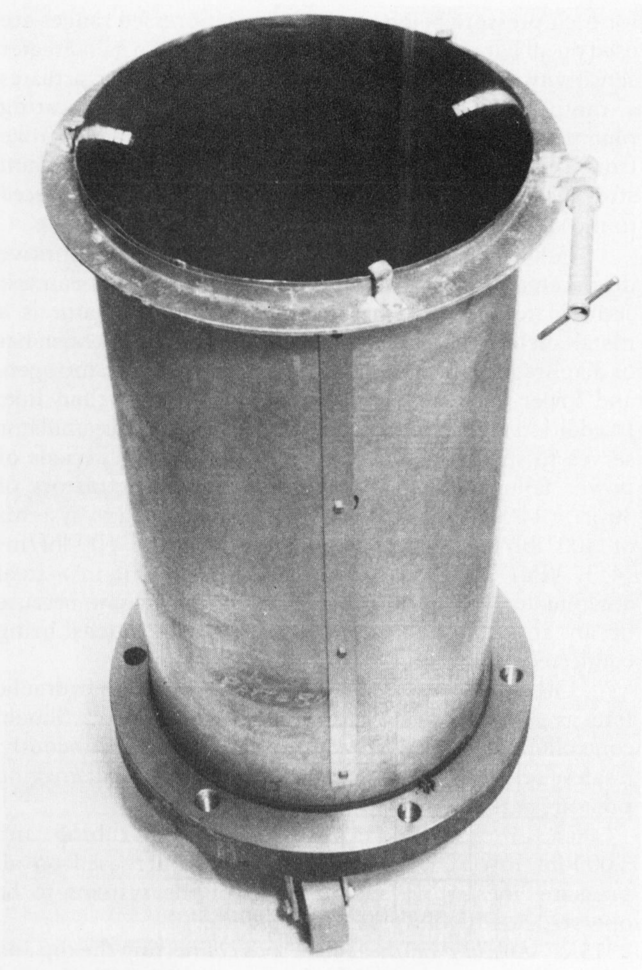


Figure 4. - Mold for casting 18- by 36-inch (457- by 914-mm) concrete cylinders for creep tests.

moisture changes, is placed inside a standard sheet steel mold. Brass inserts for measuring length change are held in place by vertical spacer bands. These inserts are placed to give three 10-inch (254-mm) gauge readings along each of three gauge lines spaced at 120° intervals around circumference of cylinder.

15.2 *Fabricating Specimen*.-The cylinder is filled in three layers, with each layer being consolidated by an internal vibrator (note 5). If internal elastic wire, vibrating wire, or other type of gauges are used for measuring strain instead of inserts and external dial-type measuring instruments, they are usually inserted manually while specimen is being cast, care being taken not to damage gauges when specimen is being fabricated. For an 18- by 36-inch (457- by 914-mm) specimen, three gauges are usually inserted vertically. When specimens are cast at a field site, particular care should be taken to cast them on a flat surface so that top of finished specimen is perpendicular to axis of specimen. A stiffener ring (fig. 4) is placed around top of mold during casting to maintain cylinder in a circular shape.

NOTE 5.-This consolidation is usually accomplished using a 2-inch (51-mm) spud vibrator operating at about 10,000 vibrations per minute. To minimize any possible damage to the internal wires or inserts, the filling may be made in two equal layers if it is obvious that the concrete is receiving adequate consolidation.

15.3 *Number of Specimens*.-One test specimen shall be cast for each loading age. One specimen shall also be cast to remain unloaded for use as a control specimen to indicate deformations due to causes other than load. One or two specimens shall be cast and tested in 6- by 12-, 12- by 24-, or 18- by 36-inch (152- by 305-, 305- by 610-, or 457- by 914-mm) molds, depending on the maximum size aggregate. Each strength and control specimen shall have the same storage treatment as a loaded specimen (note 6).

NOTE 6.-With high percentages of pozzolan replacement of cement, stripping of the outer mold may have to be delayed to the 72-hour specimen age. Also, lapping and sealing may not be accomplished until 6-day's age. Because of the extensive amount of labor involved, the 14- and 28-day creep specimens may not be lapped and sealed the same day as the control specimens. In no case should the specimens be allowed to stay in the 100-percent humidity room longer than 28 days of age.

15.4 *Smaller Specimens*.-The described loading system has been adapted for testing 6-inch (152-mm) diameter cylinders by modifying the loading frames. Figure 5 shows a loading frame with a 6-inch diameter piston plate installed into each head plate for loading two cylinders. The previous method of loading used a hydraulic ram placed between the two specimens. The testing procedure should follow that of Method A (sec. 9).

16. Conditioning

16.1 *Curing and Storage*.-The main purpose of Method B is to determine the creep of mass concrete. The curing condition that best simulates mass interior concrete is the one where specimens have been sealed against moisture changes. Therefore, unless otherwise directed, specimens shall be cured and tested sealed in copper jackets at a temperature of 73.4±2 °F (23.0±1.1 °C).

16.2 *End Conditions*.-The ends of each cylinder shall be flat to a tolerance of 0.002 inch (0.05 mm). This requirement can be met by lapping or, at time of casting, by fitting ends with bearing plates normal to axis of cylinder. Experience has shown that voids (from trapped bleed water, air, and settlement) occur beneath the top end plate. Because of this, lapping is preferred. When test program calls for specimens to be loaded at 2 days, and also at 7 days on some lean mass concrete, concrete does not have sufficient strength for lapping before being placed under load, and end plates must be fitted to specimen during casting. Secure top plate to specimen by troweling top surface of concrete into a cone shape, center of cone being about 1 inch (25 mm) higher than base of cone. After concrete has finished bleeding, the top end plate is vibrated securely down onto top of specimen and soldered to copper

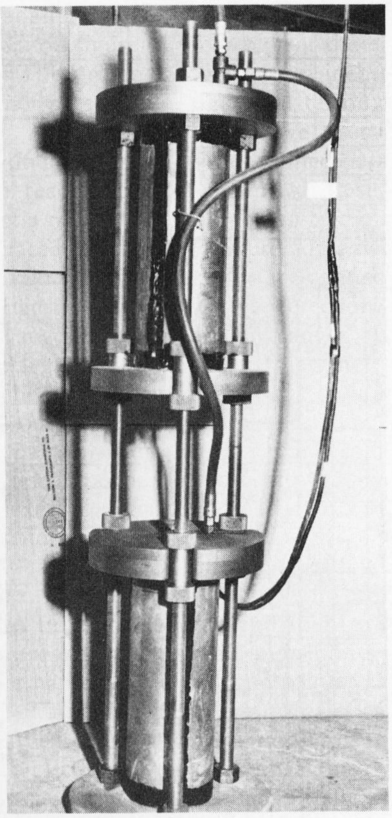


Figure 5. - Loading frame for creep tests on 6-inch (152-mm) diameter cylinders.

jacket. On specimens that are lapped, place a sheet of copper of same thickness as liner on top surface of specimen. Crimp copper extending over the edge down around the specimen and solder to copper liner to form a seal. Apply a coat of coal-tar enamel to all solder joints to guard against moisture loss through pinholes in joints.

17. Calibration and Standardization

17.1 Calibration of pressure gauges shall be made in accordance with USBR 1040.

17.2 Strain measuring devices of the fulcrum-plate type shall be checked by comparing with a constant-length standard reference bar made of invar steel. Elastic-wire and vibrating-wire type strain measuring devices use the certified calibrations submitted by manufacturer. These calibrations should be checked in jigs with optical micrometers to ensure that gauges have not been damaged during handling.

18. Procedure

18.1 *Age at Loading*.–When complete creep behavior of a given concrete is desired, prepare specimens for initial loading at 2-, 7-, 28-, and 90-days and 1-year age. If the 2- and 7-day tests are not required or information is desired for other ages, include such information in the report.

18.2 *Loading Details*.–Center specimen in frame such that loading head covers end of test cylinder. Because loading head and test specimen are same diameter, the pressure read on hydraulic gauge is the same as load on cylinder. When using loads over 400 lbf/in^2 (2758 kPa), place test specimen on an equalizer cell on bottom base plate (sec. 13.2 and note 7). Load specimens at an intensity of not more than 40 percent of compressive strength at age of loading. Make strain readings immediately before and after loading, 2 to 6 hours after loading, daily for 1 week, weekly for 1 month, and monthly until end of 1 year. Make readings on control specimen each time loaded specimens are read.

NOTE 7.–Recent tests by the Bureau have eliminated using the equalizer cell.

19. Calculations

19.1 Calculations shall be the same as for method A (sec. 10).

19.2 Figures 6 through 10 show typical calculation forms and plotted curves.

19.3 In recent years, Bureau creep studies have discontinued using the Carlson strain meter in the cylinders; therefore, no sample forms for recording the data are included in this procedure.

20. Report

20.1 The report shall be the same as for method A (sec. 11).

21. Precision and Bias

21.1 The precision and bias statements for method B have not been established.

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA — Date 10-5-88
Project SALT RIVER	Item CREEP STUDY ON MASS CONCRETE Location DENVER CONCRETE LAB	Computed by D. ARNEY — Date 10-5-88
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date 10-5-88

CREEP OF CONCRETE IN COMPRESSION

Mix ID	W/C or W/(C + P)	S/A	Mix Quantities Per [✓ Cubic Yard] or Cubic Meter							Properties of Fresh Concrete									
			AEA	WRA	Water	Cementitious		Sand	Agg.	Mix Temp.	Slump	Density, [✓ lbm/ft³] (kg/m³)				Percent Air			
						Cement	Pozzolan					Theoretical		Actual		Gravimetric		Pressure	
		%	[✓ oz.] cm³	[✓ oz.] cm³	[✓ lbm] kg	[✓ lbm] kg	[✓ lbm] kg	[✓ lbm] kg	[✓ lbm] kg	[✓ °F] °C	[✓ inches] mm	Total Mix	___ Mix	Total Mix	___ Mix	Total Mix	___ Mix	Total Mix	1½ Mix
CONV. CONC.	0.54	28.5	5	11	167	187	81	1,022	2,573	45	2.5	148.8				4.5			4.7

Loading	Cylinder Size	Compressive Strength, [✓ lbf/in²] (kPa)						Direct Tensile Strength, [✓ lbf/in²] (kPa)						Splitting Tensile Strength, [✓ lbf/in²] (kPa)					
		Age in Days						Age in Days						Age in Days					
		2	7	14	28	90				14	28	90		2	7	14	28	90	
3,000 lbf/in² @ 1-year age, Adiabatic Cure	6- by 12-inch ___- by ___-mm	3 days 1,010	1,670		3,580	4,100													
	Modulus of Elasticity $E \times 10^6$				4.64	4.45													
	Poisson's Ratio, μ				0.18	0.18													
3,000 lbf/in² @ 1-year age	6- by 12-inch ✓ 152- by 305-mm	1,010	2,090	2,730	3,230	4,050				260	350	300		150	260	285	330	385	
	Modulus of Elasticity $E \times 10^6$		3.12	3.72	4.03	4.81													
	Poisson's Ratio, μ		0.20	0.14	0.18	0.22													
3,000 lbf/in² @ 1-year age	12- by 24-inch ✓ 305- by 610-mm		1,910	2,510	2,820	3,420													
	Modulus of Elasticity $E \times 10^6$		2.80	4.16	4.30	5.02													
	Poisson's Ratio, μ		0.14	0.20	0.20	0.21													
4,000 lbf/in² @ 28 days age	6- by 12-inch ___- by ___-mm	650	2,450	2,800	3,310	4,460				305	260	290		280	350	305	350	465	
	Modulus of Elasticity $E \times 10^6$		3.40	4.30	4.46	4.95													
	Poisson's Ratio, μ		0.18	0.20	0.21	0.21													

Sand

Supplier: GOV. BLM Source: MEDDLER POINT
Supplier: ______ Source: ______
Sp. Gr. = 2.70 % Absorption = 0.90 FM = 2.93 M- 7924
Sp. Gr. = ______ % Absorption = ______ FM = ______ M- ______

Sieve Size	Minus No. 200 (~~75-µm~~)	No. 100 (~~150-µm~~)	No. 50 (~~300-µm~~)	No. 30 (~~600-µm~~)	No. 16 (~~1.18-mm~~)	No. 8 (~~2.36-mm~~)	No. 4 (~~4.75-mm~~)
% Retained	3.4	10	20	32	23	11	0

Coarse Aggregate

MSA = ______ inches (mm), Scalped to ______ inches (mm)
Supplier: GOV. BLM Source: MEDDLER POINT
Supplier: ______ Source: ______
Sp. Gr. = 2.61 % Absorption = 0.82 M- 7924
Sp. Gr. = ______ % Absorption = ______ M- ______

Nominal Size Fraction	3/8 inch __ mm	1 inch __ mm	2 inch __ mm	4 inch __ mm	__ inch __ mm	__ inch __ mm
% Retained	3.2	30.3	41.3	25.2		

M-	Cement	Pozzolan	AEA	WRA
Brand		WESTERN ASH		WRDA -79
Supplier	ARIZ. PORTLAND		DENVER LAB	
Description	LOW HEAT		VINSOL RESIN	
Type	V MODIF.			A
Class		F		
Specific Gravity	3.15	2.32		
Cement Replaced, %		30		

Figure 6. – Sample reporting form for mix design and properties of fresh concrete for creep studies.

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA Date 10-5-88 & 11-21-89
Project SALT RIVER	Item CREEP STUDIES-MASS CONCRETE Location DENVER CONCRETE LAB	Computed by D. ARNEY Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION

SPECIMEN DATA

Control Specimen, Cylinder No. 119
Creep Specimen, Cylinder No. 120-123

☒ Not Loaded (Fig. 8, sheets 1&2)
☒ Loaded (Fig. 8, sheets 3-6)
☐ Unloaded Date ______

Date Cast 10-5-88 Cylinder Nos. Cast 119-127 Dimensions: 18- by 36- [✓ inches] (mm)
MSA (Maximum Size Aggregate) = 4½ [✓ inches] (mm) Scalped to NA inches (mm)
Temp. of Mix = 45 [✓ °F] (°C) Thermal Coefficient of Expansion (α) = 3.5 × 10^{-6} inch/inch ~~(mm/mm)~~
Conditioning and Curing: Cast and stripped from molds at about 72 hours, stored in 100% humidity at 73.4±3 °F until 6-days age, lapped and sealed, stored in 50% humidity at 73.4±3 °F until start of test.
Comparator No. LPW7 Invar Bar No. 1 Gauge Whittemore LPW7 Gauge Length (*GL*) = 10 [✓ inches] (mm)
Standard Bar Zero = 1557 Loading Condition = No LOAD, 100 and 400 [✓ lbf/in²] (kPa) at 7&14 days age

DESCRIPTION OF DATA COLUMNS SHOWN ON FIGURE 8

Column (1): Time of day and/or date that specimens are started on creep test. For control specimens, this is the time for reading at start; for creep specimens, the time immediately before and after loading.

Column (2): Specimen age and loading or unloading time in minutes, hours, or days.

Column (3): Temperature, T, in °F or °C taken in the 50-percent humidity room at the time creep readings are taken.

Column (4): Temperature difference, ΔT, in °F or °C, where $\Delta T = 73.4$ °F or 23.0 °C − T.

Column (5): Standard bar base reading, which is the calibration for the standard bar with a standard gauge reading in inches or millimeters × 10^{-4}.

Column (6): Standard bar correction for the temperature difference from 73.4 °F or 23.0 °C, see appendix table X1.2 in USBR 4901. If coefficient of thermal expansion of invar steel from which standard or reference bar is fabricated is equal to 0.96 × 10^{-6} (inch/inch)/°F or 1.72 × 10^{-6} (mm/mm)/°C and the dial gauges are accurate to 10^{-4}, the gauge lengths are as shown in table X1.2. If this criteria is not valid, a new table must be generated. With a 10-inch (254-mm) gauge length, ΔT must be greater than ±5.2 °F (±2.89 °C).

Column (7): This column contains the dial gauge readings between the bands of gauge lines that are spaced uniformly around the perifery of the specimen. Readings are in inch per inch × 10^{-4} or millimeter per millimeter × 10^{-4}.

Column (8): This column shows the average or summation of the dial gauge readings shown in column (7); readings are in inches or millimeters × 10^{-4}.

Column (9): Thermal correction to the dial gauge reading for the concrete specimen based on the thermal coefficient of expansion of the concrete for the gauge length, summation of gauge lengths, and ΔT. When a control specimen is used along with a test specimen and readings are taken at same time and temperature, this correction is not required.

Column (10): This column shows the dial gauge reading corrected for the thermal correction to 73.4 °F or 23.0 °C. Readings are shown in inches or millimeters × 10^{-4}. When a control specimen is used along with a test specimen and readings are taken at same time and temperature, this correction is not required.

Column (11): Shows the creep from first creep speciman as ΔL_1 in inches or millimeters × 10^{-4}.

Column (12): Shows the creep from second (or companion) specimen as ΔL_2 in inches or millimeters × 10^{-4}.

Column (13): Average creep, ΔL_A, of creep specimens shown in columns (11) and (12).

Column (14): Length change of control specimen at age test specimen was loaded at specified design loading. Length change, ΔL, shown in inches or millimeters × 10^{-4}.

Column (15): Creep or recovery of specimen corrected for thermal correction (if applicable) and/or control correction. Correction shown for creep (ΔL_3) or recovery (ΔL_4) in inches or millimeters × 10^{-4}.

Column (16): Creep ΔL_c, which is ΔL_3 divided by gauge length *GL* times 100, for converting to unit deformation. Shown in inches or millimeters × 10^{-6}.

Column (17): Normalized or unit creep ΔL_c, which is column (16) divided by the load in inch per inch per pound force per square inch × 10^{-6} or millimeter per millimeter per kilopascal × 10^{-6}. Creep value shown in inches or millimeters × 10^{-6}.

Column (18): Recovery ΔL_R, which is ΔL_4 divided by gauge length *GL* times 100, for converting to unit recovery. Units same as shown in column (16).

Column (19): Normalized or unit recovery ΔL_R, which is column (18) divided by load. Units same as shown in column (17).

Figure 7. – Specimen data and description of data columns shown on figure 8.

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D.ARNEY & C.PRUSIA Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D.ARNEY Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C.PRUSIA Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION

CREEP CYL. NOS. 120, 121
NO LOAD

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h, [✓ d]		(3) T Temp. [✓ °F] °C	(4) ΔT 73.4-T 23.0-T [✓ °F] °C	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings									(8) Σ of Dial Readings or 12,845 = 0 or Base Avg.	(9) Thermal Corr-ection
	Age	Time						1	2	3	4	5	6	7	8	9		
					*			Inches ~~or millimeters~~ × 10^{-4}										
10-12-88	7d	0d	73.2	+0.2	1557	0	1557	1539	1372	1388	1535	1392	1498	1527	1125	1469	12,845	+1
10-13	8	1	74.8	-1.4				1540	1372	1391	1538	1397	1501	1530	1129	1473	12,871	-4
10-15	10	3	74.0	-0.6				1540	1371	1393	1537	1395	1501	1529	1129	1472	12,867	-2
10-19	14	7	72.8	+0.6				1540	1371	1391	1536	1395	1500	1529	1128	1470	12,860	+2
10-20	15	8	74.2	-0.8				1540	1372	1392	1535	1395	1500	1527	1128	1473	12,862	-3
10-24	19	12	74.0	-0.6				1539	1370	1390	1536	1395	1500	1527	1127	1473	12,857	-2
11-2	28	21	71.9	+1.5				1539	1370	1392	1535	1394	1500	1527	1127	1472	12,856	+5
11-3	29	22	72.9	+0.5				1540	1370	1393	1536	1394	1500	1527	1127	1472	12,859	+2
11-4	30	23	74.3	-0.9				1539	1370	1392	1535	1394	1500	1526	1127	1472	12,855	-3
11-7	33	26	71.0	+2.4				1539	1369	1392	1535	1395	1499	1525	1126	1470	12,850	+8
11-14	40	33	74.3	-0.9				1539	1369	1391	1536	1394	1500	1526	1127	1472	12,854	-3
11-17	43	36	70.4	+3.0				1538	1368	1390	1535	1393	1499	1526	1126	1472	12,847	+9
11-18	44	37	75.0	-1.6				1539	1368	1392	1536	1393	1500	1526	1126	1473	12,853	-5
11-29	55	48	74.6	-1.2				1539	1368	1391	1535	1394	1500	1526	1126	1472	12,851	-4
12-9	65	58	75.0	-1.6				1540	1369	1393	1537	1395	1500	1527	1127	1474	12,862	-5
12-19	75	68	72.2	+1.2				1539	1368	1391	1535	1394	1500	1526	1126	1473	12,852	+4
1-4-89	91	84	73.5	-0.1				1540	1370	1392	1536	1395	1501	1528	1127	1473	12,862	0
1-5	92	85	74.0	-0.6				1539	1370	1392	1536	1394	1500	1527	1127	1473	12,858	-2
1-6	93	86	72.6	+0.8	↓	↓	↓	1540	1370	1392	1537	1394	1501	1527	1127	1473	12,861	+3

(10) 12,846 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. __ Length Change ΔL_1	(12) Creep Cyl. No. __ Length Change ΔL_2	(13) Avg. Length Change of Creep Cyl. ΔL_A	(14) Control Cylinder Number 119								(15) Creep or Recovery Corrected for Temp. and/or Control ΔL_3 or ΔL_4	(16) Creep ΔL_c $\frac{\Delta L_3}{GL\,(100)}$	(17) Col. (16) / Load	(18) Recovery ΔL_R $\frac{\Delta L_4}{GL\,(100)}$	(19) Col. (18) / Load
				ΔL at 7d	ΔL at 14d	ΔL at 28d	ΔL at 90d	ΔL at	ΔL at	ΔL at	ΔL at					
Inches ~~or millimeters~~ × 10^{-4}													Inches or millimeters × 10^{-6}			
12,846				0												
12,867				+21												
12,865				+19												
12,862				+16	0											
12,862	= 0, or base reading for 14-day loading of test specimen															
12,859				+13	-3											
12,855				+9	-7											
12,861				+15	-1											
12,861	= 0, or base reading for 28-day loading of test specimen															
12,861				+15	-1	0										
12,852				+6	-10	-9										
12,858				+12	-4	-3										
12,851				+5	-11	-10										
12,856				+10	-6	-5										
12,848				+2	-14	-13										
12,847				+1	-15	-14										
12,857				+11	-5	-4										
12,856				+10	-6	-5										
12,862				+16	0	+1	0									
12,862	= 0, or base reading for 90-day loading of test specimen															
12,856				+10	-6	-5	-6									
12,864				+18	+2	+3	+2									

*See table X1.2 of USBR 4901 if applicable.

Figure 8. – Sample form for recording creep data and applying corrections for temperature and control (sheet 1 of 6).

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA — Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D. ARNEY — Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION

CREEP CYL. NOS. 120, 121
NO LOAD

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h [✓ d]		(3) T Temp. [✓ °F] °C	(4) ΔT 73.4-T 23.0-T [✓ °F] °C	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings									(8) Σ of Dial Readings or 12,845 = 0 or Base Avg.	(9) Thermal Corr-ection
	Age	Time			*			1	2	3	4	5	6	7	8	9		
					Inches ~~or millimeters~~ × 10^{-4}													
1-9-89	96 d	89 d	69.5	+3.9	1557	0	1557	1538	1368	1390	1534	1392	1498	1526	1126	1471	12,841	+12
1-13	100	93	72.5	+0.9				1538	1369	1390	1534	1393	1498	1525	1125	1473	12,845	+3
1-18	105	98	71.5	+1.9				1540	1369	1391	1537	1395	1501	1528	1128	1475	12,864	+6
1-26	113	106	73.0	+0.4				1539	1368	1391	1534	1392	1499	1525	1125	1471	12,844	+1
2-22	140	133	74.0	-0.6				1540	1371	1392	1536	1395	1501	1528	1128	1473	12,863	-2
4-12	189	182	74.0	-0.6				1539	1368	1391	1536	1393	1499	1525	1125	1472	12,848	-2
8-1	300	293	72.3	+1.1				1539	1370	1392	1536	1394	1501	1527	1127	1474	12,860	+3
10-2	362	355	72.2	+1.2				1540	1368	1391	1536	1395	1500	1526	1126	1470	12,852	+4
11-21	412	405	71.8	+1.6				1538	1368	1390	1535	1394	1498	1525	1125	1471	12,844	-5
								Discontinued Readings										

(10) 12,846 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. __ Length Change ΔL_1	(12) Creep Cyl. No. __ Length Change ΔL_2	(13) Avg. Length Change of Creep Cyl. ΔL_A	(14) Control Cylinder Number 119								(15) Creep or Recovery Corrected for Temp. and/or Control ΔL_3 or ΔL_4	(16) Creep ΔL_c $\frac{\Delta L_3}{GL\ (100)}$	(17) Col. (16) Load	(18) Recovery ΔL_R $\frac{\Delta L_4}{GL\ (100)}$	(19) Col. (18) Load
				ΔL at 7 d	ΔL at 14 d	ΔL at 28 d	ΔL at 90 d	ΔL at	ΔL at	ΔL at	ΔL at					
Inches ~~or millimeters~~ × 10^{-4}													Inches or millimeters × 10^{-6}			
12,858				+7	-9	-8	-9								No rebound determinations made	
12,848				+2	-14	-13	-14									
12,870				+24	+8	+9	+8									
12,845				-1	-17	-16	-17									
12,861				+15	-1	0	-1									
12,846				0	-16	-15	-16									
12,863				+17	+1	+2	+1									
12,856				+10	-6	-5	-6									
12,839				-7	-23	-22	-23									

where 12,839 = 0, or base reading to measure recovery of creep specimens as they enter an unloading cycle if recovery must be measured.

*See table X1.2 of USBR 4901 if applicable.

Figure 8. - Sample form for recording creep data and applying corrections for temperature and control (sheet 2 of 6).

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA — Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D. ARNEY — Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION CREEP CYL. No. 120 100 lbf/in² @ 7 days

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h, [✓ d]		(3) T Temp.	(4) ΔT 73.4-T 23.0-T	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings									(8) Σ of Dial Readings or 13,412 = 0 or Base Avg.	(9) Thermal Corr-ection
	Age	Time	[✓ °F] °C	[✓ °F] °C	*			1	2	3	4	5	6	7	8	9		
								Inches ~~or millimeters~~ × 10⁻⁴										
10-12-88	7d	0 d	73.2	+0.2	1557	0	1557	968	1476	1680	1008	1444	1954	1878	1149	1855	13,412	+1
10-12	7	0	73.2	+0.2				960	1475	1680	1004	1444	1952	1874	1147	1852	13,388	+1
10-12	7	0	73.2	+0.2				951	1476	1680	1005	1444	1953	1875	1147	1853	13,384	+1
10-13	8	1	74.8	-1.4				963	1477	1682	1006	1445	1954	1876	1148	1855	13,406	-4
10-15	10	3	74.0	-0.6				963	1477	1681	1007	1445	1954	1875	1148	1854	13,404	-2
10-20	15	8	74.2	-0.8				962	1475	1681	1006	1444	1954	1875	1147	1853	13,397	-3
10-24	19	12	74.0	-0.6				960	1475	1680	1004	1442	1952	1873	1146	1852	13,384	-2
11-4	30	23	74.3	-0.9				960	1474	1680	1006	1442	1952	1872	1146	1851	13,382	-3
11-18	44	37	75.0	-1.6				960	1475	1680	1004	1442	1952	1873	1147	1851	13,384	-5
12-9	65	58	75.0	-1.6				960	1476	1680	1004	1442	1952	1873	1145	1852	13,383	-5
1-5-89	92	85	74.0	-0.6				966	1474	1679	1005	1442	1951	1873	1145	1853	13,388	-2
2-22	140	133	74.0	-0.6				961	1475	1680	1007	1443	1952	1873	1146	1849	13,386	-2
4-12	189	182	74.0	-0.6				960	1473	1678	1004	1441	1949	1871	1144	1849	13,369	-2
8-1	300	293	72.3	+1.1				960	1474	1680	1004	1441	1951	1872	1144	1850	13,376	+3
10-2	362	355	72.2	+1.2				960	1473	1680	1004	1441	1950	1872	1145	1850	13,375	+4
11-21	412	405	71.8	+1.6	↓	↓	↓	960	1473	1677	1005	1440	1950	1871	1143	1850	13,369	+5
								Discontinued Readings										

(10) 13,413 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. 120 Length Change ΔL_1	(12) Creep Cyl. No. __ Length Change ΔL_2	(13) Avg. Length Change of Creep Cyl. ΔL_A	(14) Control Cylinder Number 119								(15) Creep or Recovery Corrected for Temp. and/or Control ΔL_3 or ΔL_4	(16) Creep ΔL_C $\frac{\Delta L_3}{GL(100)}$	(17) Col. (16) / Load	(18) Recovery ΔL_R $\frac{\Delta L_4}{GL(100)}$	(19) Col. (18) / Load
				ΔL at 7 d	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at					
Inches ~~or millimeters~~ × 10⁻⁴													Inches ~~or millimeters~~ × 10⁻⁶			
18,413	0											0			No rebound	
13,389	-24											-24	-27	-0.27	determinations	
13,385	-28			0								-28	-31	-0.31	made	
13,402	-11			+21								-32	-36	-0.36		
13,402	-11			+19								-30	-33	-0.33		
13,394	-19			+13								-32	-36	-0.36		
13,382	-31			+9								-40	-44	-0.44		
13,379	-34			+6								-40	-44	-0.44		
13,379	-34			+2								-36	-40	-0.40		
13,378	-35			+11								-46	-51	-0.51		
13,386	-27			+10								-37	-41	-0.41		
13,384	-29			+15								-44	-49	-0.49		
13,367	-46			0								-46	-51	-0.51		
13,379	-34			+17								-51	-57	-0.57		
13,379	-34			+10								-44	-49	-0.49		
13,374	-39			-7								-32	-36	-0.36		
where 13,374=0, or base reading to measure recovery of creep specimens as they																
enter an unloading cycle if recovery must be measured.																

*See table X1.2 of USBR 4901 if applicable.

Figure 8. – Sample form for recording creep data and applying corrections for temperature and control (sheet 3 of 6).

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D. ARNEY Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION CREEP CYL. No. 121 100 lbf/in² @ 7 days

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h, [✓ d] Age	Time	(3) T Temp. [✓ °F] °C	(4) ΔT 73.4-T 23.0-T [✓ °F] °C	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings 1	2	3	4	5	6	7	8	9	(8) Σ of Dial Readings or 11,528 = 0 or Base Avg.	(9) Thermal Corr-ection
					*			Inches ~~or millimeters~~ × 10^{-4}										
10-12-88	7 d	0 d	73.2	+0.2	1557	0	1557	1181	1088	1793	1316	804	787	1961	1285	1313	11,528	+1
10-12	7	0	73.2	+0.2				1176	1087	1789	1313	802	786	1954	1284	1310	11,501	+1
10-12	7	0	73.2	+0.2				1178	1088	1790	1315	803	787	1955	1284	1310	11,510	+1
10-13	8	1	74.8	-1.4				1180	1089	1791	1316	804	786	1956	1286	1310	11,518	-4
10-15	10	3	74.0	-0.6				1178	1087	1790	1315	804	786	1954	1285	1309	11,508	-2
10-20	15	8	74.2	-0.8				1179	1087	1790	1314	803	786	1954	1284	1310	11,507	-3
10-24	19	12	74.0	-0.6				1178	1086	1789	1312	802	785	1953	1283	1309	11,497	-2
11-4	30	23	74.3	-0.9				1178	1086	1789	1312	802	784	1952	1284	1310	11,497	-3
11-18	44	37	75.0	-1.6				1178	1087	1789	1312	802	785	1953	1283	1309	11,498	-5
12-9	65	58	75.0	-1.6				1178	1086	1789	1313	802	784	1953	1283	1309	11,497	-5
1-5-89	92	85	74.0	-0.6				1177	1086	1789	1312	801	785	1953	1283	1309	11,495	-2
2-22	140	133	74.0	-0.6				1179	1086	1790	1313	803	785	1954	1282	1310	11,502	-2
4-12	189	182	74.0	-0.6				1176	1085	1788	1311	800	782	1952	1280	1307	11,481	-2
8-1	300	293	72.3	+1.1				1178	1085	1789	1311	801	783	1953	1282	1308	11,490	+3
10-2	362	355	72.2	+1.2				1176	1085	1789	1311	801	784	1952	1281	1307	11,486	+4
11-21	412	405	71.8	+1.6				1176	1084	1788	1311	800	783	1951	1280	1306	11,479	-5
								Discontinued Readings										

(10) 11,529 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. 120 Length Change ΔL₁	(12) Creep Cyl. No. 121 Length Change ΔL₂	(13) Avg. Length Change of Creep Cyl. 120 & 121 ΔL_A	(14) Control Cylinder Number 119 ΔL at 7 d	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	(15) Creep or Recovery Corrected for Temp. and/or Control ΔL₃ or ΔL₄	(16) Creep ΔLc ΔL₃/GL (100)	(17) Col. (16)/Load	(18) Recovery ΔL_R ΔL₄/GL (100)	(19) Col. (18)/Load
Inches ~~or millimeters~~ × 10^{-4}													Inches ~~or millimeters~~ × 10^{-6}			
11,529	0	0	0									0				
11,502	-24	-27	-26									-26	-29	-0.29	No REBOUND	
11,511	-28	-18	-23	0								-23	-26	-0.26	DETERMINATIONS	
11,514	-11	-15	-13	+21								-34	-38	-0.38	MADE	
11,506	-11	-23	-17	+19								-36	-40	-0.40		
11,504	-19	-25	-22	+13								-35	-39	-0.39		
11,495	-31	-34	-33	+9								-42	-47	-0.47		
11,494	-34	-35	-35	+6								-41	-46	-0.46		
11,493	-34	-36	-35	+2								-37	-41	-0.41		
11,492	-35	-37	-36	+11								-47	-52	-0.52		
11,493	-27	-36	-32	+10								-42	-47	-0.47		
11,500	-29	-29	-29	+15								-44	-47	-0.47		
11,479	-46	-50	-48	0								-48	-53	-0.53		
11,493	-34	-36	-35	+17								-52	-58	-0.58		
11,490	-34	-39	-37	+10								-47	-52	-0.52		
11,474	-39	-55	-47	-7								-40	-44	-0.44		

where 11,474=0, or base reading to measure recovery of creep specimens as they enter an unloading cycle if recovery must be measured.

*See table X1.2 of USBR 4901 if applicable.

Figure 8. – Sample form for recording creep data and applying corrections for temperature and control (sheet 4 of 6).

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA — Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D. ARNEY — Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION CREEP CYL. No. 122 400 lbf/in² @ 14 days

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h, [✓ d] Age	(2) Time	(3) T Temp. [✓ °F] °C	(4) ΔT 73.4-T 23.0-T [✓ °F] °C	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings 1	2	3	4	5	6	7	8	9	(8) Σ of Dial Readings or 13,509 = 0 or Base Avg.	(9) Thermal Correction
					*			Inches ~~or millimeters~~ × 10^{-4}										
10-19-88	14 d	0 d	72.8	+0.6	1557	0	1557	1400	1190	1989	1017	1442	1675	1665	1164	1967	13,509	+2
10-19	14	0	72.8	+0.6	↓	↓	↓	1390	1180	1980	999	1432	1667	1656	1156	1960	13,420	+2
10-20	15	1	74.2	-0.8				1390	1177	1980	999	1430	1666	1656	1154	1959	13,411	-3
10-24	20	5	74.0	-0.8				1388	1175	1977	996	1428	1664	1655	1153	1958	13,394	-3
11-7	34	19	71.0	+2.4				1387	1173	1974	995	1426	1662	1652	1150	1956	13,375	+8
11-17	44	29	70.4	+3.0				1386	1173	1975	995	1425	1661	1651	1150	1954	13,370	+9
12-9	65	51	75.0	-1.6				1385	1174	1976	995	1425	1662	1652	1150	1955	13,374	-5
1-5-89	92	78	74.0	-0.6				1385	1172	1975	995	1423	1661	1650	1150	1952	13,363	-2
2-22	140	126	74.0	-0.6				1387	1173	1975	995	1425	1662	1652	1151	1956	13,376	-2
4-12	189	175	74.0	-0.6				1384	1169	1972	992	1422	1659	1649	1147	1951	13,345	-2
8-1	300	286	72.3	+1.1				1383	1170	1974	993	1422	1660	1650	1148	1954	13,355	+3
10-2	362	348	72.2	+1.2				1382	1169	1973	993	1422	1659	1648	1148	1953	13,347	+4
11-21	412	398	71.8	+1.6				1381	1167	1973	992	1420	1658	1647	1147	1952	13,337	+5
								Discontinued Readings										

(10) 13,511 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. 122 Length Change ΔL_1	(12) Creep Cyl. No. __ Length Change ΔL_2	(13) Avg. Length Change of Creep Cyl. ΔL_A	(14) Control Cylinder Number 119 ΔL at	ΔL at 14 d	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	(15) Creep or Recovery Corrected for Temp. and/or Control ΔL_3 or ΔL_4	(16) Creep ΔL_c ΔL_3 / GL (100)	(17) Col. (16) / Load	(18) Recovery ΔL_R ΔL_4 / GL (100)	(19) Col. (18) / Load
			Inches ~~or millimeters~~ × 10^{-4}										Inches or millimeters × 10^{-6}			
13,511	0				0							0				
13,422	-89				0							-89			No Rebound Determinations Made	
13,408	-103				-3							-100				
13,391	-120				-7							-113				
13,383	-128				-4							-124				
13,379	-132				-6							-126				
13,369	-142				-5							-137				
13,361	-150				-6							-144				
13,374	-137				-1							-136				
13,343	-168				-16							-152				
13,358	-153				+1							-154				
13,351	-160				-6							-154				
13,342	-169				-23							-146				

where 13,342 = 0, or base reading to measure recovery of creep specimens as they enter an unloading cycle if recovery must be measured.

*See table X1.2 of USBR 4901 if applicable.

Figure 8. – Sample form for recording creep data and applying corrections for temperature and control (sheet 5 of 6).

Spec. or Solic. No. NONE ISSUED TO DATE	Structure DAM	Tested by D. ARNEY & C. PRUSIA Date 10-5-88 11-21-89
Project SALT RIVER	Item CREEP STUDIES Location DENVER LAB	Computed by D. ARNEY Date 10-5-88 THRU 11-21-89
Feature THEODORE ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA Date 10-3-89

CREEP OF CONCRETE IN COMPRESSION CREEP CYL. NO. 123 400 lbf/in² @ 14 days

(1) Time of Day and/or Date	(2) Specimen Age and Loading or Unloading Time, min, h, [✓ d]		(3) T Temp. [✓ °F] °C	(4) ΔT 73.4-T 23.0-T [✓ °F] °C	(5) Std. Bar Base Reading	(6) Standard Bar Correction to [✓ 73.4 °F] 23.0 °C		(7) Gauge Line Dial Readings									(8) Σ of Dial Readings or 11,920 = 0 or Base Avg.	(9) Thermal Correction
	Age	Time						1	2	3	4	5	6	7	8	9		
					*			Inches ~~or millimeters~~ × 10^{-4}										
10-19-88	14 d	0 d	72.8	+0.6	1557	0	1557	1127	1418	1210	1607	1167	1500	1174	1380	1337	11,920	+2
10-19	14	0	72.8	+0.6	↓	↓	↓	1119	1410	1202	1600	1158	1491	1167	1372	1327	11,846	+2
10-20	15	1	74.2	-0.8	↓	↓	↓	1118	1408	1200	1599	1157	1490	1165	1370	1325	11,832	-3
10-24	19	5	74.0	-0.8	↓	↓	↓	1115	1406	1197	1596	1154	1487	1163	1368	1323	11,809	-3
11-7	33	19	71.0	+2.4	↓	↓	↓	1114	1404	1197	1595	1152	1486	1161	1367	1321	11,797	+8
11-17	43	29	70.4	+3.0	↓	↓	↓	1113	1404	1195	1594	1150	1484	1161	1366	1321	11,788	+9
12-9	65	51	75.0	-1.6	↓	↓	↓	1113	1404	1196	1594	1151	1485	1160	1366	1322	11,791	-5
1-5-89	92	78	74.0	-0.6	↓	↓	↓	1111	1402	1195	1592	1150	1483	1159	1364	1320	11,776	-2
2-22	140	126	74.0	-0.6	↓	↓	↓	1114	1404	1195	1593	1150	1485	1161	1360	1321	11,783	-2
4-2	189	175	74.0	-0.6	↓	↓	↓	1111	1401	1195	1590	1147	1480	1158	1363	1317	11,762	-2
8-1	300	286	72.3	+1.1	↓	↓	↓	1111	1402	1194	1591	1149	1482	1159	1361	1318	11,767	+3
10-2	362	348	72.2	+1.2	↓	↓	↓	1110	1401	1193	1590	1148	1481	1158	1362	1318	11,761	+4
11-21	412	398	71.8	+1.6	↓	↓	↓	1111	1400	1191	1590	1147	1480	1157	1362	1316	11,754	+5
								Discontinued Readings										

(10) 11,922 Equals Corr. Base Reading to [✓ 73.4 °F] 23.0 °C	(11) Creep Cyl. No. 122 Length Change ΔL₁	(12) Creep Cyl. No. 123 Length Change ΔL₂	(13) Avg. Length Change of Creep Cyl. 122 & 123 ΔL_A	(14) Control Cylinder Number 119								(15) Creep or Recovery Corrected for Temp. and/or Control ΔL₃ or ΔL₄	(16) Creep ΔLc: ΔL₃/GL (100)	(17) Creep ΔLc: Col. (16)/Load	(18) Recovery ΔLR: ΔL₄/GL (100)	(19) Recovery ΔLR: Col. (18)/Load
				ΔL at	ΔL at 14 d	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at	ΔL at					
Inches ~~or millimeters~~ × 10^{-4}													Inches ~~or millimeters~~ × 10^{-6}			
11,922	0	0	0		0							0			No Rebound	
11,848	-89	-74	-82		0							-82	-91	-0.23	Determinations	
11,829	-103	-93	-98		-3							-95	-106	-0.27	Made	
11,806	-120	-116	-118		-7							-111	-123	-0.31		
11,805	-128	-117	-123		-4							-119	-132	-0.33		
11,797	-132	-125	-129		-6							-123	-137	-0.34		
11,786	-142	-136	-139		-5							-134	-149	-0.37		
11,774	-150	-148	-149		-6							-143	-159	-0.40		
11,781	-137	-141	-139		-1							-138	-153	-0.38		
11,760	-168	-162	-165		-16							-149	-166	-0.42		
11,770	-153	-152	-153		+1							-154	-171	-0.43		
11,765	-160	-157	-159		-6							-153	-170	-0.43		
11,759	-169	-163	-166		-23							-143	-159	-0.40		

where 11,759 = 0, or base reading to measure recovery of creep specimens as they enter an unloading cycle if recovery must be measured.

*See table X1.2 of USBR 4901 if applicable.

Figure 8. – Sample form for recording creep data and applying corrections for temperature and control (sheet 6 of 6).

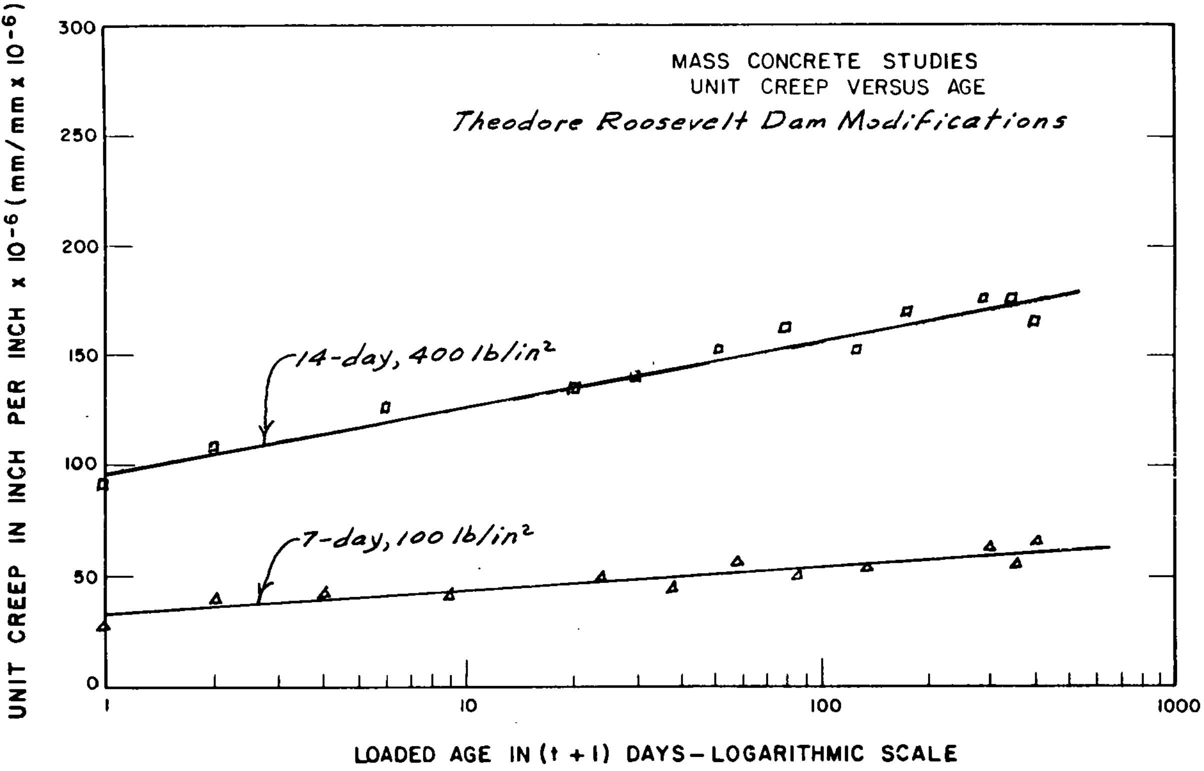


Figure 9. – Unit creep versus age.

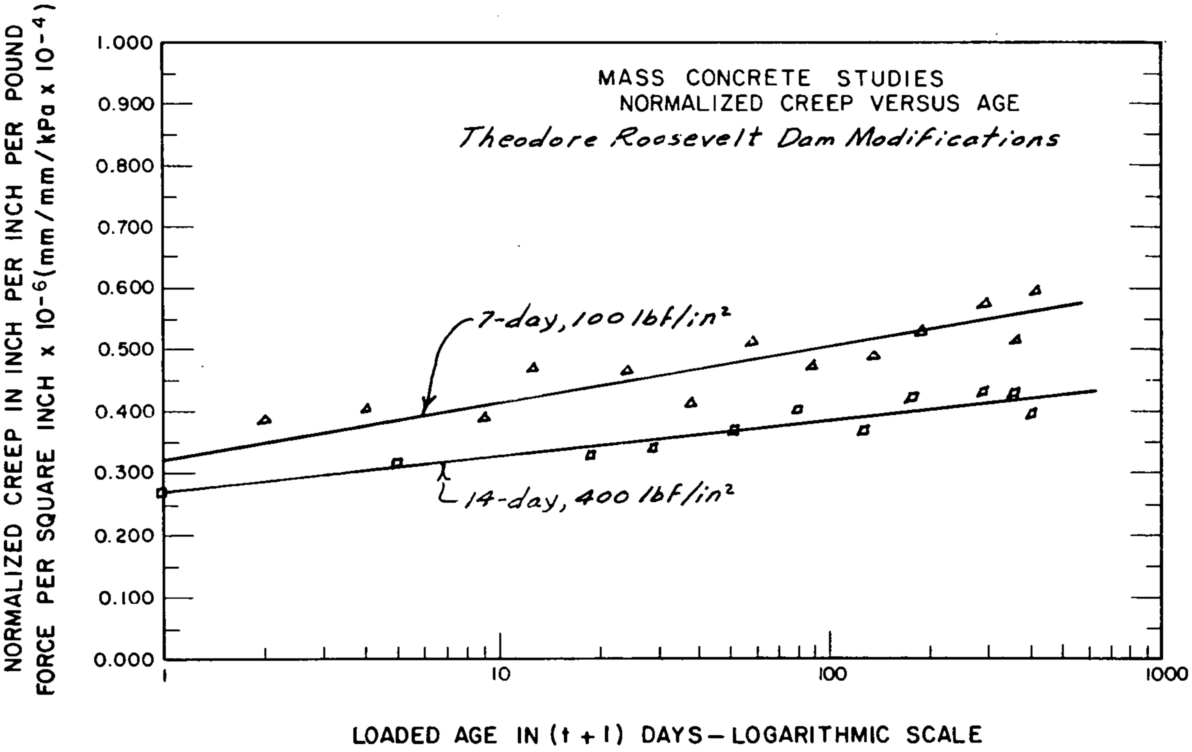
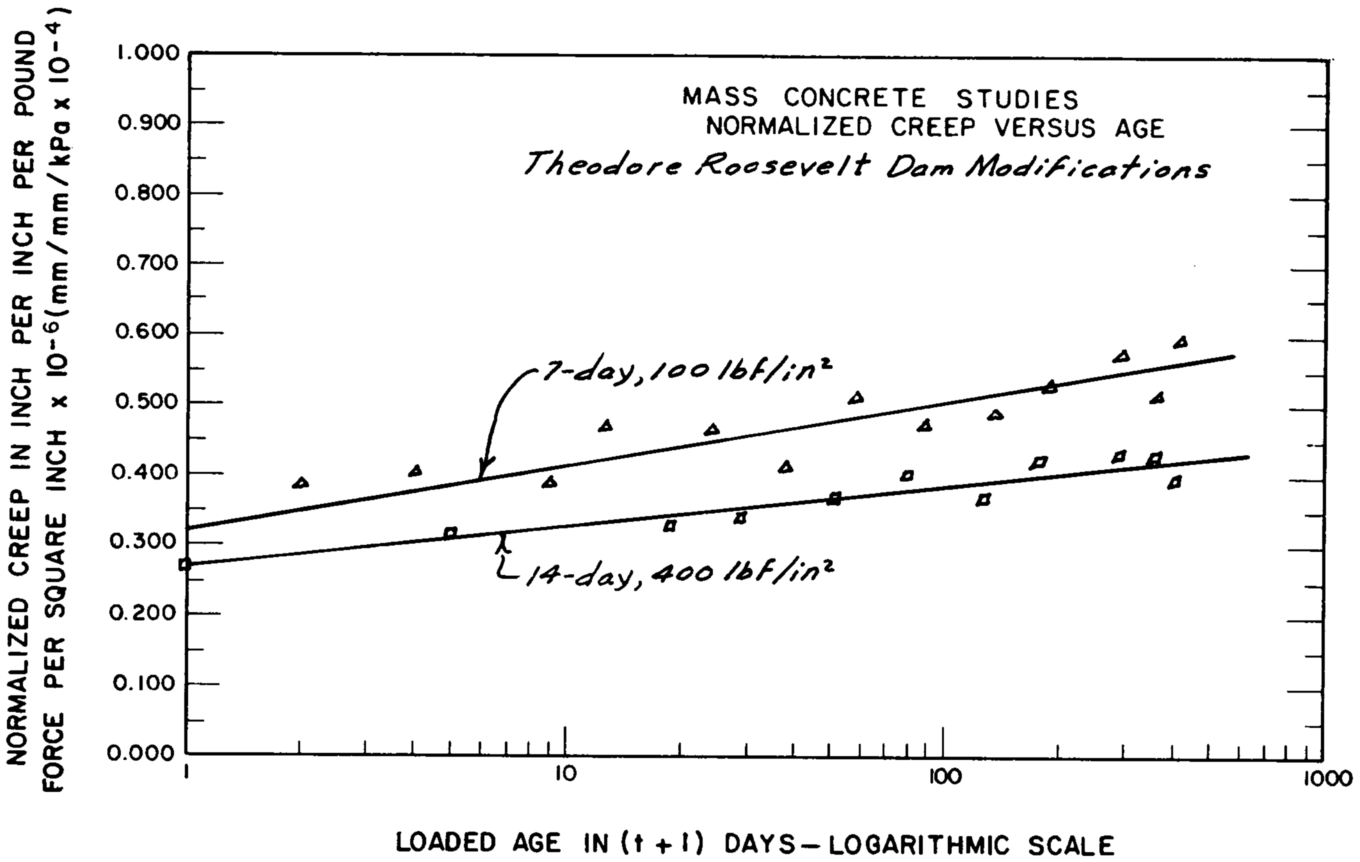
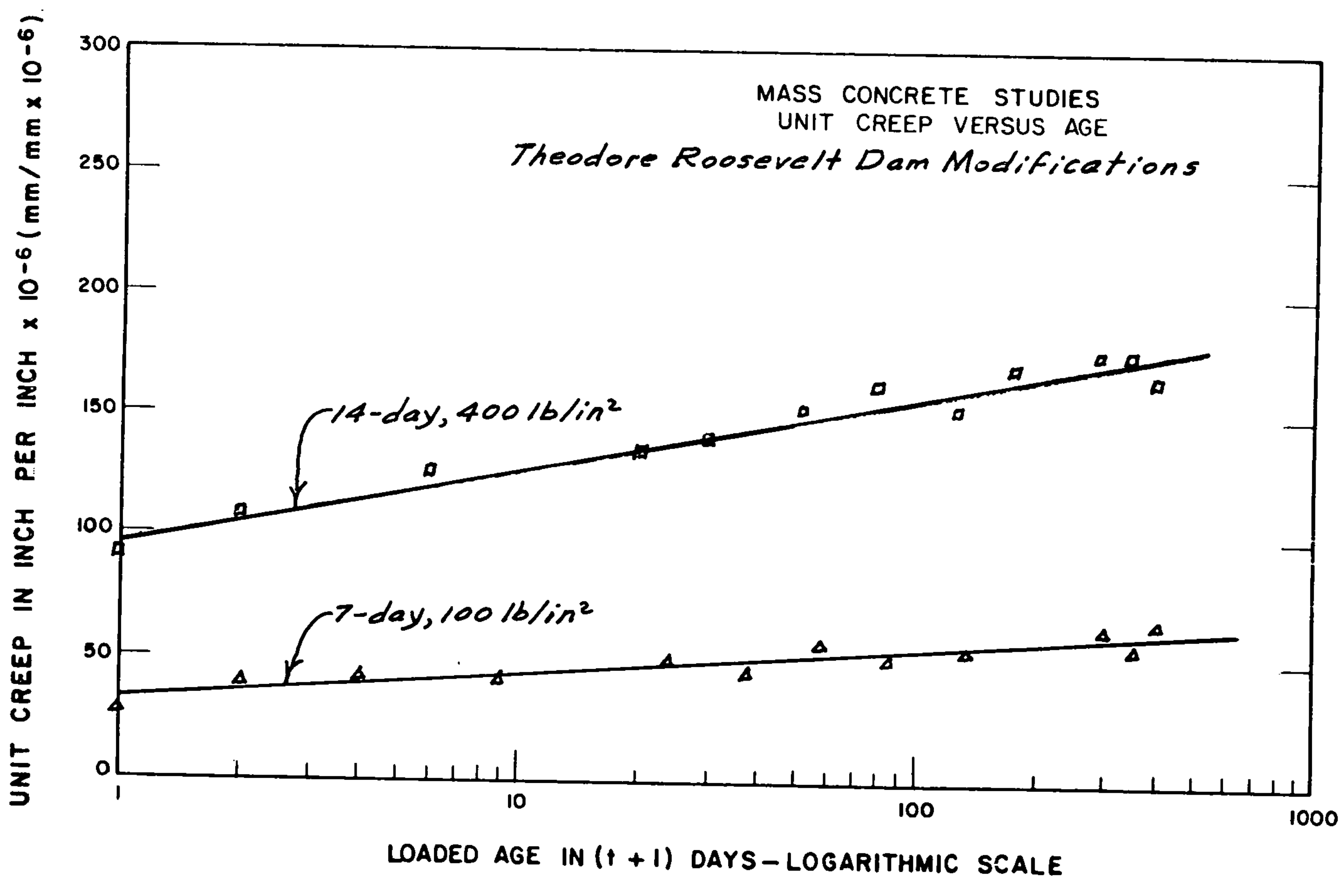


Figure 10. – Normalized creep versus age.


MASS CONCRETE STUDIES
NORMALIZED CREEP VERSUS AGE
Theodore Roosevelt Dam Modifications
7-day, 100 lbf/in²
14-day, 400 lbf/in²
NORMALIZED CREEP IN INCH PER INCH PER POUND FORCE PER SQUARE INCH x 10⁻⁶ (mm/mm/kPa x 10⁻⁴)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1
10
100
1000
LOADED AGE IN (t + 1) DAYS – LOGARITHMIC SCALE


MASS CONCRETE STUDIES
UNIT CREEP VERSUS AGE
Theodore Roosevelt Dam Modifications
14-day, 400 lb/in²
7-day, 100 lb/in²
UNIT CREEP IN INCH PER INCH x 10⁻⁶ (mm/mm x 10⁻⁶)
300
250
200
150
100
50
0
1
10
100
1000
LOADED AGE IN (t + 1) DAYS – LOGARITHMIC SCALE

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4535-92

PROCEDURE FOR

RESISTANCE TO DEGRADATION OF LARGE-SIZE, COARSE AGGREGATE BY ABRASION AND IMPACT IN LOS ANGELES MACHINE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4535; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 535-81.

1. Scope

1.1 This designation covers the procedure for testing sizes of coarse aggregate larger than 3/4 inch (19.0 mm) for resistance to degradation using the Los Angeles testing machine.

NOTE 1.–A procedure for testing coarse aggregate smaller than 1-1/2 inches (37.5 mm) is covered in USBR 4131.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1025 Checking Sieves
4075 Sampling Aggregates
4131 Resistance to Degradation of Small-Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:
C 535 Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1]

3. Summary of Procedure

3.1 The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres; the number of which depends upon grading of test sample. As drum rotates, a shelf plate picks up sample and steel spheres, carrying them around until they are dropped to opposite side of drum, creating an impact-crushing effect. The contents roll within the drum with an abrading and grinding action until shelf plate impacts, and then the cycle is repeated. After the prescribed number of revolutions, contents are removed from drum and aggregate portion is sieved to measure degradation as percent loss.

4. Significance and Use

4.1 The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions; however, the results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Specification limits based on this test should be assigned with extreme care in consideration of available aggregate types and their performance history concerning specific uses.

5. Apparatus

5.1 *Los Angeles Machine*.–The Los Angeles machine shall conform to the requirements of section 5.1 and figure 1 of USBR 4131.

5.1.1 The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed of from 30 to 33 r/min (note 2). If a section of rolled angle is used for shelf, direction of rotation shall be such that charge is caught on outside face of angle.

NOTE 2.–Backlash or slip in driving mechanism will probably give test results that are not duplicated by other Los Angeles machines producing constant peripheral speed.

5.1.2 The machine shall be equipped with an adjustable revolution counter that will automatically stop machine after required number of revolutions.

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

5.1.3 A material discharge catch pan of suitable dimensions is required to preclude any test sample loss.

5.2 *Sieves*.–Sieves shall conform to ASTM E 11.

5.3 *Balance*.–A balance or scale accurate to within 0.1 percent of test load over range required for this test is required.

5.4 *Charge*.–The charge shall consist of 12 steel spheres averaging about 1-27/32 inches (46.8 mm) in diameter, with each sphere having a mass of between 0.86 and 0.98 lbm (390 and 445 g), and having a total mass of 11.02±0.055 lbm (5000±25 g).

NOTE 3.–Steel ball bearings 1-13/16 inches (46.0 mm) and 1-7/8 inches (47.6 mm) in diameter, with a mass of about 0.88 and 0.97 lbm (400 and 440 g) each, respectively, are readily available. Steel spheres 1-27/32 inches (46.8 mm) in diameter with a mass of about 0.93 lbm (420 g) may also be obtainable. The charge may consist of a mixture of these sizes provided the mass tolerances of section 5.4 are met.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the reponsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 A precaution on backlash or slip in the driving mechanism of the machine is outlined in note 2, section 5.

6.3 *Maintenance of Shelf*:

6.3.1 The shelf of the machine is subject to severe surface wear and impact. With use, working surface of shelf is peened by the steel spheres and tends to develop a ridge of metal parallel to and about 1-1/4 inches (32 mm) from junction of shelf and inner surface of cylinder. If shelf is made from section of rolled angle, not only may this ridge develop, but the shelf may be bent longitudinally or transversely from its proper position.

6.3.2 Shelf should be inspected periodically to determine whether it is bent either lengthwise or from its normal radial position with respect to cylinder. If either condition exists, shelf should be repaired or replaced before further tests are made. The influence that a developed metal ridge from peening of working face of shelf has on test results is not known; however, for uniform test conditions, it is recommended that ridge be ground off if its height exceeds 0.1 inch (2 mm).

7. Sampling

7.1 The field sample shall be obtained in accordance with USBR 4075, and reduced to test portion size in accordance with USBR 4702.

8. Conditioning of Test Sample

8.1 The test sample shall be washed and oven dried at 221 to 230 °F (105 to 110 °C) to a substantially constant mass (note 4), separated into individual size fractions, and recombined to the grading shown in table 1 that most nearly corresponds to range of aggregate sizes furnished for work. The mass of the sample prior to test shall be recorded to nearest 0.002 lbm (1 g).

NOTE 4.–If aggregate is essentially free of adherent coatings and dust, requirement for washing before and after test may be waived. Elimination of washing after test will seldom reduce the measured loss by more than about 0.2 percent of original sample mass.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 The Los Angeles machine shall be checked periodically for wear and to assure compliance with section 5.1 of USBR 4131.

9.3 Sieves shall be calibrated to meet requirements of ASTM E 11 in accordance with USBR 1025.

9.4 The balance or scale shall be calibrated to meet requirements of section 5.3 in accordance with USBR 1012.

Table 1. – Gradings of test samples.

Sieve size, inch (mm) (square openings)		Mass of indicated sizes, lbm (g) Grading		
Passing	Retained on	1	2	3
3 (75)	2-1/2 (63)	5.51±0.11 (2500±50)	–	–
2-1/2 (63)	2 (50)	5.51±0.11 (2500±50)	–	–
2 (50)	1-1/2 (37.5)	1.02±0.11 (5000±50)	11.02±0.11 (5000±50)	–
1-1/2 (37.5)	1 (25.0)	–	11.02±0.055 (5000±25)	11.02±0.055 (5000±25)
1 (25.0)	3/4 (19.0)	–	–	11.02±0.055 (5000±25)
	Totals	22.05±0.22 (10 000±100)	22.05±0.17 (10 000±75)	22.05±0.11 (10 000±50)

9.5 The charge dimensions shall be checked to meet requirements of section 5.4 by using the linear measurement devices in accordance with USBR 1000. The mass of the charge shall meet requirements of section 5.4 by using scales calibrated in accordance with USBR 1012.

9.6 Calibration of revolution counter shall be accomplished by visual observation and by manually counting revolutions.

9.7 Speed of revolution counter shall be checked with an appropriate tachometer. This will provide the "average" rotational speed of cylinder but not the uniformity of the "peripheral" speed.

10. Procedure

10.1 Place graded test sample and charge in Los Angeles machine and rotate for 200 revolutions. Discharge material from machine and make a preliminary separation of sample on a No. 4 (4.75-mm) sieve. Sieve the finer portion on a No. 12 (1.70-mm) sieve in a manner conforming to USBR 4136. The total mass of material that would be retained on the No. 12 sieve is determined to nearest 0.01 lbm (5 g). Care should be taken to avoid loss of any part of sample. The entire sample, including the dust of abrasion and fracture, is then returned to testing machine and rotated for 800 revolutions. Discharge sample from machine and repeat previous sieving procedure. Wash material coarser than No. 12 sieve (note 4), oven dry at 221 to 230 °F (105 to 110 °C) to a substantially constant mass, and determine mass to nearest 0.01 lbm (5 g) (note 5).

NOTE 5.–Valuable information concerning uniformity of sample under test may be obtained by determining loss after 200 revolutions. Ratio of loss after 200 revolutions to loss after 1000 revolutions should not exceed 0.20 for material of uniform hardness. It is standard Bureau practice to determine percent loss after both 200 and 1000 revolutions.

11. Calculation

11.1 Express the loss (difference between original and final mass of test sample) as a percentage of original mass of test sample. Report this value as the percent loss.

11.2 Figure 2 of USBR 4075 shows a suggested calculation worksheet.

NOTE 6.–The percent loss determined by this procedure has no known consistent relationship to percent loss for same material when tested by USBR 4131.

12. Report

12.1 Figure 3 of USBR 4075 shows a suggested reporting form with typical data.

13. Precision and Bias

13.1 The precision and bias for this procedure have not been determined; however, they are expected to be comparable to those of USBR 4131.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4566-92

PROCEDURE FOR

TOTAL MOISTURE CONTENT OF AGGREGATE BY DRYING

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4566; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 566-84.

1. Scope

1.1 This designation covers the procedure for determination of the percentage of evaporable moisture in a sample of aggregate by drying.

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
2.2 *ASTM Standard*:
C 566 Standard Test Method for Total Moisture Content of Aggregate by Drying[1]

3. Significance and Use

3.1 This procedure is sufficiently accurate for usual purposes such as adjusting batch masses of concrete ingredients; it will generally measure the moisture in the test sample more reliably than the sample can be made to represent the aggregate supply. In cases where aggregate itself is altered by heat or where more refined measurement is required, the test should be conducted using a ventilated, controlled-temperature oven.

3.2 Large particles of coarse aggregate, especially those larger than 1-1/2 inches (37.5 mm), will require more time for the moisture to travel from interior of particle to surface. The user of this test procedure should determine by trial if rapid drying methods provide sufficient accuracy for intended use when drying large size particles.

4. Apparatus

4.1 *Balance.*–A balance or scale sensitive throughout the operating range to 0.1 percent of mass of sample being tested.

4.2 *Heat Source.*–A suitable source of heat such as an electric or gas hot plate, electric heat lamps, or ventilated oven capable of maintaining temperature surrounding sample at 230±9 °F (110±5 °C).

NOTE 1.–A microwave oven is not recommended for use in this procedure because minerals are occasionally present in aggregates which may cause particles to overheat and explode. If this should occur, the microwave oven could be damaged and, more importantly, it would create a safety hazard if exploding particles were to break through the front glass of oven. Larger size particles with high absorption cannot release steam fast enough and may explode. If a microwave oven is ever used, it should never be used with particle sizes larger than a No. 10 (2.00-mm) sieve.

4.3 *Sample Container.*–A container not affected by heat, of sufficient volume to contain sample without danger of spilling, and of such shape that depth of sample will not exceed one-fifth of the container's minimum lateral dimension.

NOTE 2.–Except for testing large samples, an ordinary frying pan is suitable for use with a hot plate; or any shallow, flat-bottomed metal pan with heat lamps or oven.

4.4 *Stirrer.*–A metal spoon or spatula of convenient size.

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5.2 Care should be exercised if alcohol is used to expedite drying as described in note 3.

6. Sampling

6.1 Sampling shall generally be accomplished in accordance with USBR 4075.

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[1] *Annual Book of ASTM Standards*, vol. 04.02

NOTE 3.–When a hot plate is used, drying can be expedited by adding sufficient anhydrous denatured alcohol to cover moist sample. Stir and allow suspended material to settle. Decant as much of the alcohol as possible without losing any of sample. Ignite the remaining alcohol and allow it to burn off during drying over the hot plate. Care should be exercised to control the ignition operation to prevent injury or damage from the burning alcohol.

7. Sample

7.1 Secure a sample of aggregate representative of moisture content in supply being tested and, in the case of normal-density aggregate, determine a mass of not less than amount listed in table 1.

Table 1.–Sample size for normal-density aggregate.

Maximum nominal size,[1] (sieves with square openings)	Minimum mass of sample,[2] lbm (kg)
1/4 inch (sand) (6.3 mm)	1.1 (0.5)
3/8 inch (9.5 mm)	3.3 (1.5)
1/2 inch (12.5 mm)	4.4 (2)
3/4 inch (19.0 mm)	6.6 (3)
1 inch (25.0 mm)	8.8 (4)
1-1/2 inches (37.5 mm)	13.2 (6)
2 inches (50 mm)	17.6 (8)
2-1/2 inches (63 mm)	22.0 (10)
3 inches (75 mm)	28.7 (13)
3-1/2 inches (90 mm)	35.3 (16)
4 inches (100 mm)	55.1 (25)
6 inches (150 mm)	110.2 (50)

[1] Largest sieve size upon which any material is permitted to be retained.

[2] To determine minimum mass of sample for low density aggregate, multiply mass shown by approximate dry-loose density of aggregate in lbm/ft^3 (kg/m^3) and divide by 99.9 (1600).

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

8.2 Balance shall be calibrated in compliance with USBR 1012.

8.3 Oven shall be checked for compliance with section 4.2 in accordance with USBR 1020.

9. Procedure

9.1 Determine mass of sample to nearest 0.1 percent or 1 gram, whichever is greater, over the range required for this test avoiding any loss of moisture from sample to maximum extent possible.

9.2 Dry sample thoroughly in sample container to a constant mass using the selected source of heat, exercising care to avoid loss of any particles. Rapid heating may cause some particles to explode, resulting in partial loss of sample. If a source of heat other than the controlled-temperature oven is used, stir sample during drying to accelerate the operation and to avoid localized overheating. The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 percent additional loss in mass.

NOTE 4.–A quick method of determining if sample specimen has given off its absorbed moisture is by placing a piece of cigarette paper on specimen. If moisture is still being released, steam will cause paper to curl. If all moisture has been driven off, paper will remain flat.

9.3 Determine mass of dried sample to nearest 0.1 percent after it has cooled sufficiently not to damage the balance.

10. Calculation

10.1 Calculate total moisture content as follows:

$$p = \frac{M - D}{D} (100) \qquad (1)$$

where:

p = moisture content of sample in percent,
M = mass of original sample in pound mass (grams), and
D = mass of dried sample in pound mass (grams).

10.2 Surface moisture content is equal to the difference between total moisture content and the absorption. Absorption may be determined in accordance with USBR 4127 or 4128.

10.3 Figure 2 of USBR 4075 shows a suggested calculation worksheet.

11. Report

11.1 No report is necessary covering this test procedure.

12. Precision and Bias

12.1 Data are not available to develop a statement of precision and bias. Since any size of sample above the minimum quantities given in table 1 are permitted, it is believed that a meaningful statement is not possible.

12.2 For each particular application of this test procedure, an indication of the precision associated with the actual sample sizes and equipment used can be developed by: (1) running tests on duplicate test portions taken from same sample, or (2) taking duplicate samples representing same lot of aggregate. Data on the bias of the procedure might also be developed by adding a known quantity of water to a dry aggregate, ensuring that no water is lost prior to testing.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4597-92

PROCEDURE FOR

PULSE VELOCITY THROUGH CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4597; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 597-71 (Reapproved 1979).

1. Scope

1.1 This designation covers the procedure for determination of pulse velocity of propagation of compressional waves in concrete for the purpose of comparatively determining condition of concrete.

1.2 Results obtained using this procedure should not be considered as a means of measuring strength nor as an adequate test for establishing compliance of modulus of elasticity of field concrete with that assumed in design (note 1). The procedure is applicable for both field and laboratory testing regardless of size or shape of specimen, within limitations of available pulse energy sources (note 2).

NOTE 1.–When circumstances permit conducting pulse velocity and compressive strength tests on an adequate number of the same samples of a given concrete, a velocity-strength relationship may be established which will serve as an index for estimation of strength on the basis of further pulse velocity tests on that concrete.

NOTE 2.–Presently, available generators limit ranges to about 2 inches (50 mm) minimum and 50 feet (15 m) maximum. The upper limit depends partly on surface conditions and on characteristics of interior concrete under investigation, as well as on nature of generated signal. The maximum range is obtained by using relatively low vibrational frequencies in the wave burst pulses (10 to 20 kHz) to minimize absorption of signal in concrete. The resonant frequency of the transducer assembly; that is, crystals plus backing plate, determines frequency of vibration in concrete, see also section 7.2.2. For shorter path lengths, where loss of signal is not governing factor, it is possible to use vibrational frequencies of 50 kHz or higher to achieve more accurate time measurements and therefore, greater sensitivity in detecting deterioration as well as cracks and other discontinuities.

1.3 This procedure covers only the measurement of velocity of propagation of groups of compressional waves in concrete and does not apply to the propagation of other vibrations within the material.

2. Applicable Documents

2.1 *ASTM Standards*:

C 597 Standard Test Method for Pulse Velocity Through Concrete[1]

D 653 Standard Terms and Symbols Relating to Soil and Rock[2]

D 2845 Standard Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock[2]

3. Summary of Method

3.1 This method provides the details of essential procedures for determination of pulse velocity, measured in terms of travel time and distance of the compression waves in concrete. Method also includes requirements of instrumentation, suggested types of transducers, and effects of aggregate size.

4. Significance and Use

4.1 This method, which consists of measuring the time of travel of a pulse or train of waves through a measured path length in the material, may be used to advantage to assess uniformity of field concrete, indicate changes in characteristics in concrete, and (in survey of field structures) estimate severity of deterioration, cracking, or both.

5. Terminology

5.1 All definitions are in accordance with ASTM D 653.

6. Apparatus

6.1 The testing apparatus is shown schematically on figure 1.

6.1.1 *Pulse Generator Circuit and Transducer*.–The pulse generator circuit shall consist of electronic circuitry for generating pulses of voltage, and a transducer for transforming these electronic pulses into wave bursts of mechanical energy having vibrational frequencies in the range of 10 to 150 kHz. The electronic circuit should produce repetitive pulses at a rate not less than 10 per second nor more than 150 per second. The transducer shall be constructed of piezoelectric, magnetostrictive, or other voltage-pressure-sensitive material (Rochelle salt, quartz,

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.08.

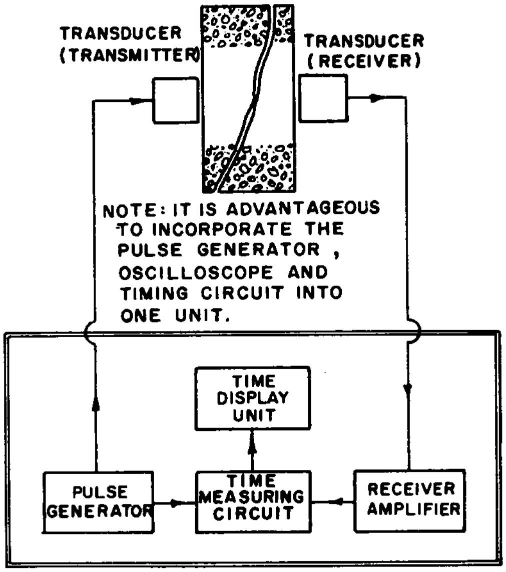


Figure 1. - Schematic diagram of a pulse velocity testing circuit.

barium titanate, etc.), housed for protection. Transducer shall be provided with a suitable coupling medium to obtain adequate contact with concrete (note 3). The voltage output and impedance of the electronic circuit shall be designed for use with the pressure-sensitive material used (note 4). The electronic circuits shall be such that the use of long connecting cables does not result in appreciable loss of voltage. Triggering voltages suitable for driving the oscilloscope and time-delay circuits shall be stable and suitably spaced in time so that sharp images can be obtained on oscilloscope.

NOTE 3.-Use of distended rubber diaphragms and an oil-filled housing under slight pressure have been found to be satisfactory on rough surfaces. The particular kind of rubber and oil should be carefully selected to avoid damage by oil to rubber or to crystals. Castor oil and pure gum rubber or neoprene have been found to perform satisfactorily. Thin, metal diaphragms may be used against smooth, plane surfaces.

NOTE 4.-Voltage pulses of 500 to 1,000 volts have been found satisfactory for use with 45°, X-cut, Rochelle salt crystals.

6.1.2 *Receiving Circuit and Transducer.*-The receiving circuit shall consist of a transducer similar to the transmitter, with housing, a coupling medium, and an electronic amplifier. The voltage generated at the receiver may be amplified in a suitable preamplifier or head amplifier, or may be matched to the connecting cable with a suitable transformer, prior to its transmission over connecting cables to display unit. The amplifier or transformer shall have an essentially flat response between the frequencies of 5 kHz and one that is 10 times the resonant frequency of receiving transducer.

6.1.3 *Display Unit.*-The display unit shall consist of a cathode-ray oscilloscope on which transmitted and received pulses are viewed simultaneously. An intermixing circuit shall be provided to allow a fraction of transmitted pulse to pass through vertical amplifiers so that time of transmitted pulse can be obtained. The oscilloscope shall be provided with a triggered (driven) sweep circuit that is operated from pulse generator circuit via an interconnecting cable. Available sweep circuit velocities shall be so related to time of travel through the concrete that both transmitted and received pulses are within limits of oscilloscope face. Higher sweep velocities shall be available to facilitate accurate measurement of time interval (note 5). A deflection amplifier shall be provided to which a connecting cable from receiver may be connected. The frequency response of this amplifier shall be similar to that given in section 6.1.2. The overall amplifier gain shall be sufficient to allow full deflection of weakest signals which are received (note 6). The cathode-ray tube may be of the single- or double-beam type. If a single-beam type is used, means must be provided for superimposing a timing wave or marker pulse on the trace or face of tube in addition to transmitted and received signals.

NOTE 5.-This is achieved conveniently by using a delay trigger circuit combined with an increase in sweep velocity by a factor of four or more.

NOTE 6.-An approximate gain of 200,000 maximum, including preamplifier if used, has been found sufficient for use with Rochelle salt receivers.

6.1.4 *Time-Measuring Circuit.*-If timing wave is not displayed during test, time-measuring circuit shall be capable of measuring intervals between 0.0001 and 0.005 second to a precision of one part of 200, except that for laboratory use an upper limit of 0.001 second is satisfactory. The circuit shall be provided with multiple scales so that desired accuracy can be obtained throughout entire time range. The circuit should be initiated by a triggering voltage from the pulse generator circuit and should operate at the repetition frequency of the latter. The timing circuit should provide an output marker pulse or "strobe" at end of delay period that can be observed on one of the cathode-ray tube traces as a reference marker.

6.1.4.1 The marker pulse image shall be continuously adjustable in position by a calibrated dial. The use of a multiturn potentiometer equipped with a dial divided into 1,000 divisions is recommended. The calibration of delay time against dial diversions shall be essentially linear in time intervals (note 7). The time-measuring circuit should be reasonably insensitive to thermal and line voltage changes.

NOTE 7.-Ranges of 0.0002, 0.001, and 0.005 second full scale have been found convenient for use with both laboratory specimens and field structures although the latter range may be omitted for laboratory use.

6.1.4.2 A calibration device shall be provided for checking linearity and range of time-measuring circuit.

NOTE 8.-One type of calibrator widely used consists of a quartz-crystal oscillator with a frequency of 100 kHz, synchronized with pulse generator circuit. The calibration is connected to vertical amplifier for use.

7. Precautions

7.1 *Safety Precautions.–Caution:*This procedure includes the use of high-voltage equipment. It is the responsibility of the user to establish appropriate safety practices and to determine the applicability of regulatory limitations prior to use.

7.2 *Technical Precautions*:

7.2.1 Where pulse velocity measurements will encounter materials with higher pulse velocities than the concrete, necessary precautions must be taken to incorporate any effect on readings.

7.2.2 Caution must be used with regard to the average aggregate size of the concrete. The travel distance of the pulse through the concrete shall be at least 10 times the average aggregate size, and the wave length shall be at least 3 times the average aggregate size. Wave length is the wave velocity in the concrete divided by natural response frequency of transducers.

8. Calibration

8.1 *Determination of Calibration Correction.*–Where time intervals are measured with a dial, check accuracy of dial measurement against a calibration circuit. Any difference between dial reading and calibration circuit indication is the calibration correction, which must be included in determination of travel time, section 10.2. Check the calibration over a range including both the zero correction reading (sec. 10.1) and the received pulse reading.

9. Conditioning

9.1 Moisture content of the concrete can affect the measured pulse velocity. Therefore, in certain circumstances, it may be advantageous to the testing program to evaluate effect of water on pulse velocity. However, such evaluations are usually limited to laboratory investigations.

9.2 Pulse velocities may be determined on the velocity test specimen for concrete in the oven-dry state (0 percent saturation), in a saturated condition (100 percent saturation), or in any intermediate state. If pulse velocities are to be determined with the concrete in the same moisture condition as received or as exists underground, care must be exercised during the preparation procedure so that moisture content does not change. In this case, it is suggested that both the sample and test specimen be stored in moisture-proof bags or coated with wax, and that dry surface-preparation procedures be employed. If results are desired for specimens in oven-dried condition, oven temperature shall not exceed 150 °F (66 °C). The specimen shall remain submerged in water up to the time of testing when results are desired for the saturated state.

10. Procedure

10.1 *Determination of Zero Correction.*–Apply zero time correction to measured time intervals. The zero correction is equal to the travel time between transmitting and receiving transducers with zero thickness of concrete between the two. Measure the travel time directly by pressing the two transducers together with the same pressure used in the actual measurement, and measure the time on the cathode-ray tube.

NOTE 9.–For transducers with a distended rubber diaphragm and oil-filled housing, a ring of sheet cork attached to rim of each transducer will enable transducers to be employed in a more uniform manner. The transducer should be pressed against the surface with which it is in contact until ring rests against that surface throughout its circumference. The cork ring, usually about 1/16 inch (1.6 mm) thick, should not materially decrease contact area of diaphragm on concrete. If necessary, additional oil may be injected into housing to force diaphragm to distend beyond ring.

10.2 *Determination of Travel Time in Concrete.*–Press faces of transducers against faces of concrete after establishing contact through a coupling medium. Wetting concrete with water, oil, or other viscous materials may be used to exclude entrapped air from between concrete surfaces of transducer and surface of concrete. Measure length of shortest direct path between centers of transducer's faces and the time of travel on the cathode-ray tube by aligning strobe marker pulse opposite received wave front and reading calibrated dial, or by counting number of cycles of timing wave between transmitted and received pulses.

10.2.1 In field applications where effective beam width of transducers is wide, they need not be pointing at each other. Transmission times can be measured across corners of structures or along one face, although in the latter case the maximum range is reduced. For laboratory specimens, this may not be the case and reference should be made to ASTM D 2845.

10.2.2 For greatest accuracy in time measurement, increase amplifier gain until wave front of received signal is as nearly vertical as possible to provide best delineation of received signal. The error due to rounding off the received wave is then minimized. The use of the sweep expansion circuit will result in an increase in the accuracy of measurement under most conditions of measurement.

10.2.3 Where pulse velocity measurements on large structures are required, long interconnecting low capacity, shielded, coaxial type cables are to be used.

11. Calculations

11.1 Calculate the pulse velocity as follows:

$$V = \frac{S_1}{D_c\,T} = \frac{S_1}{D_c\,(S_p - D_d)} \qquad (1)$$

where:

V = pulse velocity in feet per second (meters per second),
S_1 = path length in feet (meters),
D_c = manual calibration factor,

T = effective time in seconds × 10^{-6} (measured time minus zero time correction),
S_p = received pulse in seconds × 10^{-6}, and
D_d = delay in seconds × 10^{-6}.

11.2 A typical calculation form is shown on figure 2.

NOTE 10.–Some designers prefer to use pulse velocity to calculate the modulus of elasticity:

$$E = \frac{V^2 \rho \, (1 + \mu)(1 - 2\mu)}{1 - \mu} \tag{2}$$

where:

E = dynamic modulus of elasticity in pound force per square inch (gigapascals),
ρ = mass density in pound mass per cubic foot (kilograms per cubic meter),
μ = Poisson's ratio (this is an assumed value based on the density of the concrete), and
V = as defined in equation (1).

As defined in ASTM C 597, the pulse velocity is related to the physical properties of a solid by:

$$V^2 = K\left(\frac{E}{\rho}\right) \tag{3}$$

where:

K = a constant, and
V, E, and ρ = as defined in equation (2).

12. Report

12.1 A typical reporting form is shown on figure 3. The report shall consist of at least the following:

- Location of test or identification of specimen
- Path length
- Orientation of transducers
- Pulse velocity
- Coupling medium used between transducers and concrete

13. Precision and Bias

13.1 The precision and bias for this procedure are not currently known.

Spec. or Solic. No. SPECIAL STUDIES	Structure DAM	Tested by G. HOAGLAND Date 3-1-63
Project CENTRAL VALLEY	Item 6- BY 12-INCH CORES-PULSE VELOC. Location NOT IDENTIFIED	Computed by G. HOAGLAND Date 3-1-63
Feature SHASTA DAM	Station NO ID Offset NO ID Depth NO ID to NO I.D	Checked by E. HARBOE Date 3-1-63

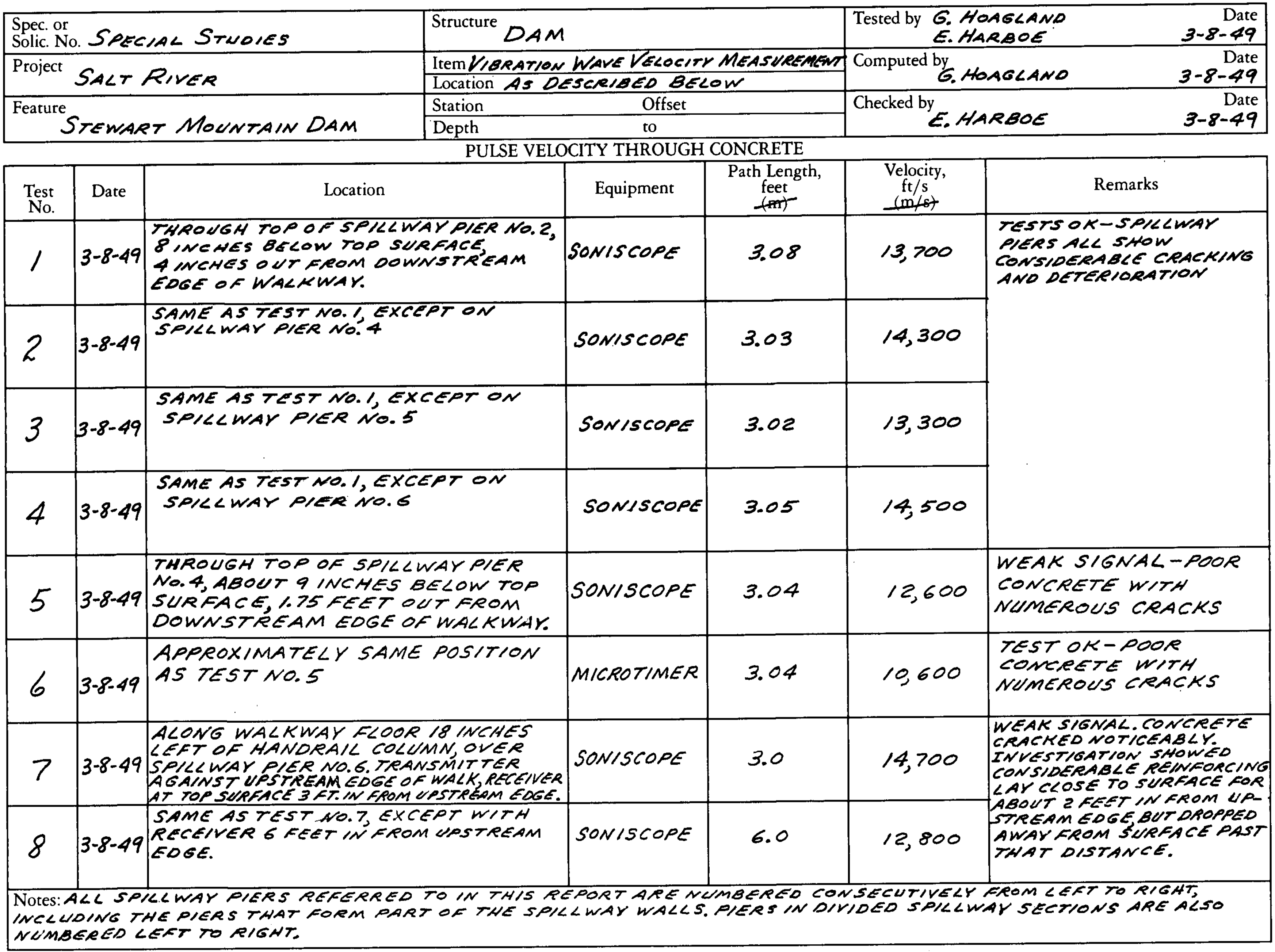
PULSE VELOCITY THROUGH CONCRETE

Specimen Configuration: ☐ Cylinder ☐ Cube ☒ Core ☐ Prism
Moisture Condition: ☐ Air Dried ☐ Saturated ☒ Other (Define): 10 DAYS IN 100% HUMIDITY ROOM & 10 DAYS IN 50% ROOM

Specimen No.	1 L Length, inches ~~(mm)~~	2 W Width, inches (mm)	3 H Height, inches (mm)	4 D Diameter, inches ~~(mm)~~	5 A Oven-Dried Mass in Air, lbm ~~(kg)~~	6 B SSD Mass in Air, lbm (kg)	7 C SSD Mass in Water lbm (kg)	8 Prismatic Area (1) × (2) in² (mm²)	9 Prismatic Volume $\frac{(8) \times (3)}{1,728 \text{ or } (1000)}$ ft³ (m³)	10 Cylindrical Area $\frac{\pi D^2}{4}$ in² ~~(mm²)~~	11 Cylindrical Volume $\frac{(10) \times (1)}{1,728 \text{ or } (1000)}$ ft³ ~~(m³)~~	12 Measured Volume $\frac{(5)}{(6)-(7)} \times 62.4$ or × (1000) ft³ (m³)	13 ρ Density (5) divided by (9), (11), or (12) lbm/ft³ ~~(kg/m³)~~
16-0.70-1	12			6	28.44					28.27	0.196		145.1
-2	12			6	28.67					28.27	0.196		146.3
-3	12			6	29.15					28.27	0.196		148.7
17-0.70-1	12			6	28.91					28.27	0.196		147.5
-2	12			6	27.95					28.27	0.196		142.6
-3	12			6	28.11					28.27	0.196		143.4
18-0.70-1	12			6	28.26					28.27	0.196		144.2

Specimen No.	14 Age (YEARS)	15 S_1 Pulse Path Length, ft ~~(m)~~	16 Range, hertz	17 D_c Manual Calibration Factor	18 D_d Delay, s × 10⁻⁶	19 S_p Received Pulse, s × 10⁻⁶	20 V Pulse Velocity, ft/s ~~(m/s)~~	21 Compressive Strength, lbf/in² (MPa)	22 E Modulus of Elasticity, lbf/in² (GPa)	23 μ Poisson's Ratio	24 Maximum Size Aggregate, inches ~~(mm)~~	Remarks
16-0.70-1	22	0.96	500	0.54	43.0	162.5	14,877	ND	NC	NE	1½	FOR E & μ, REFER
-2	22	.80	500	0.54	43.0	146.0	14,383	ND	NC	NE	1½	TO NOTE 10
-3	22	.96	500	0.54	43.0	171.0	13,889	ND	NC	NE	1½	ND-NOT DETERMINED
17-0.70-1	22	.96	500	0.54	42.0	169.5	13,943	ND	NC	NE	1½	NC-NOT CALCULATED
-2	22	.99	500	0.54	42.5	160.0	15,602	ND	NC	NE	1½	NE-NOT ESTIMATED
-3	22	.96	500	0.54	42.5	160.0	15,130	ND	NC	NE	1½	
18-0.70-1	22	.99	500	0.54	40.0	161.5	15,089	ND	NC	NE	1½	

Figure 2. – Typical soniscope data and calculation form.



Spec. or Solic. No. SPECIAL STUDIES	Structure DAM	Tested by G. HOAGLAND E. HARBOE — Date 3-8-49
Project SALT RIVER	Item VIBRATION WAVE VELOCITY MEASUREMENT Location AS DESCRIBED BELOW	Computed by G. HOAGLAND — Date 3-8-49
Feature STEWART MOUNTAIN DAM	Station — Offset Depth — to	Checked by E. HARBOE — Date 3-8-49

PULSE VELOCITY THROUGH CONCRETE

Test No.	Date	Location	Equipment	Path Length, feet ~~(m)~~	Velocity, ft/s ~~(m/s)~~	Remarks
1	3-8-49	THROUGH TOP OF SPILLWAY PIER NO. 2, 8 INCHES BELOW TOP SURFACE, 4 INCHES OUT FROM DOWNSTREAM EDGE OF WALKWAY.	SONISCOPE	3.08	13,700	TESTS OK—SPILLWAY PIERS ALL SHOW CONSIDERABLE CRACKING AND DETERIORATION
2	3-8-49	SAME AS TEST NO. 1, EXCEPT ON SPILLWAY PIER NO. 4	SONISCOPE	3.03	14,300	
3	3-8-49	SAME AS TEST NO. 1, EXCEPT ON SPILLWAY PIER NO. 5	SONISCOPE	3.02	13,300	
4	3-8-49	SAME AS TEST NO. 1, EXCEPT ON SPILLWAY PIER NO. 6	SONISCOPE	3.05	14,500	
5	3-8-49	THROUGH TOP OF SPILLWAY PIER NO. 4, ABOUT 9 INCHES BELOW TOP SURFACE, 1.75 FEET OUT FROM DOWNSTREAM EDGE OF WALKWAY.	SONISCOPE	3.04	12,600	WEAK SIGNAL—POOR CONCRETE WITH NUMEROUS CRACKS
6	3-8-49	APPROXIMATELY SAME POSITION AS TEST NO. 5	MICROTIMER	3.04	10,600	TEST OK—POOR CONCRETE WITH NUMEROUS CRACKS
7	3-8-49	ALONG WALKWAY FLOOR 18 INCHES LEFT OF HANDRAIL COLUMN, OVER SPILLWAY PIER NO. 6. TRANSMITTER AGAINST UPSTREAM EDGE OF WALK, RECEIVER AT TOP SURFACE 3 FT. IN FROM UPSTREAM EDGE.	SONISCOPE	3.0	14,700	WEAK SIGNAL. CONCRETE CRACKED NOTICEABLY. INVESTIGATION SHOWED CONSIDERABLE REINFORCING LAY CLOSE TO SURFACE FOR ABOUT 2 FEET IN FROM UPSTREAM EDGE, BUT DROPPED AWAY FROM SURFACE PAST THAT DISTANCE.
8	3-8-49	SAME AS TEST NO. 7, EXCEPT WITH RECEIVER 6 FEET IN FROM UPSTREAM EDGE.	SONISCOPE	6.0	12,800	

Notes: ALL SPILLWAY PIERS REFERRED TO IN THIS REPORT ARE NUMBERED CONSECUTIVELY FROM LEFT TO RIGHT, INCLUDING THE PIERS THAT FORM PART OF THE SPILLWAY WALLS. PIERS IN DIVIDED SPILLWAY SECTIONS ARE ALSO NUMBERED LEFT TO RIGHT.

Figure 3. – Typical vibration wave velocity measurements and reporting form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4617-92

PROCEDURE FOR

CAPPING CYLINDRICAL CONCRETE SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4617; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 617-84.

1. Scope

1.1 This designation covers the apparatus, materials, and procedures for capping freshly molded (2 to 4 hours after molding) concrete cylinders with neat cement and hardened cylinders and drilled concrete cores with high-strength gypsum plaster or sulfur mortar.

1.2 The cap shall have a compressive strength equal to or greater than the compressive strength of the concrete to be tested. When this is not possible, planeness of the ends of specimens shall be obtained by sawing or grinding. The surfaces of capped compression specimens shall be plane within a tolerance of 0.002 inch (0.05 mm) across any diameter.

2. Auxiliary Tests

2.1 The requirement that capping materials for hardened specimens must equal or exceed the anticipated compressive strength of the cylinder shall be assured by compliance with procedures as outlined under ASTM C 472 and USBR 4109 (also covered in section 5.2.2.1).

3. Applicable Documents

3.1 *USBR Procedures*:

4109 Compressive Strength of Hydraulic Cement Mortars Using 2-Inch or 50-Millimeter Cube Specimens

4305 Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

3.2 *ASTM Standards*:

C 150 Standard Specification for Portland Cement[1,2]

C 230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement[1,2]

C 472 Standard Methods for Physical Testing of Gypsum Plasters and Gypsum Concrete[1]

C 617 Standard Practice for Capping Cylindrical Concrete Specimens[2]

E 18 Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[3]

3.3 *ANSI Standards*:

B46.1 Standard for Surface Texture[4]

4. Apparatus

4.1 *Competency of Capping Material*:

4.1.1 The apparatus used to make cubes such as scales, glass graduates, specimen molds, mixer bowl and paddle, flow table and flow mold, tamper, trowel, and testing machine are described in USBR 4109; with further reference to USBR 4305 for mixer bowl and paddle; and to ASTM C 230 for flow table and flow mold.

4.1.2 Additional equipment required under the procedure for molding high-strength, gypsum-plaster cubes is the Vicat apparatus described in ASTM C 472.

4.1.3 An acceptable mold is shown on figure 1.

4.2 *Capping Equipment*:

4.2.1 *Capping Plates.*–Neat cement caps and high-strength, gypsum-plaster caps shall be formed against a glass plate at least 1/4 inch (6 mm) thick, a machined metal plate at least 1/2 inch (13 mm) thick, or a polished plate of granite or diabase at least 3 inches (76 mm) thick. Sulfur mortar caps shall be formed against similar metal or stone plates. In all cases, plates shall be at least 1 inch (25 mm) greater in diameter than test specimen, and working surfaces shall not depart from a plane by more than 0.002 inch (0.05 mm) in 6 inches (152 mm). The surface roughness of newly finished metal plates shall not exceed that set forth in table 4 of American National Standard B46.1, which is 125 μ inch (3.175 μm) for any type of surface and direction of lay. The surface, when new, shall be free of gouges, grooves, or indentations beyond those caused by finishing operation. Metal plates that have been in use shall be free of any gouges, grooves, and indentations greater than 0.010 inch (0.25 mm) deep or greater than 0.05 in^2 (32 mm^2) in surface area. If a recess is machined into the metal plate, thickness of plate beneath recessed area shall be at least 1/2 inch (13 mm). In no case shall recess in plate be deeper than 1/2 inch.

NOTE 1.–In vertical capping devices, the use of two-piece metal capping plates is advantageous as this facilitates refinishing of

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[1] *Annual Book of ASTM Standards*, vol. 04.01.

[2] *Annual Book of ASTM Standards*, vol. 04.02.

[3] *Annual Book of ASTM Standards*, vols. 02.03, 03.01.

[4] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

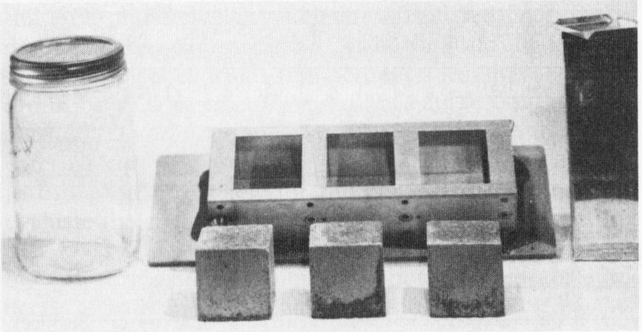

Figure 1. - Three-gang mold for 2-inch or 50-millimeter cube specimens.

capping surface should it become necessary to do so. In such devices, lower section is a solid plate and upper section has a circular hole which forms recess. The two sections are customarily fastened together with machine screws. It is also advantageous to have upper surface of lower plate case hardened. A Rockwell hardness of 48 HRC is suggested as defined in ASTM E 18.

4.2.2 *Alignment Devices.*–Suitable alignment devices such as guide bars or bull's-eye levels shall be used in conjunction with capping plates to ensure that no single cap will depart from perpendicularity to the axis of a cylindrical specimen by more than 0.25°, approximately equivalent to 1/16 inch in 12 inches (1.6 mm in 305 mm). A typical alignment device is shown on figure 2. The same requirement is applicable to the relationship between axis of alignment device and surface of capping plate when guide bars are used. In addition, location of each bar with respect to its plate must be such that no cap will be off-centered on a test specimen by more than 1/16 inch (1.6 mm).

4.2.3 *Melting Pots for Sulfur Mortars.*–Pots used for melting sulfur mortars shall be equipped with automatic temperature controls, and shall be made of metal or lined with a material that is nonreactive with molten sulfur.

NOTE 2.–***Caution:*** Melting pots equipped with peripheral heating will ensure against accidents during reheating of cooled sulfur mixtures that have a crusted-over surface. When using melting pots not so equipped, a buildup of pressure under hardened surface crust on subsequent reheating may be avoided by use of a metal rod which contacts bottom of pot and projects above surface of fluid sulfur mix as it cools. The rod should be of sufficient size to conduct enough heat to the top to melt a ring around rod first, and thus prevent development of pressure. A large metal ladle can be substituted for rod.

NOTE 3.–Sulfur melting pots should be used under an exhaust hood. Heating over an open flame is dangerous because flash point of sulfur is about 440 °F (227 °C), and mixture can ignite due to overheating. Should mixture start to burn, cover to snuff out flame. The pot should be recharged with fresh material after flame has been extinguished.

4.2.4 *Concrete Saw or Grinder.*–If ends of hardened cylinders are not planar to a degree that thickness of cap will not exceed 5/16 inch (7.94 mm) for any portion, cylinders must be ground or sawed.

4.2.5 *Small Tools.*–Straightedge; feeler gauge, 0.002 inch (0.05 mm); metal thermometer, 265 °F (129 °C) range; steel file; wire brush; rawhide hammer; burlap sacks; and polyethylene sheeting.

5. Capping Materials

5.1 *Fresh Specimens.*–The top surface of freshly molded specimens may be capped 2 to 4 hours after molding with a thin layer of stiff portland cement paste. The portland cement shall conform to requirements of ASTM C 150.

5.2 *Hardened Specimens (Moist-Cured).*–Hardened specimens which have been moist cured may be capped with high-strength, gypsum plaster or sulfur mortar meeting the requirements of 5.2.1 and 5.2.2. The strength of capping material shall be determined on receipt of a new lot and at intervals not exceeding 3 months. If a given lot of capping material fails to conform to strength requirements, it shall not be used, and strength tests of replacement material shall be made weekly until four consecutive determinations conform to specifications requirements.

5.2.1 *High-Strength, Gypsum Plaster.*–Unadulterated, neat, high-strength, gypsum plaster may be used if 2-inch (50-mm) cubes are found to develop a strength as specified under section 1.2, when subjected to same environment for same length of time as capped specimens. The cubes shall be made in accordance with procedure for molding specimens in section 14.2 of ASTM C 472 using same percentage of mixing water used in preparing capping material.

NOTE 4.–Low-strength molding plasters, commonly called plaster of paris, or mixtures of plaster and portland cement are unsuitable for capping specimens.

NOTE 5.–The percent of mixing water, based on mass of dry plaster, should be between 26 and 30. Use of minimum percentages of mixing water and vigorous mixing usually permit development of acceptable strength after 1 or 2 hours.

5.2.2 *Sulfur Mortar.*–Proprietary or laboratory prepared sulfur mortars may be used if allowed to harden until their compressive strength is at least as high as the compressive strength of the concrete being tested.

5.2.2.1 *Determination of Compressive Strength.*–Prepare test specimens using a cube mold and base plate (fig. 1) conforming to requirements of USBR 4109, and a metal cover plate (note 6) conforming in principle to design shown on figure 3. Bring various parts of apparatus to a temperature of 68 to 86 °F (20 to 30 °C), lightly coat surfaces that will be in contact with sulfur mortar with mineral oil, and assemble near melting pot. Bring temperature of molten-sulfur mortar in pot within a range of 265 to 290 °F (129 to 143 °C), stir thoroughly, and begin casting cubes. Using a ladle or other suitable pouring device, quickly fill each of the three compartments until molten material reaches top of filling hole. Allow sufficient time for maximum shrinkage, due to cooling, and solidification to occur (about 15 min), and refill each hole

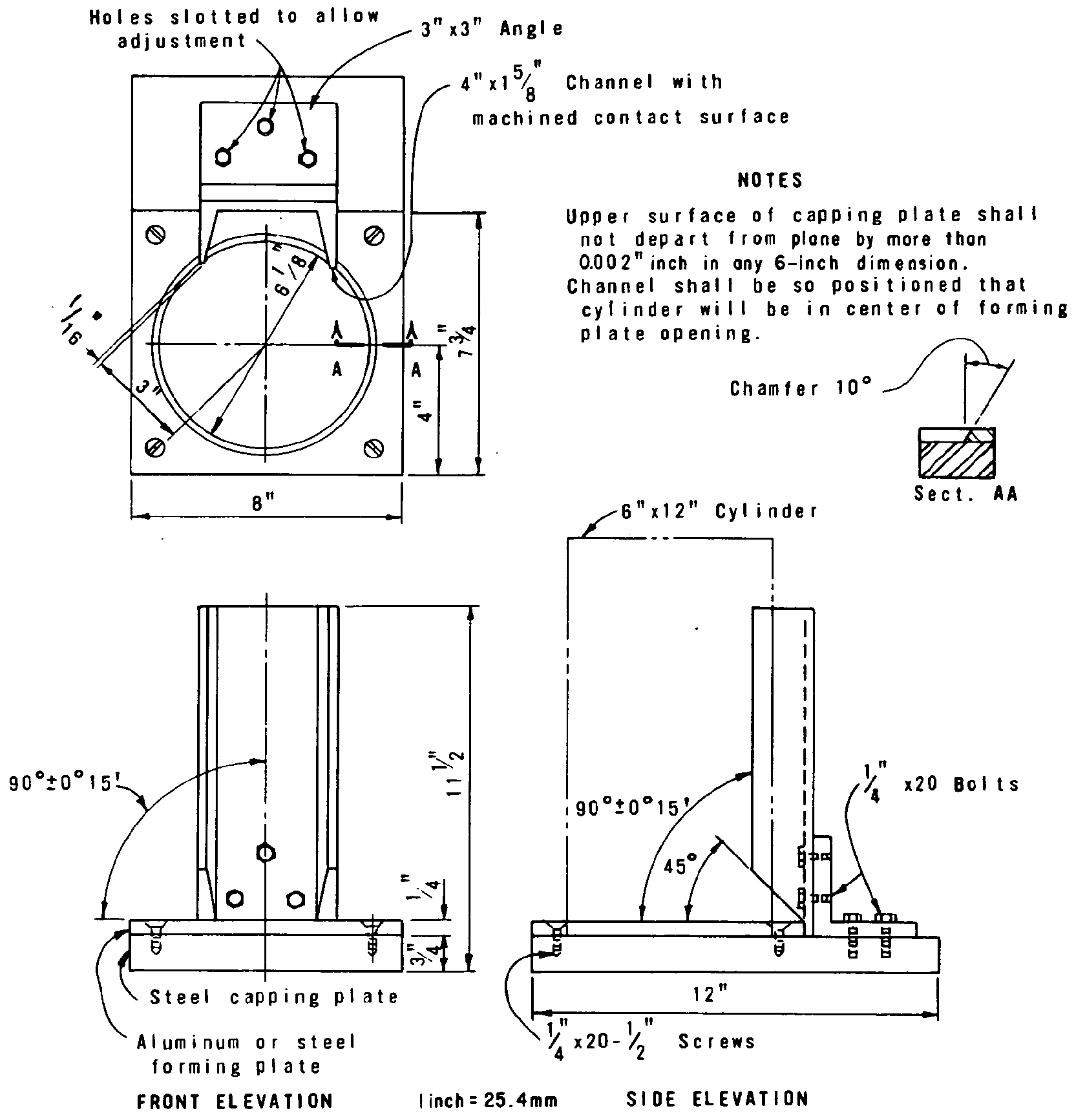

Figure 2. - Cylinder capping mold and alignment device.

with molten material (note 7). After solidification is complete, remove cubes from mold without breaking off knob formed by the filling hole in cover plate. Remove oil, sharp edges, and fins from cubes and check planeness of bearing surfaces in manner described in note 5 of USBR 4109. After storage at room temperature, test cubes in compression at intervals of 30 minutes to 2 hours following procedure described in section 11.6.3 of USBR 4109, and calculate compressive strength in pound force per square inch (megapascals).

NOTE 6.-If desired, a plane phenol formaldehyde (bakelite) plate of 1/8-inch (3-mm) thickness, provided with three appropriately spaced filling holes, may be inserted between cover plate and mold to slow rate of cooling of test specimens.

NOTE 7.-The second filling helps prevent formation of a large void or shrinkage pipe in body of cube. However, such defects may occur no matter how much care is exercised, and it therefore is advisable to inspect interior of tested sulfur mortar cubes for homogeneity whenever strength values obtained are significantly lower than anticipated.

5.3 *Hardened Specimens (Air-Dried).*-Hardened specimens which must be tested in an air-dry condition, or must be soaked for 20 to 28 hours before testing, may be capped with sulfur mortar conforming to requirements of section 5.2.2.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

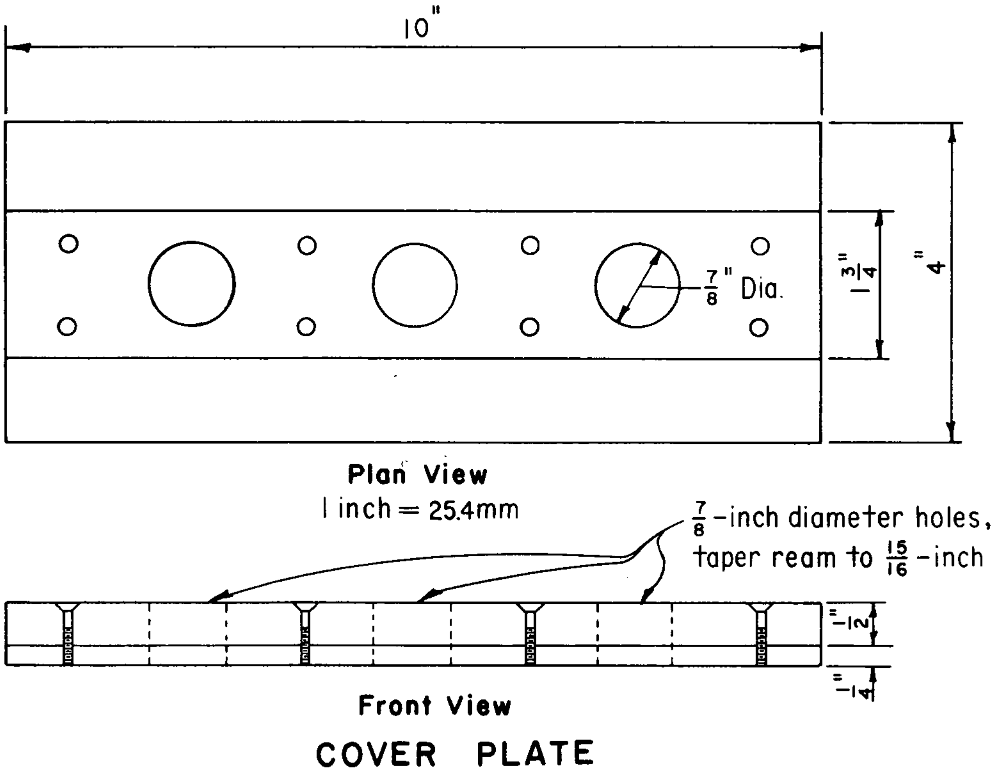

Figure 3. - Cover plate for 2-inch or 50-millimeter cube mold used when fabricating cubes of capping materials. From ASTM C 617, volume 04.02, 1984.

6.2 Safety clothing shall be worn when capping with sulfur mortar materials: safety glasses and full face shield, leather gloves with gauntlets, plastic or rubber apron, and safety shoes.

6.3 Specific precautions with sulfur melting pots are given in notes 2 and 3 of section 4.2.3 and note 10 of section 9.2.3.

7. Calibration or Standardization

7.1 *Capping Devices*:

7.1.1 Dimensions of plates and surface planarity shall be checked periodically for compliance with section 4.2.1.

7.1.2 The alignment devices shall be checked periodically for perpendicularity both to axis of a cylindrical specimen and to surface of capping plate for compliance with section 4.2.2.

7.2 *Miscellaneous Equipment*:

7.2.1 *Straightedge.*-Check periodically with a known flat surface (lower platen of a testing machine suggested).

7.2.2 *Feeler Gauge.*-Accept certificate of inspection by manufacturer.

7.2.3 *Thermometer.*-Accept certificate of inspection by manufacturer. Check against at least one other thermometer.

7.3 *Capping Materials*:

7.3.1 *Portland Cement.*-Conformance with ASTM C 150 shall be assured by a review of mill test for each shipment received.

7.3.2 *High-Strength Gypsum Plaster.*-Compliance with strength requirements shall be performed in accordance with section 5.2.1 upon receipt of each new lot of capping material, and at intervals not exceeding 3 months as outlined under section 5.2.

7.3.3 *Sulfur Mortar.*-Compliance with strength requirements shall be performed in accordance with sections 5.2.2 and 5.2.2.1 upon receipt of each new lot of capping material, and at intervals not exceeding 3 months as outlined under section 5.2.

7.4 *Capped Specimens.*-For each day's capping operation, planeness of caps on at least three specimens representing start, middle, and end of run shall be checked using a straightedge and feeler gauge, making a minimum of three measurements on different diameters to ensure surfaces of caps do not depart from being plane by more than 0.002 inch (0.05 mm).

8. Conditioning

8.1 *Fresh Molded Specimens*:

8.1.1 *Before Capping.*-Do not apply neat paste to exposed end until concrete has ceased settling in molds, generally from 2 to 4 hours after molding.

8.1.2 *After Capping.*-Cover capping plate and mold with damp burlap and a polyethylene sheet to prevent drying for a time as suggested in section 9.1.

8.1.3 *Before Testing.*-Store in moist condition for 6 days with Type I neat cement or for 2 days with Type III neat cement as outlined under note 8 of section 9.1.

8.2 *Hardened Concrete Specimens (Moist-Cured)*:

8.2.1 *High-Strength Gypsum Plaster*:

8.2.1.1 *Before Capping.*-No further conditioning required.

8.2.1.2 *After Capping.*-Moist-cured specimens shall be maintained in a moist condition between completion of capping and time of testing by returning them to moist storage or wrapping with a double layer of wet burlap. Specimens with gypsum plaster caps shall not be immersed in water and shall not be stored in a moist room for more than 4 hours. If stored in a moist room, gypsum plaster caps shall be protected against water dripping on their surfaces.

8.2.2 *Sulfur Mortar*:

8.2.2.1 *Before Capping.*-The ends of moist-cured specimens shall be dry enough at time of capping to comply with directions as outlined under section 9.2.3. The ends of the specimen shall not be oiled prior to application of cap. Heat sulfur mortar as outlined under section 9.2.3.

8.2.2.2 *After Capping.*-Moist-cured specimens shall be maintained in a moist condition between completion of capping and time of testing by returning them to moist storage or wrapping with a double layer of wet burlap.

8.3 *Hardened Concrete Specimens (Air-Dried)*:

8.3.1 No conditioning required if specimens are to be tested in an air-dry condition.

8.3.2 If specimens are to be tested in a moist condition, they must be soaked from 20 to 28 hours before testing, as cited in section 5.3.

8.4 *Capping Material*:

8.4.1 *Neat Cement Paste.*-Mix neat cement paste to a stiff consistency 2 or 4 hours before paste is to be used, as outlined under section 9.1.

8.4.2 *High-Strength Gypsum Plaster*:

8.4.2.1 Mix high-strength gypsum plaster for capping using same percentage of mixing water used in qualification test described in section 5.2.1.

8.4.2.2 The gypsum plaster cubes shall be subjected to same environment for same length of time as gypsum plaster capped specimens, as outlined under section 5.2.1.

8.4.3 *Sulfur Mortar*:

8.4.3.1 Fresh sulfur mortar must be dry when placed in pot as dampness may cause foaming, as discussed under section 9.2.3.

8.4.3.2 Keep water away from molten sulfur mortar because of the tendency to foam, as discussed under section 9.2.3.

8.4.3.3 Heat to about 265 °F (129 °C), as outlined under section 5.2.2.1.

8.4.3.4 Proprietary or laboratory prepared sulfur mortars must be allowed to harden, as outlined under section 5.2.2.

8.4.3.5 After initial filling of cube mold with molten sulfur (5.2.2.1) to determine adequacy of sulfur mortar caps (5.2.2), allow sufficient time for maximum shrinkage (about 15 min) before final filling. Store at room temperature for 30 minutes to 2 hours before starting compression testing.

8.5 *Capping Device.*-The capping plate or device should be oiled and warmed before use, as discussed under section 9.2.3.

9. Procedures

9.1 *Freshly Molded Cylinders.*-Use only neat portland cement pastes (note 8) to cap freshly molded cylinders. Make caps as thin as practicable. Do not apply paste to exposed end until concrete has ceased settling in molds, generally from 2 to 4 hours after molding. During molding of cylinder, strike off upper end even with or slightly below the plane of the mold's rim. Mix neat paste to a stiff consistency 2 to 4 hours before using to allow paste to go through period of initial shrinkage. The strength of the paste will depend on the consistency, water-cement ratio, curing, and brand and type of cement. For Type I and Type II cement pastes, optimum consistency is generally produced at a water-cement ratio of 0.32 to 0.36 by mass. For Type III cement, the water-cement ratio should generally be between 0.35 and 0.39 by mass. The paste will stiffen during the 2- to 4-hour waiting period and the use of retempering water is not recommended. However, if retempering water is used, the amount should not increase the water-cement ratio by more than 0.05 by mass. Remove free water and laitance from top of specimen immediately before capping. Form cap by placing a conical mound of paste on specimen and then gently pressing a freshly oiled capping plate on the conical mound until plate contacts rim of mold. A very slight twisting motion may be required to remove excess paste and minimize air voids in the paste. The capping plate must not rock during this operation. Carefully cover capping plate and mold with a double layer of damp burlap and a polyethylene sheet to prevent drying. Removal of capping plate after hardening may be accomplished by tapping edge with a rawhide hammer in a direction parallel to plane of cap.

NOTE 8.-Type I neat cement caps generally require at least 6 days to develop acceptable strength, and Type III caps at least 2 days. Dry concrete specimens will absorb water from freshly mixed neat cement paste and produce unsatisfactory caps. Neat cement paste caps will shrink and crack on drying and; therefore, should be used only for specimens which are to be moist cured continuously until time of testing.

9.2 *Hardened Concrete Specimens*:

9.2.1 *General.*-Cap, saw, or grind ends of hardened cylinders that are not plane within 0.002 inch (0.05 mm) to meet that tolerance. Caps should be about 1/8 inch (3 mm) thick, and in no instance shall any part of a cap be more than 5/16 inch (7.94 mm) thick. If either or both ends of a specimen have coatings or deposits of oily or waxy materials that would interfere with bond of cap, remove such coatings or deposits. If necessary, ends of a specimen may be slightly roughened with a steel file or wire brush to produce proper adhesion of cap. If desired, capping plates may be coated with a thin layer of mineral oil or grease to prevent capping material from adhering to surface of plate. Before testing cylinder, cap should be tested for air pockets by tapping it lightly with handle of a putty knife or other suitable instrument. A cap that sounds hollow at any point should be removed and replaced. Solid caps are easily obtained when capping surface is dry and clean, mixture is at right temperature, and cylinder is placed immediately in melted mixture on capping plate.

9.2.2 *Capping With High-Strength Gypsum Plaster.*–Mix high-strength plaster for capping by using same percentage of mixing water used for qualification test described in 5.2.1.

9.2.3 *Capping With Sulfur Mortar.*–Prepare the sulfur mortar by heating to about 265 °F (129 °C), as periodically determined by an all-metal thermometer inserted near center of mass. Empty pot and recharge with fresh material at frequent enough intervals to ensure oldest material in pot has not been used more than five times (note 9). Fresh sulfur mortar must be dry when placed in pot as dampness may cause foaming. Keep water away from molten sulfur mortar for same reason. The capping plate or device should be warmed slightly before use to slow rate of hardening and permit production of thin caps. Oil capping plate lightly and stir molten sulfur mortar immediately prior to pouring each cap. The ends of moist-cured specimens shall be dry enough at time of capping to preclude formation of steam or foam pockets larger than 1/4 inch (6 mm) in diameter under or in cap. To ensure that the cap shall be bonded to surface of specimen, end of specimen shall not be oiled prior to application of cap.

NOTE 9.–Reuse of material must be restricted to minimize loss of strength and pourability occasioned by contamination of mortar with oil and miscellaneous debris, and loss of sulfur through volatilization.

NOTE 10.–Hydrogen sulfide gas may be produced during capping when sulfur mortar is contaminated with organic materials such as paraffin or oil. The gas is colorless and has the notoriously bad odor of rotten eggs; however, this odor should not be relied upon as a warning sign because the sensitivity to the odor disappears rapidly on exposure. High concentrations of this gas are lethal, and less concentrated dosages may produce nausea, stomach distress, dizziness, headache, or irritation of the eyes. For these and other reasons, it is desirable that melting pot be located under a hood or near an exhaust fan and that the capping area be well ventilated.

10. Calculations

10.1 Sample calculations for determining the planeness of ends of hardened cylinders and the planeness of capped compression specimens are shown on figure 4.

10.2 Calculations for compressive strength of gypsum plaster cubes to determine competency for capping material are discussed in ASTM C 472.

10.3 Calculations for compressive strength of sulfur mortar cubes to determine competency for capping material are shown on figures 2 and 3 of USBR 4109.

11. Report

11.1 No report is necessary covering this test procedure.

11.2 If a compressive strength exceeds anticipated strength or the strength of the capping material, this fact should be noted on the compressive strength report on the specimens.

12. Precision and Bias

12.1 Due to the nature of this procedure, statements on precision and bias are not appropriate.

Spec. or Solic. No. PRECONSTRUCTION	Structure DAM	Tested by K. FORBES Date 10-31-86
Project PSMBP	Item MIX DESIGN Location DENVER LAB	Computed by NA Date
Feature BUFFALO BILL DAM & SPILLWAY MOD.	Station — Offset — Depth — to —	Checked by NA Date

CAPPING CYLINDRICAL CONCRETE SPECIMENS

Specimen No.	1		2		3	
Specimen Identification	M-7700-1		M-7700-5		M-7700-7	
	Inch	Millimeter	Inch	Millimeter	Inch	Millimeter
TOP						
Measurement No. 1	0.0019		0.0020		0.0010	
Measurement No. 2	0.0000		0.0010		0.0000	
Measurement No. 3	0.0017		0.0012		0.0020	
BOTTOM						
Measurement No. 1	0.0010		0.0010		0.0008	
Measurement No. 2	0.0020		0.0000		0.0000	
Measurement No. 3	0.0010		0.0010		0.0010	

Remarks:
6- by 12-inch cylinders

Specimen Identification						
TOP						
Measurement No. 1						
Measurement No. 2						
Measurement No. 3						
BOTTOM						
Measurement No. 1						
Measurement No. 2						
Measurement No. 3						

Remarks:

Note: No measurement to exceed 0.002 inch (0.05 mm).

Figure 4. – Planeness of capped compression specimens.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4642-92

PROCEDURE FOR

DENSITY, ABSORPTION, AND VOIDS IN HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4642; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 642-82.

1. Scope

1.1 This designation covers the procedure for determination of the density, percent absorption, and percent voids in hardened concrete.

2. Applicable Documents

2.1 *ASTM Standards*:
C 642 Standard Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete[1]
D 854 Standard Test Method for Specific Gravity of Soils[2]

3. Apparatus

3.1 *Balance.*-A balance sensitive to 0.025 percent of mass of specimen.

3.2 *Container.*-A suitable container for immersing specimen, and a suitable wire for suspending specimen in water.

4. Precautions

4.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Test Specimen

5.1 Whenever possible, sample shall consist of several individual portions of concrete, each to be tested separately. The individual portions may be pieces of cylinders, cores, or beams of any desired shape or size; except that volume of each portion shall be not less than 21.5 in^3 (352 cm^3), or 1.75 lbm (about 800 grams) of normal density concrete, and each portion shall be free from observable cracks, fissures, or shattered edges.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular standard or by reference to another.

7. Conditioning

7.1 The required conditioning is covered under section 8.

8. Procedure

8.1 *Oven-Dry Mass.*-Determine mass of specimens and dry in an oven at 212 to 230 °F (100 to 110 °C) for not less than 24 hours. After removing each specimen from oven, allow to cool in dry air (preferably in a desiccator) to 68 to 77 °F (20 to 25 °C) and again determine mass. If specimen was comparatively dry when mass was initially determined and second determination closely agrees with first, consider specimen to be dry. If specimen was wet when mass was initially determined, place specimen in oven for a second drying treatment of 24 hours, and make a third mass determination. If third determination checks the second, consider the specimen dry. If in doubt, redry specimen for 24-hour periods until check determinations are obtained. If difference between values obtained from two successive determinations exceeds 0.5 percent of lesser mass, return specimens to oven for an additional 24-hour drying period and repeat procedure until difference between any two successive determinations is less than 0.5 percent of least mass obtained. Designate this last determination as mass A.

8.2 *Saturated Mass After Immersion.*-Immerse specimen after final drying, cooling, and mass determination in water at about 70 °F (21 °C) for not less than 48 hours and until two successive mass determinations of the surface-dried sample at 24-hour intervals show an increase in mass of less than 0.5 percent of heavier mass. Surface dry specimen by removing surface moisture with

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.08.

a towel, and determine mass. Designate the final surface dry determination after immersion as mass B.

8.3 *Saturated Mass After Boiling*.-Place specimen, processed in accordance with 8.2, in a suitable receptacle, cover with tapwater, and boil for 5 hours. Allow specimen to cool by natural loss of heat for not less than 14 hours to a final temperature of 68 to 77 °F (20 to 25 °C). Remove surface moisture with a towel and determine mass. Designate the soaked, boiled, surface-dried mass as mass E.

8.4 *Immersed Mass*.-Suspend the specimen, after immersion and boiling, by a wire and determine mass in water. Designate as mass F.

9. Calculations

9.1 By using the masses determined in section 8, make the following calculations:

$$AB_1 = \frac{B-A}{A}(100) \qquad (1)$$

$$AB_2 = \frac{E-A}{A}(100) \qquad (2)$$

$$\rho_1 = \frac{A}{E-F}(X) \qquad (3)$$

$$\rho_2 = \frac{B}{E-F}(X) \qquad (4)$$

$$\rho_3 = \frac{E}{E-F}(X) \qquad (5)$$

$$\rho_4 = \frac{A}{A-F}(X) \qquad (6)$$

$$V_1 = \frac{\rho_4 - \rho_1}{\rho_4}(100), \text{ or} \qquad (7)$$

$$= \frac{E-A}{E-F}(100)$$

where:

AB_1 = absorption after immersion (percent),
AB_2 = absorption after immersion and boiling (percent),
A = mass of oven-dried sample in air, in pound mass (grams);
B = mass of saturated-surface-dry sample in air after immersion, in pound mass (grams);
C = mass of sample in water after immersion, in pound mass (grams) not part of equations;
D = mass of sample at time of sampling, in pound mass (grams) not part of equations;
E = mass of saturated-surface-dry sample in air after immersion and boiling, in pound mass (grams);
F = mass of sample in water after immersion and boiling, in pound mass (grams);
X = 62.4 for inch-pound units, or 1000 for SI-metric units;
ρ_1 = dry bulk density;
ρ_2 = bulk density after immersion;
ρ_3 = bulk density after immersion and boiling;
ρ_4 = apparent density; and
V_1 = volume of permeable pore space (voids) in percent.

Units for ρ_1, ρ_2, ρ_3, and ρ_4 are pound mass per cubic foot (kilograms per cubic meter).

9.2 *Example*:

9.2.1 Assume a sample having the following characteristics:

(1) True mass of solid part of specimen equal to 2.20 lbm (1000 g);

(2) Total volume of specimen including solids, permeable voids, and impermeable voids equal to 36.6 in^3 (600 cm^3);

(3) Absolute density of solid part of specimen equal to 124.9 lbm/ft^3 (2000 kg/m^3) or a specific gravity of 2.0; and

(4) Void space in specimen contains initially only air (no water).

9.2.2 Then, it follows that there are 30.5 in^3 (500 cm^3) of solids and 6.1 in^3 (100 cm^3) of voids making up specimen, and "true" void content is

$$\frac{6.1}{36.6}(100) = 16.67 \text{ percent.}$$

9.2.3 Assume that on immersion, 90 mL of water is absorbed, and after immersion and boiling, 95 mL of water is absorbed.

9.2.4 Based on assumptions in 9.2.1 and 9.2.3, data that would be developed from procedures of section 8 would be:

(1) Oven-dry sample mass A equals 2.20 lbm (1000 g).

(2) Saturated-surface-dry mass of sample in air after immersion, mass B equals 2.40 lbm (1090 g).

(3) Saturated-surface-dry mass of sample in air after immersion and boiling, mass E equals 2.41 lbm (1095 g).

(4) Mass of sample in water after immersion and boiling, mass F equals 1.09 lbm (495 g) (note 1).

NOTE 1.-Because the loss of mass in water is equal to the mass of displaced water and volume of specimen is 36.6 in^3 (600 cm^3), mass F of specimen in water after immersion and boiling is:

$$F = 2.41 \text{ lbm} - \left(\frac{36.6 \text{ in}^3}{1728 \text{ in}^3/\text{ft}^3}\right)(62.4 \text{ lbm/ft}^3)$$

$$= 2.41 - 1.32 = 1.09 \text{ lbm } (495 \text{ g})$$

9.2.5 Using the data given in 9.2.4, the calculations of section 9.1 may be performed (note 2):

$$AB_1 = \frac{B-A}{A}(100) = \frac{2.40 - 2.20}{2.20}(100)$$

$$= 9.1 \text{ percent}$$

$$AB_2 = \frac{E-A}{A}(100) = \frac{2.41 - 2.20}{2.20}(100)$$

$$= 9.5 \text{ percent}$$

$$\rho_1 = \frac{A}{E-F}(62.4) = \frac{2.20}{2.41 - 1.09}(62.4) = 104.0$$

$$\rho_2 = \frac{B}{E-F}(62.4) = \frac{2.40}{2.41 - 1.09}(62.4) \doteq 113.5$$

$$\rho_3 = \frac{E}{E-F}(62.4) = \frac{2.41}{2.41 - 1.09}(62.4) = 113.9$$

$$\rho_4 = \frac{A}{A-F}(62.4) = \frac{2.20}{2.20 - 1.09}(62.4) = 123.7$$

$$V_1 = \frac{\rho_4 - \rho_1}{\rho_4}(100) = \frac{123.7 - 104.0}{123.7}(100)$$

$$= 15.93 \text{ percent}$$

NOTE 2.-This procedure does not involve a determination of absolute density. Therefore, such pore space as may be present in specimen that is not emptied during specified drying or is not filled with water during specified immersion and boiling, or both, is considered "impermeable" and is not differentiated from solid portion of specimen for the calculations, especially those for percent voids. In the example presented, it was asssumed that absolute density of solid portion of specimen was 124.9 lbm/ft^3 (2000 kg/m^3), total void space was 16.67 percent, and impermeable void space was 0.30 in^3 (5 cm^3). The operations, if performed according to section 8, and calculations, if performed according to section 9, have the effect of assuming that there are 5.80 in^3 (95 cm^3) of pore space and 30.82 in^3 (505 cm^3) of solids. This would indicate that solid material has an apparent density of 123.6 lbm/ft^3 (1980 kg/m^3) rather than the absolute density of 124.9 lbm/ft^3 (2000 kg/m^3), and that specimen has a percentage of voids of 15.93 rather than 16.67. Depending on pore size distribution, pore entry radii of concrete, and on purposes for which test results are desired, this procedure may be adequate or may be insufficiently rigorous. If it is desired to fill more of the pores than will be filled by immersion and boiling, various techniques involving the use of vacuum treatment or increased pressures may be used. If a rigorous measure of total pore space is desired, it can only be obtained by determining absolute density by first reducing sample to discrete particles, each of which is sufficiently small so that no impermeable pore space can exist within any of the particles, minus No. 200 (−75-µm) sieve. If absolute density was determined by vacuum treatment or increased pressures in accordance with ASTM D 854 using the minus No. 200 material, and designated as ρ_5, and V_2 is volume of total pore space (voids), then:

$$V_2 = \frac{\rho_5 - \rho_1}{\rho_5}(100) = \frac{124.9 - 104.0}{124.9}(100)$$

$$= 16.73 \text{ percent}$$

9.2.6 Figure 1 shows a typical calculation form.

10. Report

10.1 Report absorption and voids in percent, and density in pound mass per cubic foot or kilograms per cubic meter. No typical reporting form has been devised for this procedure.

11. Precision and Bias

11.1 Currently, there are insufficient data available to justify providing precision and bias statements for this procedure.

Spec. or Solic. No. DC-7355	Structure OUTLET PORTAL	Tested by D. SCHMITT Date 2-18-82
Project SAN FELIPE DIVISION OF CVP	Item 4-inch-dia. by 2.9-inch Concrete Core Location NOT FURNISHED	Couputed by D. SCHMITT Date 2-18-82
Feature PACHECO TUNNEL	Station ~ Offset ~ Depth ~ to ~	Checked by B. BARRETT Date 2-18-82

DENSITY, ABSORPTION, AND VOIDS IN HARDENED CONCRETE

Sample No.	A Sample Mass, ~~lbm~~ (grams)	B Sample Mass, ~~lbm~~ (grams)	C Sample Mass, lbm (grams)	D Sample Mass, lbm (grams)	E Sample Mass, ~~lbm~~ (grams)	F Sample Mass, ~~lbm~~ (grams)	AB_1 $\frac{B-A}{A}$ (100), percent	AB_2 $\frac{E-A}{A}$ (100), percent	ρ_1 $\frac{A}{E-F}$ (X*), ~~lbm/ft^3~~ ÷ 1000 (kg/m^3)	ρ_2 $\frac{B}{E-F}$ (X*), ~~lbm/ft^3~~ ÷ 1000 (kg/m^3)	ρ_3 $\frac{E}{E-F}$ (X*), ~~lbm/ft^3~~ ÷ 1000 (kg/m^3)	ρ_4 $\frac{A}{A-F}$ (X*), ~~lbm/ft^3~~ ÷ 1000 (kg/m^3)	V_1 $\frac{\rho_4-\rho_1}{\rho_4}$ (100), percent
1	2.20	2.40	ND	ND	2.41	1.09	9.0	9.5	1.67	1.82	1.83	1.98	15.7

*X = 62.4 for inch-pound units, or 1000 for SI-metric units.

Figure 1. – Typical data and calculation form.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4666-92

PROCEDURE FOR

RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4666; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 666-84.

1. Scope

1.1 This designation covers the procedure for determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in water. This procedure is intended for use in determining the effects of variations in properties of concrete on resistance of concrete to freezing and thawing cycles specified. This procedure is not intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
4029 Density and Voids in Aggregate
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4183 Sampling and Acceptance of Hydraulic Cement
4192 Making and Curing Concrete Test Specimens in Laboratory
4233 Testing Air-Entraining Admixtures for Concrete
4311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
4457 Microscopical Determination of Air-Void Content and Parameters of Air-Void System in Hardened Concrete

2.1 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 150 Standard Specifications for Portland Cement[1,3]
C 260 Standard Specification for Air-Entraining Admixtures for Concrete[1]
C 494 Standard Specifications for Chemical Admixtures for Concrete[1]
C 618 Standard Specification for Fly Ash or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[1]
C 666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing[1]

3. Summary of Procedure

3.1 Concrete cylinders and cores are placed in water in an apparatus that changes temperature at center of specimen from 10 to 70 °F (-12.2 to 21.1 °C) at the rate of 50 times per week. Deterioration of concrete is evaluated by periodically measuring changes in mass and by visual inspection.

4. Significance and Use

4.1 As noted in section 1, this procedure is intended for the determination of the effects of variations in the properties and conditioning of concrete on the resistance to freezing and thawing cycles specified. Specific applications include specified use in ASTM C 494, USBR 4233, and the ranking of coarse aggregates as to their effect on concrete freeze-thaw durability, especially where soundness of aggregate is questionable.

4.2 It is assumed that this procedure will have no significantly damaging effects on frost-resistant concrete, which may be defined as: (1) any concrete not critically saturated with water; that is, not sufficiently saturated to be damaged by freezing, and (2) concrete made with frost-resistant aggregates and having an adequate air-void system that has achieved the appropriate maturity necessary to prevent critical saturation by water under common conditions.

4.3 If, as a result of performance tests described in this procedure, the concrete is found to be relatively unaffected, it can be assumed that concrete was either not critically saturated or was made with "sound" aggregates, a proper air-void system, and allowed to mature properly.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.

4.4 This procedure is most commonly used to evaluate aggregates. All aggregates not previously used should be tested to determine their suitability as a constituent of the concrete. While physical properties, petrographic examination, and sodium or magnesium sulfate tests indicate the soundness of aggregates, freezing and thawing tests indicate the performance of the aggregate when used in concrete. Wherever possible, laboratory results of accelerated freezing and thawing should be correlated with actual field data to establish standards of quality for acceptance testing.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125.

6. Interferences

6.1 Small differences in air and moisture contents at time of test can have a major effect on results. Mixture proportions and curing conditions must be carefully controlled.

7. Apparatus

7.1 *Freezing and Thawing Apparatus*:

7.1.1 The freezing and thawing apparatus shall consist of a suitable chamber or chambers where specimens may be subjected to the specified freezing and thawing cycle, along with the necessary refrigerating and heating equipment and controls to produce continuously and automatically reproducible cycles within specified temperature requirements. In the event that equipment does not operate automatically, provision shall be made for either continuous manual operation on a 24-hour basis or for storage of all specimens in a frozen condition when equipment is not in operation.

7.1.2 The apparatus shall be so arranged that, except for necessary supports, each specimen is completely surrounded by about 1/16 inch (2 mm) of water in a rubber container at all times while specimen is being subjected to freezing and thawing cycles.

7.1.3 Temperature of heat-exchanging medium shall be uniform within 6 °F (3.3 °C) throughout specimen cabinet when measured at any given time at any point on surface of any specimen container, except during transition between freezing and thawing and vice versa.

7.1.4 The automatic freezing and thawing apparatus used in the Bureau's Denver Office laboratory is illustrated on figure 1. This apparatus consists of two specimen cabinets, cold fluid tank, warm fluid tank, means for refrigerating and heating fluid, and the necessary coils, pumps, valves, and automatic electrical controls to circulate the calcium chloride brine through the system periodically. The insulated specimen cabinets (fig. 2) each have a maximum capacity of 3,000 lbm (1360 kg) of concrete, which is about 800 specimens of 3- by 6-inch (76- by 152-mm) size. The brine in the cold fluid tank is cooled to 10 °F (-12.2 °C) by an ammonia refrigeration unit. Brine in the warm fluid tank is warmed to 70 °F (21.1 °C) by electric resistance heaters. The refrigerated brine is pumped through one specimen cabinet and returned to reservoir by gravity through an overflow weir in cabinet. Simultaneously, warm brine is circulated in a similar manner through the other cabinet. At 1.5-hour intervals, pumps are stopped, brine is drained from specimen cabinets, fluid paths are interchanged, and pumps are restarted. The thawed specimens are then frozen while the frozen specimens are thawed. Fully automatic operation is effected by a clock-driven cam which actuates microswitches that, in turn, operate centrifugal pump and air-cylinder-operated plug-type valves through a system of relays and solenoid air valves. An electrically operated cycle counter is used to shut down the apparatus after a given number of cycles. Overflow protection in specimen cabinets is obtained by electrodes maintined above the normal brine level. Brine temperatures are thermostatically controlled, and a continuous record of brine and specimen temperatures is obtained. Corrosion in system is reduced by periodic additions of sodium chromate and caustic soda to the brine. A cathodic protection has also been devised to help minimize this inherent corrosion. With this equipment in 24-hour operation, it is possible to obtain 50 cycles of accelerated freezing and thawing weekly, with ample time for examining specimens whenever necessary. An electrically operated monorail hoist is provided to facilitate handling of specimens.

7.2 *Temperature-Measuring Equipment*.-This equipment consists of thermometers, resistance thermometers, or thermocouples capable of measuring temperature at various points within the specimen chamber and at centers of control specimens to within ±2 °F (±1.1 °C).

7.3 *Scales*.-The scales shall have a capacity about 50 percent greater than mass of specimens and accurate to at least 0.01 lbm (4.5 g) within the range of ±10 percent of specimen mass.

7.4 *Tempering Tank*.-The tempering tank shall have suitable provisions for maintaining test specimens in water until their mass is determined.

8. Freezing and Thawing Cycle

8.1 The nominal freezing and thawing cycle for this procedure shall consist of alternately lowering temperature of specimens from 70 to 10 °F (21.1 to -12.2 °C), and raising temperature from 10 to 70 °F (-12.2 to 21.1 °C) in not less than 1.5 hours nor more than 3 hours. A minimum of 25 percent of the time shall be used for thawing. At end of cooling period, temperature at centers of specimens shall be 10±3 °F (-12.2±1.7 °C); and at end of heating period, temperature shall be 70±3 °F (21.1±1.7 °C). The time required for the temperature at the center of any single specimen to be reduced from 67 to 13 °F (19.4 to -10.6 °C) shall be no less than one-half the cooling period. The time required for the temperature at the center of any single specimen to be raised from 13 to 67 °F (-10.6 to 19.4 °C) shall be no less than one-half the heating period.

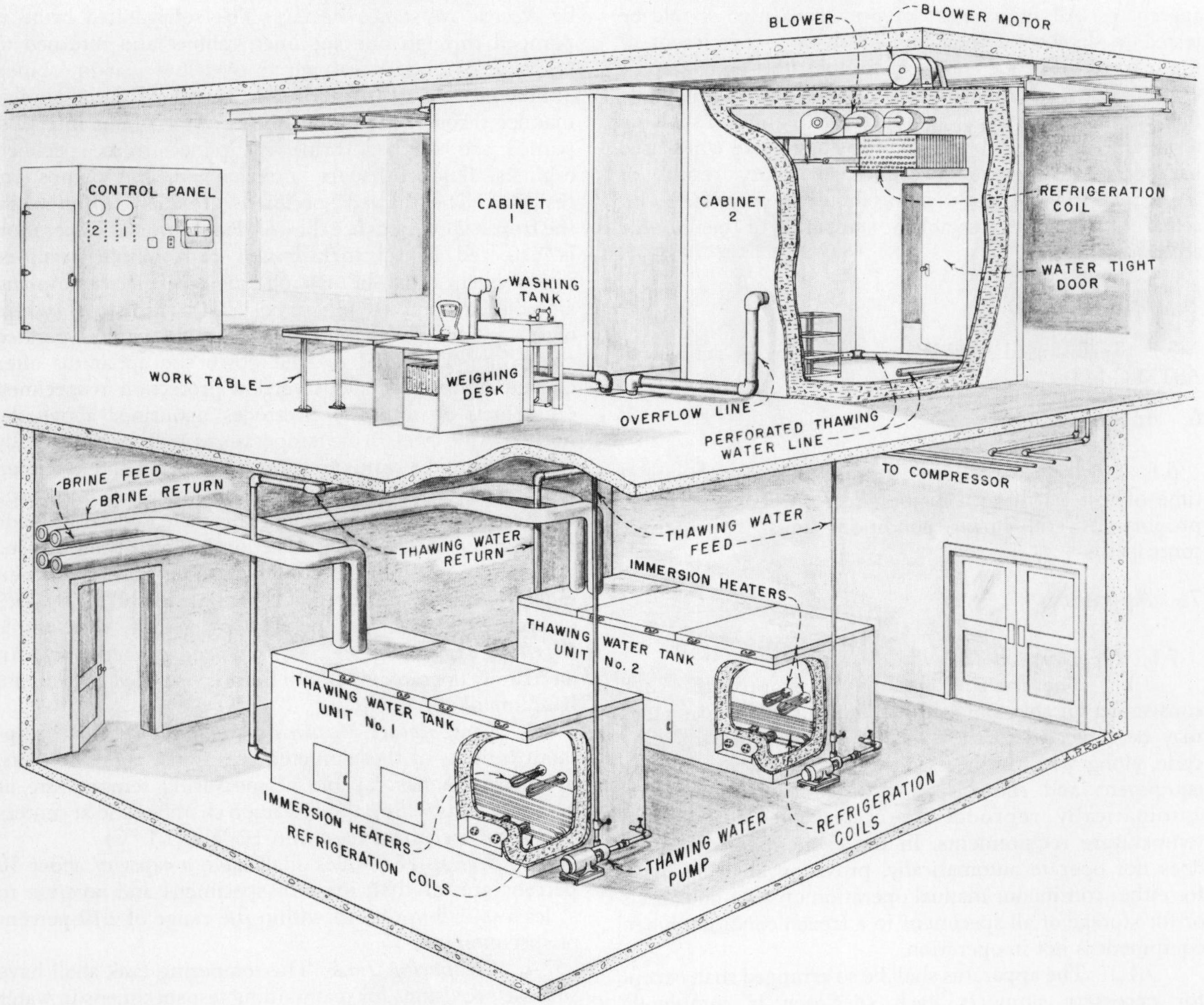


Figure 1. - Automatic freezing and thawing equipment.

8.2 The temperature cycle was established by temperature measurement of specimens that had temperature measuring devices embedded at their centers. This established a cycle period conforming to the requirements of section 8.1 for a large variety of concretes. Currently, temperature measuring devices are not being embedded in specimens, but that capability is available if required.

NOTE 1.-In most cases, uniform temperature and time conditions can be controlled conveniently by maintaining a capacity load of specimens in apparatus at all times. If a capacity load of test specimens is not available, dummy specimens can be used to fill empty spaces. This method also helps to maintain uniform fluid level conditions in the specimen and solution tanks. Testing of concrete specimens composed of widely varying materials or widely varying thermal properties in same equipment at same time may not permit adherence to the time-temperature requirements for all specimens. It is recommended that such specimens be tested at different times, and that appropriate adjustments be made to equipment.

8.3 The difference between the temperature at center of specimen and at its surface shall at no time exceed 50 °F (27.8 °C).

8.4 The period of transition between the freezing and thawing phases of the cycle shall not exceed 10 *minutes* except when specimens are being tested in accordance with section 14.3.

9. Reagents and Materials

9.1 *Reagent Materials*.-Sodium chromate and caustic soda for corrosion protection added to brine.

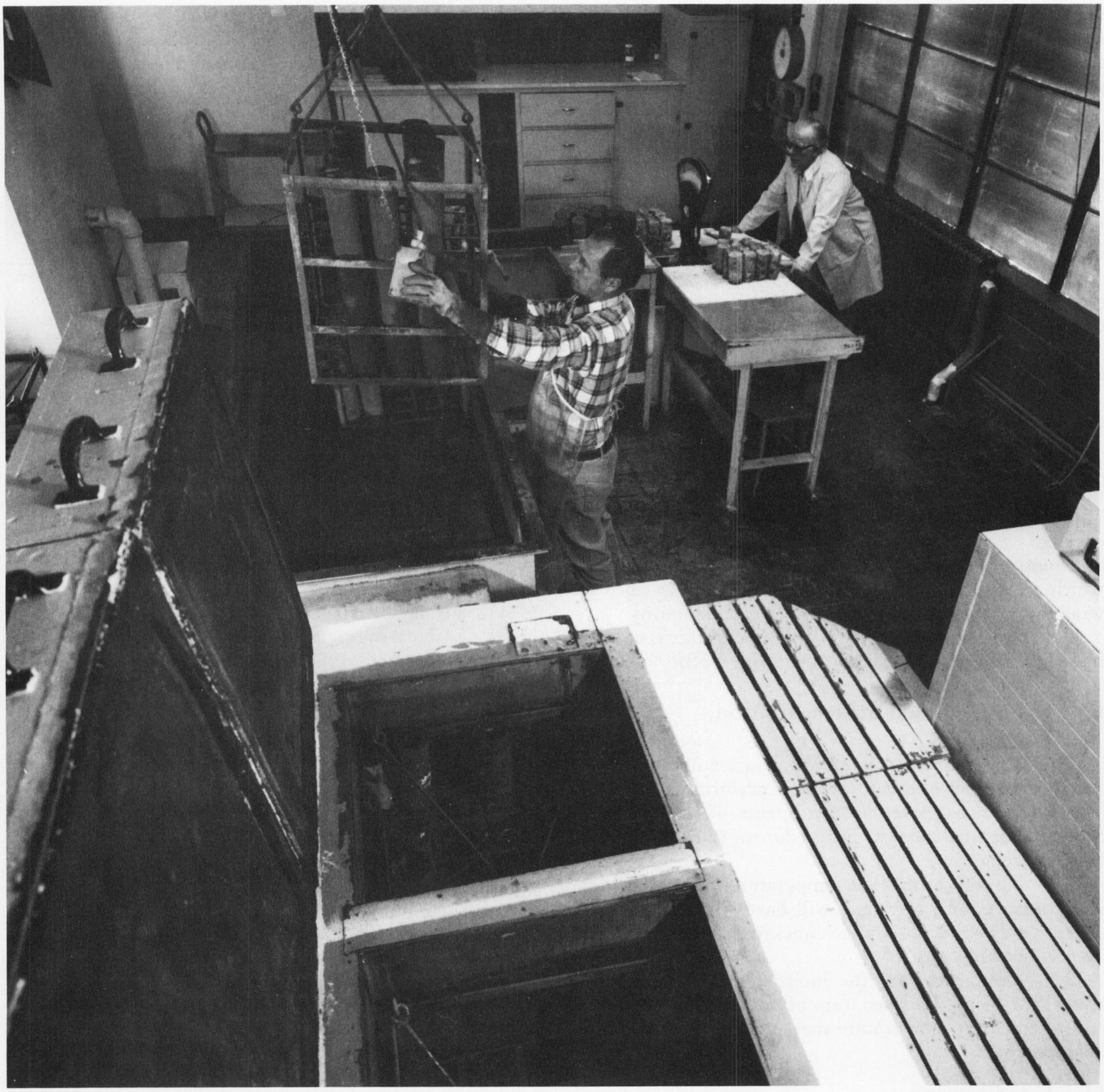


Figure 2. – Concrete specimens that have been subjected to cycles of freezing and thawing being removed for evaluation.

9.2 *Other Materials*.–Aggregates for which an evaluation is desired, cement complying with ASTM C 150, and an air-entraining admixture complying with ASTM C 260.

10. Precautions

10.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

11. Sampling, Test Specimens, and Test Units

11.1 *Cementitious*.–The cement shall be sampled in accordance with USBR 4183 and shall comply with ASTM C 150, Type II cement for the standard test unless another type of cement is specifically requested. Pozzolans will be sampled and tested in accordance with USBR 4311 and shall comply with ASTM C 618 if pozzolan is specifically requested. The standard freeze-thaw test does not use pozzolans.

11.2 *Air-Entraining Admixtures*.-These admixtures shall comply with ASTM C 260; however, for the standard freeze-thaw test, the admixture shall be a neutralized vinsol resin.

11.3 *Aggregates*.-Shall be sampled in accordance with USBR 4075, and tested for specific gravity and absorption in accordance with USBR 4127 and 4128.

11.4 *Concrete*.-Freshly mixed concrete shall be sampled in accordance with USBR 4172, and hardened concrete in accordance with USBR 4042.

11.5 Density and gravimetric air of fresh concrete shall be determined in accordance with USBR 4138.

11.6 Consistency or slump of fresh concrete shall be determined in accordance with USBR 4143.

11.7 *Test Specimens*.-Cylinder test specimens shall normally be 3- by 6-inch (76- by 152-mm) cylinders made in accordance with applicable requirements of USBR 4192. Test specimens may also be cores cut from hardened concrete. If so, specimens should not be allowed to dry to a moisture condition below that of the structure from which cores were obtained. This may be accomplished by wrapping cores in plastic or by other suitable means.

11.8 If air-void content of hardened concrete is desired, it shall be determined in accordance with USBR 4457.

12. Calibration and Standardization

12.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

12.2 Assurances that the temperature rises and lowers in accordance with section 8 will have to be verified by chart study and periodic checking with certified thermometers.

12.3 Assurances that the internal specimen temperatures are being achieved can be accomplished by the reinstatement of temperature measuring devices as noted in section 8.2.

13. Conditioning

13.1 The samples of aggregate, as received from the field, are the ovendried and scalped samples of the plus 3/4-inch (19.0-mm) material, if necessary, and split at the 3/8-inch and No. 4 (9.5 and 4.75-mm) material. The sand fraction is then washed to determine if the minus No. 200 (75-μm) material is less than 3 percent, which is the normal specifications limit for this material in Bureau concrete sand. Determine the percentage of voids in the sand in accordance with USBR 4029, and use the average of three determinations. The nominal sieve fractions of minus No. 4, No. 4 to 3/8 inch, and 3/8 to 3/4 inch (-4.75, 4.75 to 9.5, and 9.5 to 19.0 mm) are subjected to a 30-minute soaking period in tap water to determine the 30-minute specific gravity and absorption in accordance with USBR 4127 and 4128. This determination allows for the correction of water requirement and adjusting sand mass. The separated sizes are then recombined by determining the mass to 0.01 lbm (4.5 g) to satisfy the conditions of a standard grading as shown in table 1.

Table 1.-Standard grading for freeze-thaw test using 55 percent coarse aggregate and 45 percent fine aggregate.

Nominal Sieve Size Fractions		Percent Retained	
		Individual	Cumulative
3/8- to 3/4-inch	9.5 to 19.0 mm	60	60
No. 4 to 3/8-inch	4.75 to 9.5 mm	40	100
No. 8	2.36 mm	15	15
No. 16	1.18 mm	15	30
No. 30	600 μm	25	55
No. 50	300 μm	24	79
No. 100	150 μm	16	95
Pan		5	100
FM			2.74

13.2 The Bureau's practice on aggregate acceptance tests is that, to establish a data base, all aggregates should be tested under similar conditions:

(1) a standard grading,
(2) a laboratory standard Type II cement, and
(3) a 5-percent solution of neutralized vinsol resin providing a mix with:
  (a) a W/C (water-cement) ratio of 0.51,
  (b) a slump of 3±1 inches (76±25 mm),
  (c) an air content of 6±1 percent for a 3/4-inch (19.0-mm) MSA mix, and
  (d) a sand content of 45 percent by mass.

Based on many years of experience, the Bureau has found that one of the most important physical properties of an aggregate, which influences the air content and consistency of the concrete mix, is its particle shape, especially of the sand. Because of the different particle shapes of aggregates from different sources, the water requirement for a concrete with 3/4-inch (19.0-mm) MSA, 6 percent entrained air, and a 3-inch (76-mm) slump would vary from about 240 to 330 lbm/yd^3 (142 to 196 kg/m^3). Variations in the water requirement were also noted due to different concrete mixing temperatures. Because of these two factors, wide variations in concrete mixes have occurred, and production of concrete with uniform slump and air content was difficult to achieve.

The particle shape of sand is reflected in the percentage of voids determined from USBR 4029. An empirical relationship between the percentage of voids in sand and the water and air-entraining admixture requirements for the aggregate acceptance mixes is shown on figure 3. To compensate for the effect of particle shape of the coarse aggregate, each sample is examined and an allowance made for the proper selection of one of the five curves shown on figure 3. This selection is based on the percentage of natural to crushed coarse aggregate in the sample. On figure 3, curve N_4 should be used for the natural well-rounded

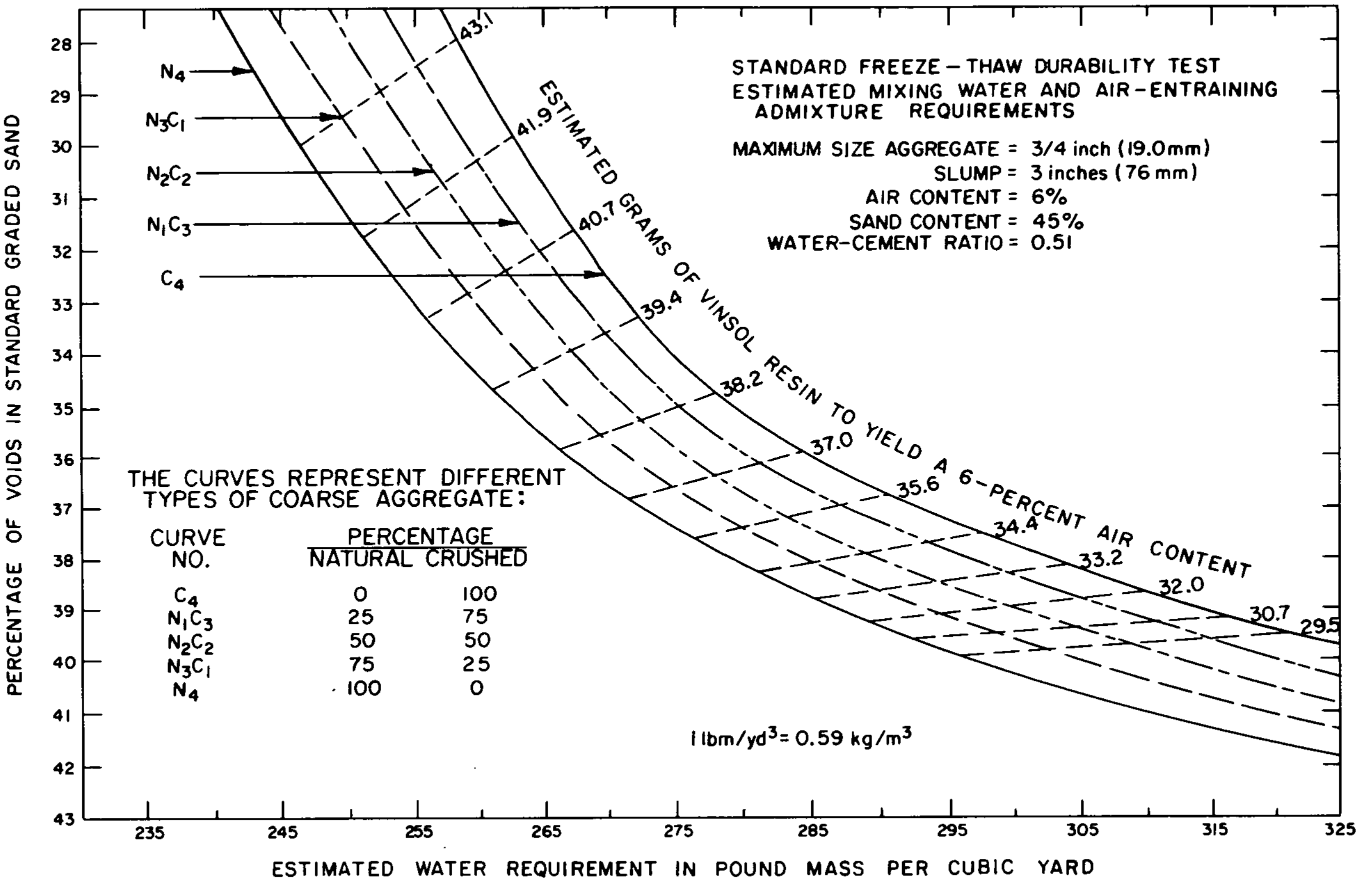


Figure 3. - Empirical curves showing relationships between percentage of voids in sand and the water and air-entraining admixture requirements of concrete.

(river-worn) coarse aggregate, and curve C_4 for the 100-percent crushed coarse aggregate. The intermediate curves (N_3C_1, N_2C_2, and N_1C_3) should be used for combinations of these two types of aggregate in 3 to 1, 2 to 2, or 1 to 3 proportions of natural to crushed coarse aggregate, respectively. To minimize the effect of temperature on the materials and the mixing temperature, all of the material (including the aggregate) should be stored at a constant temperature for 24 hours prior to mixing, and mixed at this same controlled temperature

13.3 Unless otherwise specified, specimens shall be cured at 73.4±3 °F (23.0±1.7 °C) and at 100 percent relative humidity prior to testing.

13.4 If a specified curing procedure concludes with drying, specimens shall be immersed in saturated lime water for 72 hours before proceeding with freezing and thawing tests (note 2).

NOTE 2.-Unless some other age is specified, specimens should be removed from curing and the freezing and thawing tests started when specimens are 28 days' old.

14. Procedure

14.1 Break three companion cores or cylinders at 28 days' age at the start of the freeze-thaw test. The modulus of elasticity may be determined if desired; however, the Bureau has found that the sonic modulus of elasticity method has not proven to be as satisfactory as the mass-change method.

14.2 Immediately after specified curing period, determine mass of specimens to nearest 0.01 lbm (4.5 g).

14.3 Start the freezing and thawing tests by placing specimens in the thawing water at beginning of thawing phase of cycle. Remove specimens from apparatus, in thawed condition, at intervals not exceeding 50 freezing and thawing cycles, determine mass, and then return specimens to apparatus (note 3). Protect specimens against loss of moisture while out of apparatus, and turn specimens end-for-end when returning them to apparatus. Rinse out specimen container and add clean water. Return specimens either to random positions in cabinet or to some predetermined rotation scheme that will ensure that each specimen that continues under test for any length of time is subjected to conditions in all parts of freezing apparatus. Continue testing until each specimen has been subjected to 1,000 cycles or until mass loss of specimen reaches 25 percent, whichever occurs first, unless other limits have been specified. Whenever a specimen is removed because of failure, replace it for remainder of test with a dummy specimen. Each time a specimen is tested, record its visual appearance and make special comment on any apparent defects.

NOTE 3.–Current Bureau policy is to remove specimens after 100 cycles when good durability is expected. When it is anticipated that specimens may deteriorate rapidly, they should be tested at intervals not exceeding 10 cycles when initially subjected to freezing and thawing.

14.4 When sequence of freezing and thawing cycles must be interrupted, store specimens in a frozen condition.

14.5 If, due to equipment breakdown or other reasons, it becomes necessary to interrupt the cycles for a prolonged period, store specimens in a frozen condition in such a way as to prevent loss of moisture. Maintain specimens in containers and surround them with ice, if possible. If it is not possible to store specimens in their containers, wrap and seal them in as wet a condition as possible in a moistureproof material to prevent dehydration, and store in a refrigerator or cold room maintained at 10±3 °F (−12.2±1.7 °C). Specimens should not remain in a thawed condition for more than two cycles; however, a longer period may be permissible if situation occurs only once or twice during a complete test.

15. Calculations

15.1 Calculate the change in mass as follows:

$$\Delta M_n = \frac{M_n - M_o}{M_o}(100) \qquad (1)$$

where:

ΔM_n = change in mass after n cycles, in percent;
M_n = mass after n cycles, in pound mass (kilograms); and
M_o = mass at start of freezing and thawing test, in pound mass (kilograms).

15.2 Figure 4 shows a typical data and calculation form.

16. Report

16.1 Figure 5 may be used as a typical reporting form. An abbreviated summary of results is included on figure 3 of USBR 4075. The report shall include such of the following data as are pertinent to the variables or combination of variables studied in the test.

16.1.1 *Properties of Concrete Mixture*:

- Type and proportions of cement, fine aggregate, and coarse aggregate including maximum size and grading (or designated grading indexes), and ratio of net water content to cement.
- Type and proportion of any addition or admixture used.
- Air content of fresh concrete.
- Average compressive strength.
- Average modulus of elasticity.
- Density of fresh concrete.
- Consistency of fresh concrete.
- Air content of hardened concrete.
- Average compressive strength.
- Average modulus of elasticity.
- Report if test specimens are cut from hardened concrete and, if so, state the size, shape, orientation of specimens in structure, and any other pertinent information available.

16.1.2 *Mixing, Molding, and Curing Procedures*:

- Report any departures from standard procedures for mixing, molding, and curing.

16.1.3 *Characteristics of Test Specimens*:

- Dimensions of specimens prior to start of freezing and thawing cycles.
- Mass of specimens prior to start of freezing and thawing cycles.
- Any defects in specimens prior to start of freezing and thawing cycles.

16.1.4 *Results*:

- Mass loss at specified intervals.
- Any defects in specimens that developed during testing, and the number of cycles at which such defects were noted.

NOTE 4.–For aggregate acceptance testing, three specimens are cast and the reported cycles to failure is the average of the three specimens.

17. Precision and Bias

17.1 The precision for this test procedure has not been determined.

17.2 There is no known bias.

Spec. or Solic. No. DESIGN STAGE	Structure DAM	Tested by R. PEPIN — Date 9-27-88 THRU 3-30-89
Project SALT RIVER	Item AGGREGATE EVALUATION Location DENVER LAB	Computed by R. PEPIN — Date 9-27-88 THRU 3-30-89
Feature ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date APRIL 1989

RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING

Series No.: M-7924 Conditioning Temperature 74.0 [✓ °F](°C) Date Cast: 9-27-88

MATERIAL DATA

Sieves	[✓ 3/4 to 3/8 inch] 19.0 to 9.5 mm	[✓ 3/8 inch to No. 4] 9.5 to 4.75 mm	[✓ No. 8] 2.36 mm	[✓ No. 16] 1.18 mm	[✓ No. 30] 600 µm	[✓ No. 50] 300 µm	[✓ No. 100] 150 µm	Pan	Total Batch, [✓ lbm](kg)	FM of Sand Percent Sand	2.74 45
Standard Grading, %	60	40	15	15	25	24	16	5		Percent of Voids in Sand	34.76
										Percent of Minus [✓ No. 200] (75 µm)	0.4
Mass in [✓ lbm](kg)	14.85	9.90	3.04	3.04	5.06	4.86	3.24	1.01	45.00	Particle Shape Curve	N4

CA: M-7924, M-7924 Sp. Gr. (30 min.) [✓ 3/4 inch](19.0 mm) = 2.61, [✓ 3/8 inch](9.5 mm) = 2.61, Wtd. = 2.61, Abs. (30 min) = 0.82, 0.82, Wtd. = 0.82

FA: M-7924, Sp. Gr. (30 min.): [✓ No. 4](4.75 mm) = 2.70, Abs. (30 min.) = 0.90, Wtd. Avg. Total Agg. Sp. Gr. = 2.66, Abs. = 0.86

Cement: M-7120, Sp. Gr. = 3.16 Pozzolan: M- NA, Sp. Gr. = ~, Percent of Cement Replaced (by Mass) = ~

DESIGN DATA

Mix No.	AEA	Estimated Air Content, percent	Percent Sand by Mass	Percent Pozzolan by Mass of Cement	Estimated Slump, [✓ inches](mm)	Estimated Water Content, [✓ lbm/yd³](kg/m³)	$\frac{W}{C+P}$ Ratio by Mass	Cementitious [✓ lbm/yd³](kg/m³)
A	NVX	6	45	NA	2 To 4	262	0.51	514
B								

ABSOLUTE VOLUME IN CUBIC FOOT, CUBIC YARD, OR CUBIC METER — EQUIVALENT AGGREGATE MASS

Air	Water	Cement	Pozzolan	Total, [✓ ft³](m³)	Total Aggregate, [✓ ft³](m³)	Total SSD Aggregate, [✓ lbm](kg)	Fine Aggregate, [✓ lbm](kg)	Coarse Aggregate, [✓ lbm](kg)
1.62	4.21	2.61	NA	8.44	18.56	3074	1383	1691

ACTUAL MIXING DATA (Batch Quantities)

Volume of Density Measure = 0.2493 [✓ ft³](m³) Batch Ratio[1] in [✓ yd³] or m³ = 0.0148

SSD Aggregate Mass, [✓ lbm](kg)	Cement, [✓ lbm](kg)	Net Water, [✓ lbm](kg)	Total Mass, [✓ lbm](kg)	Gross Water, [✓ lbm](kg)	AEA, [✓ oz](mL)	Slump, [✓ inches](mm)	Mass of Container and Concrete [✓ lbm](kg)	Tare Mass of Container, [✓ lbm](kg)	Mass of Concrete, [✓ lbm](kg)	Actual Density, [✓ lbm/ft³](kg/m³)	Theoretical Density[2] [✓ lbm/ft³](kg/m³)
45.39	7.61	3.88	56.88	4.27	13	3.5	43.85	8.33	35.52	142.48	151.70

Batches per volume ([✓ cubic yards] or cubic meters)[3] = 67.63

QUANTITIES PER CUBIC YARD OR CUBIC METER

SSD Aggregate Mass, [✓ lbm](kg)	Volume of Aggregate, [✓ ft³](m³)	Cement Mass, [✓ lbm](kg)	Volume of Cement, [✓ ft³](m³)	Water Mass, [✓ lbm](kg)	Volume of Water, [✓ ft³](m³)	Total Mass, [✓ lbm](kg)	Total Volume, [✓ ft³](m³)	Temp. [✓ °F](°C)		Air Content, %		AEA [✓ oz/yd³] mL/m³	Actual $\frac{W}{C+P}$
								Water	Concrete	Meter	Grav.[4]		
3070	18.53	515	2.62	262	4.21	3847	25.36	73	NM	6.4	6.1	879	0.51

FM = fineness modulus, CA = coarse aggregate, FA = fine aggregate, AEA = air-entraining admixture, SSD = saturated-surface-dry, and W/(C + P) = ratio of water to cement plus pozzolan.

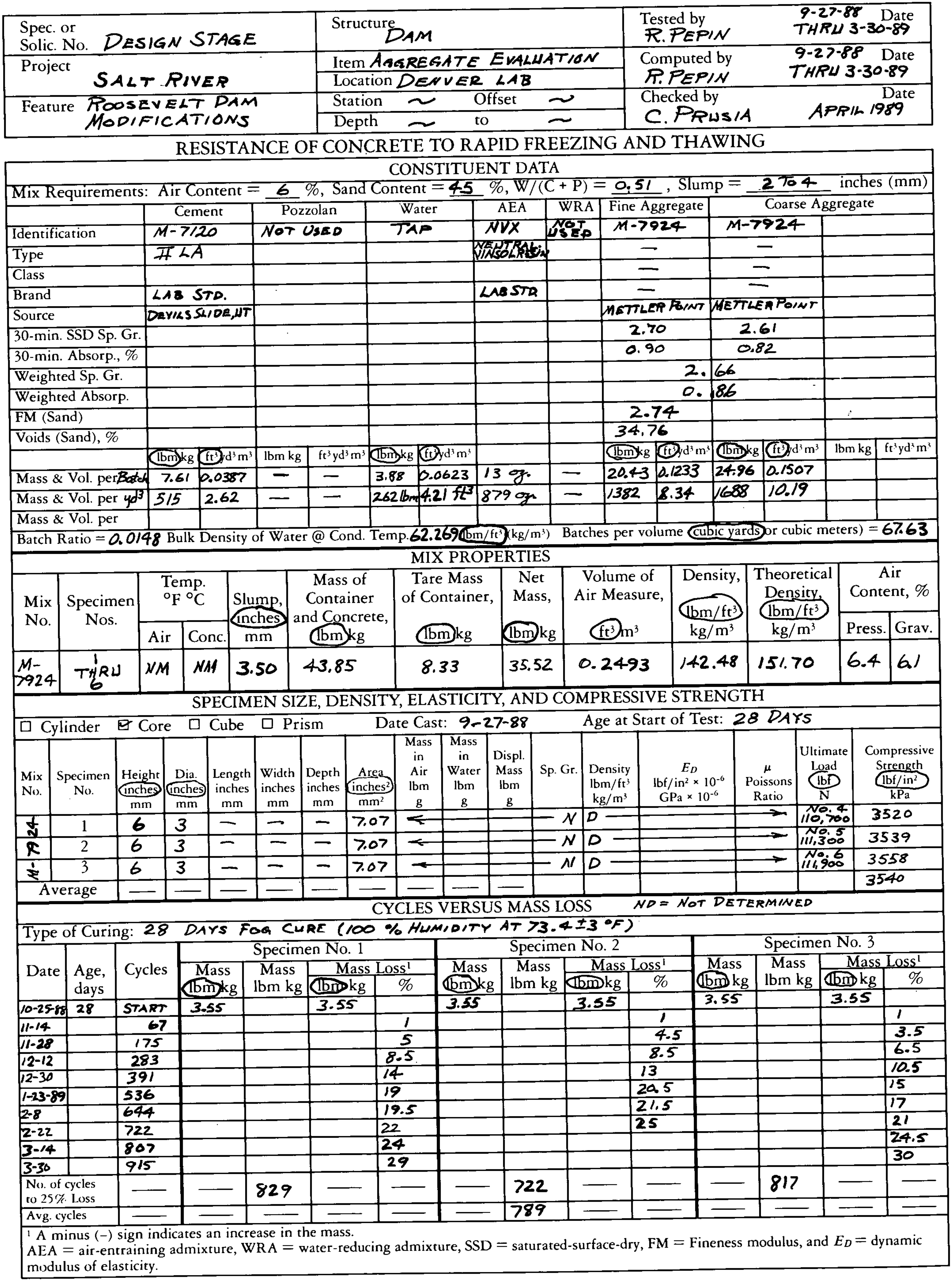
[1] The batch ratio is the total ovendry aggregate of 45 lbm (20.4 kg) plus the water of absorption, divided by the total mass of the SSD aggregate from the "Absolute Volume" calculations.

[2] The theoretical density is the total mass divided by the total calculated volume of the air-free constituents, both values obtained from the "Quantities per Cubic Yard or Cubic Meter" calculations.

[3] The batches per volume is the actual density times 27, divided by the total mass, both values obtained from the "Actual Mixing Data" calculations.

[4] The gravimetric air content is the volume of the design batch minus the volume of the air-free batch, divided by the volume of the design batch, then multiply by 100 to get air content in percent.

Figure 4. – Sample concrete mix data form.



Spec. or Solic. No. DESIGN STAGE	Structure DAM	Tested by R. PEPIN — Date 9-27-88 THRU 3-30-89
Project SALT RIVER	Item AGGREGATE EVALUATION Location DENVER LAB	Computed by R. PEPIN — Date 9-27-88 THRU 3-30-89
Feature ROOSEVELT DAM MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by C. PRUSIA — Date APRIL 1989

RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING

CONSTITUENT DATA

Mix Requirements: Air Content = 6 %, Sand Content = 45 %, W/(C + P) = 0.51 , Slump = 2 TO 4 inches (mm)

	Cement		Pozzolan		Water		AEA	WRA	Fine Aggregate		Coarse Aggregate			
Identification	M-7120		NOT USED		TAP		NVX	NOT USED	M-7924		M-7924			
Type	II LA						NEUTRAL VINSOL RESIN		—		—			
Class									—		—			
Brand	LAB STD.						LAB STD		—		—			
Source	DEVILS SLIDE, UT								METTLER POINT		METTLER POINT			
30-min. SSD Sp. Gr.									2.70		2.61			
30-min. Absorp., %									0.90		0.82			
Weighted Sp. Gr.									2.66					
Weighted Absorp.									0.86					
FM (Sand)									2.74					
Voids (Sand), %									34.76					
	[✓ lbm] kg	[✓ ft³] yd³ m³	lbm kg	ft³ yd³ m³	[✓ lbm] kg	[✓ ft³] yd³ m³			[✓ lbm] kg	[✓ ft³] yd³ m³	[✓ lbm] kg	[✓ ft³] yd³ m³	lbm kg	ft³ yd³ m³
Mass & Vol. per Batch	7.61	0.0387	—	—	3.88	0.0623	13 oz.	—	20.43	0.1233	24.96	0.1507		
Mass & Vol. per yd³	515	2.62	—	—	262 lbm	4.21 ft³	879 oz.	—	1382	8.34	1688	10.19		
Mass & Vol. per														

Batch Ratio = 0.0148 Bulk Density of Water @ Cond. Temp. 62.269 ([✓ lbm/ft³] kg/m³) Batches per volume ([✓ cubic yards] or cubic meters) = 67.63

MIX PROPERTIES

Mix No.	Specimen Nos.	Temp. °F °C		Slump, [✓ inches] mm	Mass of Container and Concrete, [✓ lbm] kg	Tare Mass of Container, [✓ lbm] kg	Net Mass, [✓ lbm] kg	Volume of Air Measure, [✓ ft³] m³	Density, [✓ lbm/ft³] kg/m³	Theoretical Density, [✓ lbm/ft³] kg/m³	Air Content, %	
		Air	Conc.								Press.	Grav.
M-7924	1 THRU 6	NM	NM	3.50	43.85	8.33	35.52	0.2493	142.48	151.70	6.4	6.1

SPECIMEN SIZE, DENSITY, ELASTICITY, AND COMPRESSIVE STRENGTH

☐ Cylinder ☑ Core ☐ Cube ☐ Prism Date Cast: 9-27-88 Age at Start of Test: 28 DAYS

Mix No.	Specimen No.	Height [✓ inches] mm	Dia. [✓ inches] mm	Length inches mm	Width inches mm	Depth inches mm	Area [✓ inches²] mm²	Mass in Air lbm g	Mass in Water lbm g	Displ. Mass lbm g	Sp. Gr.	Density lbm/ft³ kg/m³	E_D lbf/in² × 10⁻⁶ GPa × 10⁻⁶	μ Poissons Ratio	Ultimate Load [✓ lbf] N	Compressive Strength [✓ lbf/in²] kPa
M-7924	1	6	3	—	—	—	7.07	←			N	D		→	No. 4 110,700	3520
	2	6	3	—	—	—	7.07	←			N	D		→	No. 5 111,300	3539
	3	6	3	—	—	—	7.07	←			N	D		→	No. 6 111,900	3558
Average		—	—	—	—	—	—	—	—	—						3540

CYCLES VERSUS MASS LOSS

ND = NOT DETERMINED

Type of Curing: 28 DAYS FOG CURE (100 % HUMIDITY AT 73.4 ± 3 °F)

Date	Age, days	Cycles	Specimen No. 1				Specimen No. 2				Specimen No. 3			
			Mass [✓ lbm] kg	Mass lbm kg	Mass Loss[1] [✓ lbm] kg	Mass Loss[1] %	Mass [✓ lbm] kg	Mass lbm kg	Mass Loss[1] [✓ lbm] kg	Mass Loss[1] %	Mass [✓ lbm] kg	Mass lbm kg	Mass Loss[1] [✓ lbm] kg	Mass Loss[1] %
10-25-88	28	START	3.55		3.55		3.55		3.55		3.55		3.55	
11-14		67				1				1				1
11-28		175				5				4.5				3.5
12-12		283				8.5				8.5				6.5
12-30		391				14				13				10.5
1-23-89		536				19				20.5				15
2-8		644				19.5				21.5				17
2-22		722				22				25				21
3-14		807				24								24.5
3-30		915				29								30
No. of cycles to 25% Loss		—	—	829	—	—	—	722	—	—	—	817	—	—
Avg. cycles		—	—	—	—	—	—	789	—	—	—	—	—	—

[1] A minus (−) sign indicates an increase in the mass.

AEA = air-entraining admixture, WRA = water-reducing admixture, SSD = saturated-surface-dry, FM = Fineness modulus, and E_D = dynamic modulus of elasticity.

Figure 5. – Sample reporting form for freeze-thaw test.

APPENDIX

(Nonmandatory Information)

X1. MAJOR ITEMS OF VARIATION BETWEEN ASTM C 666-84 AND USBR 4666-90

X1.1 Procedure

X1.1.1 *ASTM C 666.*–Two procedures: Procedure A, Rapid Freezing and Thawing in Water; and Procedure B, Rapid Freezing in Air and Thawing in Water.

X1.1.2 *USBR 4666.*–One procedure: Rapid Freezing and Thawing in Water. The Bureau has facilities available to test by ASTM Procedure B; however, we do not currently perform this alternate procedure.

X.1.2 Age at Start of Test

X.1.2.1 *ASTM C 666.*–14 days.
X.1.2.2 *USBR 4666.*–28 days.

X.1.3 Freeze-Thaw Temperature Range

X.1.3.1 *ASTM C 666*: 0 to 40 °F (–17.8 to 4.4 °C)
X.1.3.2 *USBR 4666*: 10 to 70 °F (–12.2 to 21.1 °C).

X.1.4 Specimens

X.1.4.1 *ASTM C 666.*–Generally prisms.
X.1.4.2 *USBR 4666.*–Generally cores or cylinders.

X.1.5 Tests Performed

X.1.5.1 *ASTM C 666*:

- Fundamental Transverse Frequency (as cycles progress).
- Mass Determination (as cycles progress).
- Length Determination (as cycles progress).
- Compressive Strength (as cycles progress on companion specimens).

X.1.5.2 *USBR 4666*:

- The use of the modulus of elasticity (sonic method) has not proven to be as satisfactory as the mass-change method; therefore, the sonic modulus is not used in Bureau investigations.
- Mass Determination (as cycles progress).
- Length Determination (as cycles progress). Currently, the Bureau is not performing length determinations because the stud inserts become loose, making the comparator readings inaccurate.
- Compressive Strength (three companion cores or cylinders of 28 days' age are broken at start of freeze-thaw test).

X.1.6 Freeze-Thaw Completion

X.1.6.1 *ASTM C 666.*–Completion after 300 cycles or until relative dynamic modulus of elasticity, which is calculated from fundamental transverse frequency, reaches 60 percent of initial modulus.

X.1.6.2 *USBR 4666.*–Completion after 1,000 cycles or until a 25-percent mass loss has been reached.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4671-92

PROCEDURE FOR

CRITICAL DILATION OF CONCRETE SPECIMENS SUBJECTED TO FREEZING

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4671; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 671-77.

1. Scope

1.1 This designation covers the procedure for determination of the test period of frost immunity of concrete specimens as measured by the length of time of water immersion required to produce critical dilation when subjected to a prescribed slow freezing method. The significance of the results in terms of potential field performance depends upon the degree to which field conditions can be expected to correlate with those employed in the laboratory.

2. Applicable Documents

2.1 *USBR Procedures*:
4192 Making and Curing Concrete Test Specimens in Laboratory
4227 Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
4341 Length Change of Drilled or Sawed Specimens of Cement Mortar and Concrete

2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]
C 490 Standard Specification for Apparatus for Use in Meaurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[2]
C 671 Standard Test Method for Critical Dilation of Concrete Specimens Subjected to Freezing[3]

3. Summary of Procedure

3.1 Specimens are conditioned to moisture condition anticipated in service at start of freezing season, and then placed in a water bath and frozen and unfrozen once every 2 weeks. The test continues until critical dilation occurs or until duration of test equals length of freezing season for anticipated in-service exposure.

4. Significance and Use

4.1 This procedure is intended to give site-specific information which is not available from conventional freezing and thawing tests. If a particular concrete can withstand continuous soaking throughout the anticipated freezing season without experiencing critical dilation when frozen, the concrete may be expected to perform well at the site. If concrete undergoes critical dilation before the end of freezing season, the concrete may be expected to undergo deterioration at site.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 490.

6. Interferences

6.1 The most critical part of the test is conditioning the test specimens to the moisture content anticipated in the prototype at the start of the freezing season. This moisture content can best be determined by exposing a mass of concrete of the same cross-sectional dimensions as the prototype throughout the spring, summer, and fall, and measuring the moisture content in areas most likely to be exposed to freezing.

NOTE 1.-Moisture determinations may be made on core retrieved from the prototype structure or by using a probe moisture gauge inserted into the cored drill hole.

7. Apparatus

7.1 *Cooling Bath*.-The cooling bath shall be of sufficient size and depth to completely immerse test specimens in water-saturated kerosene. The bath shall have a sufficient volume of kerosene per specimen and shall be provided with controls to permit lowering temperature of bath and specimens uniformly from 35 to 15 °F (1.7 to -9.4 °C) at the rate of 5±1 °F (2.8±0.6 °C) per hour. Suitable bath temperature recording facilities shall be provided.

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.
[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.
[3] *Annual Book of ASTM Standards*, vol. 04.02.

7.2 *Constant-Temperature Water Bath.*-A refrigerated bath capable of containing the specimens completely immersed, and equipped with control facilities capable of maintaining temperature of specimens at 35±2 °F (1.7±1.0 °C) before and between test cycles.

7.3 *Strain-Measuring and Recording Facilities.*-These facilities (note 2) and a supply of strain frames to support specimens in the cooling bath and to provide alignment for strain-measuring apparatus are required, see figure 1. The strain-measuring apparatus shall have the capability of measuring strains of 0.00001 inch (0.00025 mm) or less.

NOTE 2.-The LVDT (linear variable differential transformer), with appropriate associated electronic actuating and indicating apparatus, appears to give the best results with respect to stability, sensitivity, and reliability. Multichannel recording of outputs has been found to be practical and efficient (fig. 1).

7.4 *Room or Cabinet.*-Required for storing specimens at desired temperature and relative humidity, with provision for constant circulation of air in immediate vicinity of specimens.

7.5 *Miscellaneous Equipment.*-Specimen molds and apparatus are specified in the applicable sections of USBR 4192.

8. Materials

8.1 Materials shall be those for which the durability

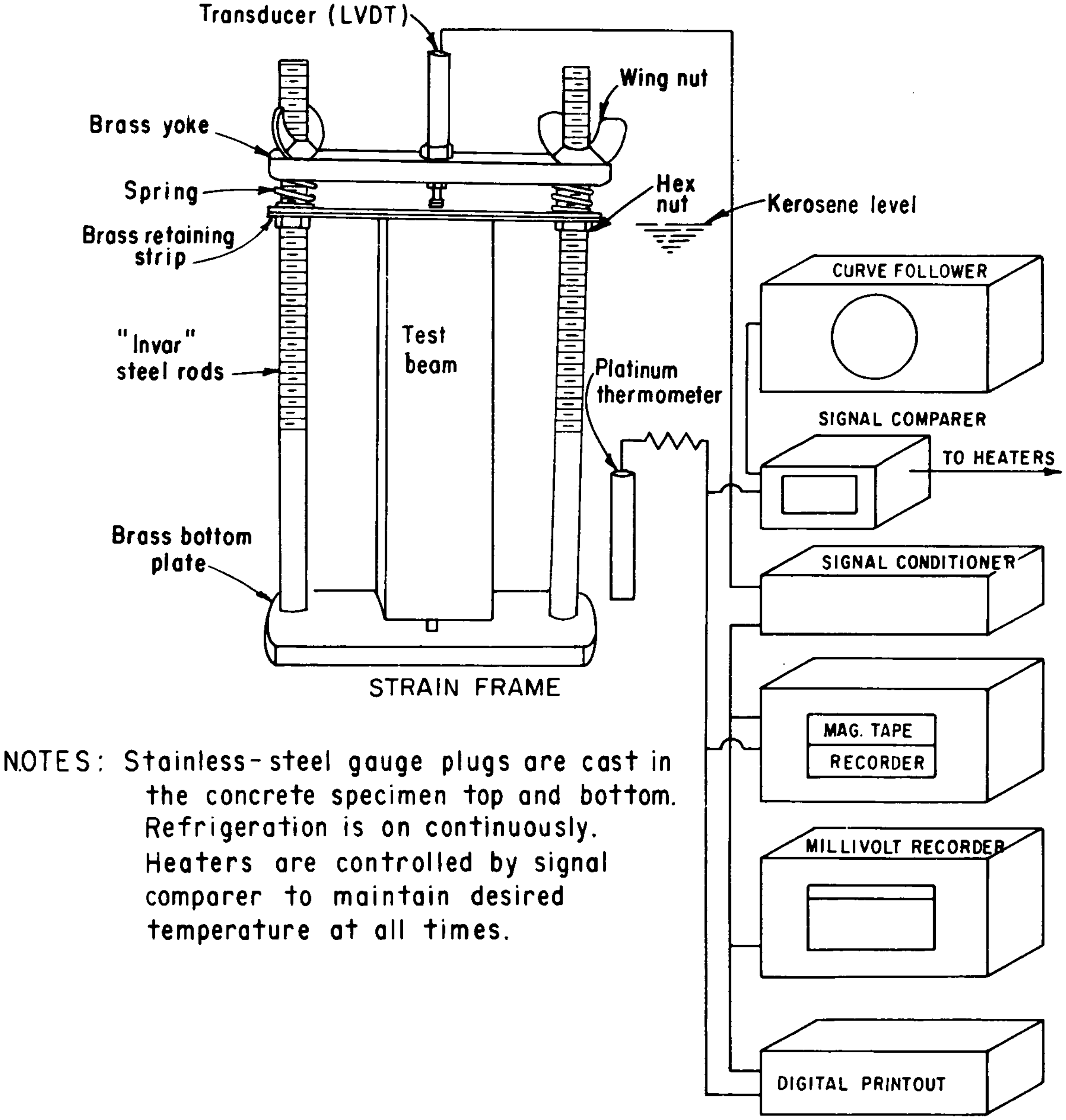

Figure 1. - Schematic of length and temperature measuring system.

information is desired, and conditioned to the moisture conditions at the in-service location.

8.2 A supply of kerosene must be available to maintain the cooling bath at temperatures specified in section 7.1.

9. Precautions

9.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

10. Sampling, Test Specimens, and Test Units

10.1 Test specimens shall be concrete cylinders that have been mixed, molded, and cured as prescribed in USBR 4192. Specimens shall be 3 inches (76 mm) in diameter by 6 inches (152 mm) high, and shall be fitted with axially-centered stainless steel gauge studs both top and bottom (note 3). Gauge studs shall conform to requirements of USBR 4227.

NOTE 3.–Other sizes of specimens may be used at some expense of efficiency and convenience. However, a 1:3 ratio of aggregate to specimen size should be preserved. Comparison of concrete must be made on specimens of same size.

10.2 Test specimens may also be cores, cubes, or prisms cut from hardened concrete; these specimens should not be allowed to dry to a moisture condition below that of the structure from which they were taken. This may be accomplished by wrapping specimens in plastic or by other suitable means.

NOTE 4.–For cores, cubes, or prisms, the gauge studs and method of installation shall comply with sections 6 and 8.3 of USBR 4341.

11. Calibration and Standardization

11.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

11.2 The adequacy to maintain the temperature control as described in section 7 for the cooling bath and constant temperature water bath will have to be assured by checking against a certified thermometer.

11.3 Each strain-measuring device should be calibrated before each test to ensure accuracy. Since the device remains on the specimen throughout the test, periodic checking against a reference bar is not possible.

12. Conditioning

12.1 Results of the use of this procedure are strongly dependent on the curing and conditioning procedures to which the specimens have been subjected prior to testing. The most important variable related to conditioning is the degree of saturation of the specimens when tests are started. Therefore, the curing and conditioning procedures must be carefully described in terms of the purpose for which the procedure is being used, and must be closely followed (see sec. 6).

13. Procedure

13.1 Testing shall commence immediately following completion of specimen conditioning.

13.2 *Test Cycle.*–The test cycle shall consist of cooling the specimens in the water-saturated kerosene from 35 to 15 °F (1.7 to -9.4 °C) at the rate of 5±1 °F (2.8±0.6 °C) per hour followed by immediate return of specimens to the 35 °F water bath, where they shall remain until next test cycle.

13.3 *Frequency.*–One test cycle shall be carried out every 2 weeks.

13.4 *Measurements.*–The measured variables are the specimen length changes and the cooling bath temperatures during the cooling cycle. From observation of these changes, the dilation that occurs in the specimens at the time of freezing is determined (note 5). Dilation is determined by measuring the vertical distance from a straight-line projection of the prefreezing length-versus-time contraction curve (at constant cooling rate) and the maximum deviation of the strain trace from this projection, see figure 2.

NOTE 5.–Additional information of value can be obtained by measurement of the residual expansion.

13.5 *Duration of Test.*–Continue test until critical dilation is exceeded or until specimens have been exposed for the period of interest. Determine critical dilation by taking the differences between dilation values for successive cycles. Designate the number of cycles during which the difference between successive dilations remained constant as the period of frost immunity, and designate the dilation during the last cycle before the dilation began to increase sharply (by factor of 2 or more) as the critical dilation.

14. Calculations

14.1 During the period of frost immunity, the difference between dilation values for successive cycles will be relatively constant. When numerical difference between dilations begins to increase sharply (by a factor of 2 or more) from one cycle to the next, the period of frost immunity has been exceeded. When dilations are very small (less than 0.005 percent), the variability associated with the test method may be of sufficient magnitude to produce an apparent end point that meets this criterion. Therefore, when critical dilation is less than 0.005 percent of original specimen length, run additional cycles to ensure that the difference between successive dilations continues to increase significantly. Highly frost-resistant concrete may never exhibit critical dilation.

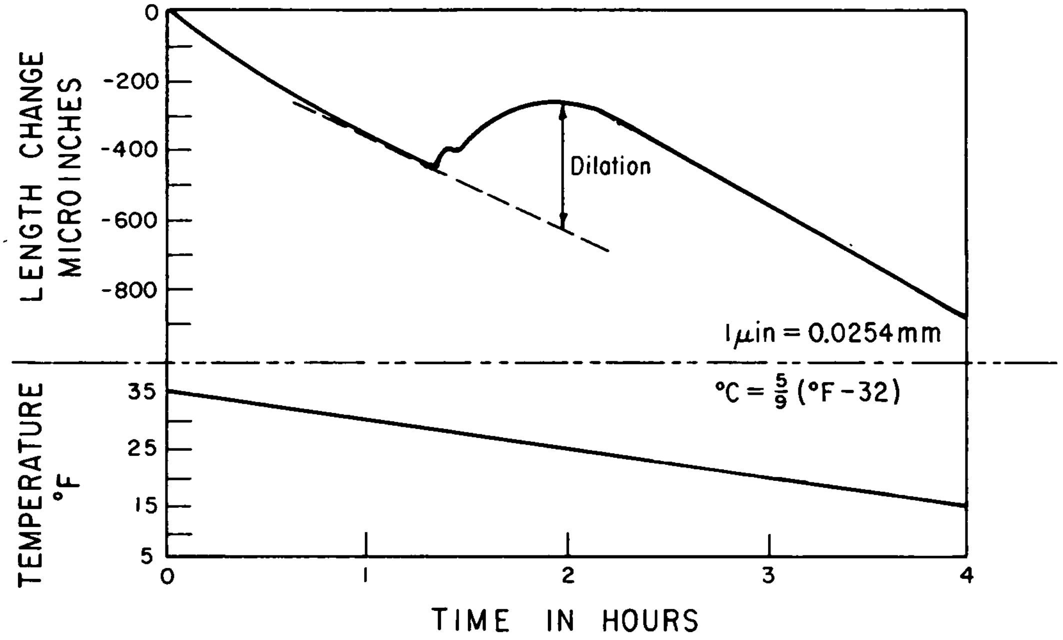

Figure 2. - Typical length change and temperature charts.

14.2 The Bureau has never performed this test; therefore, no worksheet for data has been devised. At such time as the test is run by the Bureau, calculations will probaby be performed by computer and the results expressed by digital printout. A supplement or revision to this procedure would then be issued.

15. Report

15.1 For each specimen, record the test period of frost immunity. This is the total test period for which critical dilation does not occur, and is measured by the length of time in weeks from the start of soaking in the 35 °F (1.7 °C) bath to the time of occurrence of critical dilation.

NOTE 6.-No relationship has been established between the frost immunity of specimens cut from hardened concrete and specimens prepared in the laboratory.

15.2 Compute the mean (average) value and the coefficient of variation for the test period of frost immunity for each mixture-conditioning combination. From these values, determine the 95-percent confidence interval of the mean from the appropriate curve on figure 3.

15.3 Report the period of frost immunity in the form:

$$\overline{X} \pm \frac{H\overline{X}}{100} \qquad (1)$$

where:

$\overline{X}$ = mean value, and

H = 95-percent confidence interval of the mean.

If the mean values of replicate mixtures differ by more than the square root of the sums of the squares of the standard deviations of the mixtures, then an additional mixture must be tested. This method must be repeated until two replicate mixtures meet this criterion.

15.4 The report shall also indicate if test specimens are cut from hardened concrete. If so cut, the size, shape, orientation of specimens in structure, and any other pertinent information available shall be included in the report.

15.5 Refer to section 14.2. A cover letter that includes the data will cover the items listed in section 15.4.

16. Precision and Bias

16.1 Precision of a particular set of tests is as given in section 15.3.

16.2 There is no known bias.

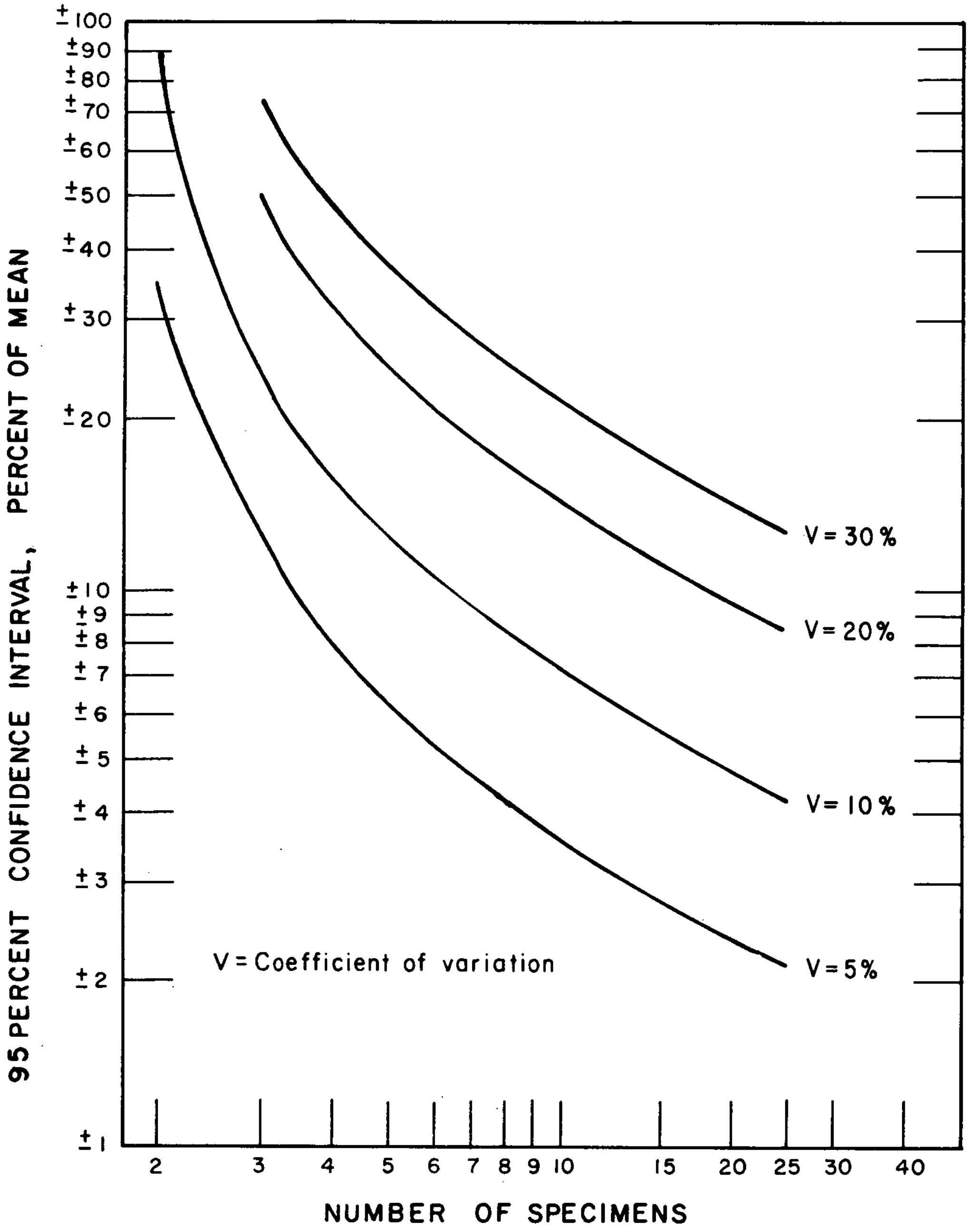

Figure 3. – Number of specimens versus the 95-percent confidence interval for determination of the period of frost immunity.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4672-92

PROCEDURE FOR

SCALING RESISTANCE OF CONCRETE SURFACES EXPOSED TO DEICING CHEMICALS

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4672; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 672-76.

1. Scope

1.1 This designation covers the procedure for the determination of the resistance to scaling of a horizontal concrete surface subject to freezing and thawing cycles in the presence of deicing chemicals. The procedure is intended for use in evaluating this surface resistance qualitatively by visual examination. The test can be used to evaluate effect of mix design, surface treatment, curing, or other variables on resistance to scaling, but is not intended to be used as a test method for durability of aggregates or other ingredients of concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4173 Air Content of Freshly Mixed Concrete by Volumetric Method
4192 Making and Curing Concrete Test Specimens in Laboratory
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4233 Testing Air-Entraining Admixtures for Concrete
2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]
C 511 Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1]
C 672 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.[1]

3. Summary of Procedure

3.1 Concrete prisms, with a mortar dike surrounding the top surface, are subjected to cycles of freezing and thawing in air with the space enclosed by the dike filled with a solution of deicing chemical. Specimens are periodically rated by visual examination.

4. Significance and Use

4.1 This procedure is useful for evaluating resistance of concretes to surface scaling when deicing chemicals are applied to horizontal surfaces. The procedure may be applied to specimens cut from hardened concrete, although no relationship has been established between the frost immunity of such specimens and laboratory specimens. Procedure may also be used to evaluate protective coatings.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125.

6. Interferences

6.1 Results are sensitive to air content and curing procedures, and must be closely controlled.

7. Apparatus

7.1 *Freezing Equipment.*-A chest or room of sufficient size to hold specimens and capable of lowering temperature of specimens to 0±5 °F (-17.8±2.8 °C) within 16 to 18 hours, and maintaining this temperature with a full load of specimens.

7.2 *Molds.*-Molds to be of proper size for test specimens used, and shall conform to requirements of USBR 4192.

7.3 *Tamping Rod.*-Shall conform with USBR 4143.

7.4 *Small Tools.*-Wood strike-off board, steel trowel, and moderately-stiff bristle brush suitable for providing desired texture of test surface.

7.5 *Slump Cone.*-Shall conform to requirements of USBR 4143.

7.6 *Air Meter.*-Shall conform to requirements of USBR 4173 or 4231.

7.7 *Scales.*-Shall conform to requirements of USBR 4192.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

7.8 *Concrete Mixer.*-A power-driven, revolving, tilting drum or pan mixer capable of thoroughly mixing suitably sized batches.

8. Reagents and Materials

8.1 Materials shall be those for which a knowledge of resistance to scaling is known, and will simulate conditions at location to be used.

8.2 If an epoxy mortar dike is to be formed, epoxies listed as currently acceptable by the Bureau will be used. The bonding agent shall also be currently acceptable by the Bureau.

8.3 A supply of anhydrous calcium chloride shall be available for use as the deicing chemical.

9. Precautions

9.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

10. Sampling, Test Specimens, and Test Units

10.1 Samples of freshly mixed concrete shall be taken in accordance with applicable provisions of USBR 4172. Samples of hardened concrete shall be taken in accordance with applicable provisions of USBR 4042.

10.2 *Proportioning.*-The air content, cementitious factor, slump, water-to-cementitious ratio, and other characteristics of the concrete and its ingredients shall be those appropriate for purposes for which tests are to be made. Concrete with the following characteristics has been found useful for the purposes for which this test procedure is generally used, such as evaluation of a surface treatment for prevention of scaling: (a) non-air-entrained; (b) cementitious content, 564±9 lbm/yd^3 (334±3 kg/m^3); (c) slump, 3±0.5 inches (76±13 mm); and (d) durable aggregate (note 1) of 1-inch (25.0-mm) maximum size. If air-entrained concrete is to be used for comparative purposes, it should have same proportions as that with which it is being compared, and the air content should be 5.5±1 percent (note 2).

NOTE 1.-Care should be taken to use an aggregate which has a good performance record in freezing and thawing exposure.

NOTE 2.-For additional information pertaining to air-entrained concrete proportions, see section 4 of USBR 4233.

10.3 *Mixing and Testing Plastic Concrete.*-Machine mix and test in conformance with applicable provisions of USBR 4192.

10.4 Specimens shall have a surface area of at least 72 in^2 (46 452 mm^2) and be at least 3 inches (76 mm) in depth. At least two duplicate specimens for each condition to be tested shall be made.

10.5 *Fabrication of Specimens*:

10.5.1 Coat the inside surface of mold with a light film of form oil just prior to fabrication of specimens.

10.5.2 Fill mold in one layer. Rod one time for each 2 in^2 (1290 mm^2) of surface, leaving a slight excess of material after final rodding. Tap mold to close any voids, and spade around periphery of mold with a flat trowel. Level surface with several passes of a wood strike-off board.

10.5.3 After concrete has stopped bleeding, finish surface with three sawing-motion passes of a wood strike-off board. Brush surface with a medium-stiff brush as a final finishing operation unless another method of surface finishing such as a steel-troweled surface, burlap drag, or a troweled-in surface treatment is to be evaluated.

10.5.4 After the finishing operation, place a dike, about 1 inch (25 mm) wide and 3/4 inch (20 mm) high, around perimeter of top surface of specimen. The dike may be made of any material that will adhere to specimen and serve to maintain brine pond on top of specimen throughout test period. If the dike is of mortar, it shall be air entrained and applied immediately after final finishing operation. The surface, where mortar is to be applied, shall be roughened to provide a mechanical bond. If an epoxy mortar dike is to be formed or a proven satisfactory bonding material is used to bond dike to surface, the dike may be applied after concrete has set. Take care to remove any coating from bond area prior to application.

10.5.5 Test specimens cut from hardened concrete in a structure should not be cut or damaged on the surface to be tested, and should not be allowed to dry to a moisture condition below that of the structure they were cut from. This may be accomplished by wrapping specimens in a waterproof material or by other suitable means.

11. Calibration and Standardization

11.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

11.2 The adequacy to maintain temperature and humidity control as listed under sections 7 and 12 will have to be assured by checking with a certified thermometer and humidity gauge.

11.3 Specimens are rated in accordance with the subjective scale given in table 1. No calibration is possible, although it is useful for a laboratory to develop a series of slabs with different amounts of scale to serve as reference standards.

12. Conditioning

12.1 Except where the method of curing is an element of study or is otherwise specified, cover specimens with a polyethylene sheet immediately after finishing. Take care to prevent contact between sheet and concrete surface.

12.2 Remove specimens from molds at an age of 20 to 24 hours after addition of water to mix, and place in moist storage for 13 days as provided for in ASTM C 511.

Table 1. - Surface rating index.

Rating	Condition of surface
0	No scaling
1	Very light scaling [1/8-inch (3.2-mm) max. depth, no coarse aggregate visible]
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

12.3 Remove specimens from moist storage at the age of 14 days and store in air for 14 days at 73±3 °F (23±1.7 °C) and at 45 to 55 percent relative humidity.

12.4 If protective coatings are to be evaluated, apply them in accordance with manufacturer's recommendations regarding quantity and method of application at the age of 21 days. When a material proposed for a dual-purpose curing compound/protective coating is being evaluated, apply it at the proper time of application for curing compounds.

NOTE 3.-When evaluating penetration-type coatings for application to pavement surfaces subject to traffic wear, it may be desirable to abrade treated surface of test specimens by sufficient wire brushing to break any films remaining on surface after drying.

13. Procedure

13.1 At the age of 28 days, cover flat surface of specimen with about 1/4 inch (6 mm) of a solution of calcium chloride and water having a concentration such that each 100 mL of solution contains 4 grams of anhydrous calcium chloride.

NOTE 4.-Other chemical deicers and different concentrations may be used when there is a need to evaluate their specific effect. In addition, a variation in the procedure may be adopted whereby the solid deicer is added directly to ice produced by freezing a 1/4-inch (6-mm) layer of fresh water during freezing portion of each cycle, and discarding and flushing resulting solution off surface at end of thawing portion of cycle. If this procedure is used, it should be recognized that about 100 cycles or more will be required to evaluate a surface treatment.

13.2 Place specimens in a freezing environment for 16 to 18 hours. Then, remove them from freezer and place in laboratory air at 73±3 °F (23±1.7 °C) and relative humidity of 45 to 55 percent for 6 to 8 hours. Add water between each cycle as necessary to maintain proper depth of solution. Repeat this cycle daily, flushing off surface thoroughly at end of every five cycles. After making a visual examination, replace solution and continue test.

NOTE 5.-Generally, 50 cycles may be sufficient to evaluate a surface or surface treatment. However, where comparative tests are being made, it is recommended that tests be continued beyond the recommended minimum number of cycles if differences have not developed.

13.3 Either keep specimens frozen during any interruption in the daily cycling or maintain them in a damp condition after removal of solution and flushing surfaces.

14. Calculations

14.1 There are no calculations involved in this procedure.

15. Report

15.1 The report shall include:

- Cementitious content, water-cementitious ratio, slump, and air content of mix.
- Curing and drying if other than standard.
- Type of surface treatment, time of application, and rate of application.
- Type of deicer, whether solution or solid, concentration of solution if used, and rate and time of application.
- Visual rating of the surface after 5, 10, 15, and 25 cycles and every 25 cycles thereafter in accordance with table 1.
- If test specimens are cut from hardened concrete, the size, shape, orientation of specimens in structure, and any other pertinent information available.
- Photographs and/or written description of surface.

15.2 No reporting form has been devised for this procedure because, in all probability, a memorandum would cover the above items.

16. Precision and Bias

16.1 In statistical analyses of data obtained using this procedure, it is necessary to recognize that the ratings are ranks, and as such may not appropriately be subjected to analyses based on the calculation of averages and standard deviations nor to other techniques that assume continuous distribution of measurement on at least an interval scale. If groups of similar specimens are to be reported or compared with other groups, such nonparametric quantities as median and range may be used.

16.2 There is no known bias.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4684-92

PROCEDURE FOR

MAKING, ACCELERATED CURING, AND TESTING OF CONCRETE COMPRESSION TEST SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4684; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 684-81.

1. Scope

1.1 This designation covers three procedures for making, curing, and testing specimens of concrete stored under conditions intended to accelerate development of strength. The choice of which procedure to use should be made by the user on the basis of experience and local conditions. The three procedures are: Procedure A–Warm Water Method, Procedure B–Boiling Water Method, and Procedure C–Autogenous Curing Method.

NOTE 1.–All material that is not designated as belonging specifically to one of the three procedures applies to all three procedures.

2. Auxiliary Tests

2.1 Establishing adequacy of insulating material to meet criteria as outlined under section 13.1.3.1 and appendix section X1.2 will be in accordance with ASTM C 177.

2.2 The measurement of slump and air content, which is a part of this procedure as referenced under sections 11.2.1.2, 12.2.1, and 13.2.1, shall be performed in accordance with USBR 4031 or 4192.

3. Applicable Documents

3.1 *USBR Procedures*:

4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory
4231 Air Content of Freshly Mixed Concrete by Pressure Method
4617 Capping Cylindrical Concrete Specimens

3.2 *ASTM Standards*:

C 177 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate[1]
C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically[2]
C 684 Standard Method of Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens[2]

4. Summary of Procedures

4.1 Concrete specimens are exposed to elevated temperatures and moisture conditions adequate to develop a significant portion of their ultimate strength within 24 to 48 hours, depending upon procedure selected. Procedures A and B utilize the storage of specimens in heated water at elevated curing temperatures without moisture loss. The primary function of the moderately heated water used in Procedure A is to serve as insulation to conserve the heat generated by hydration. The temperature level employed in Procedure B provides thermal acceleration. Procedure C involves storage of specimens in insulated curing containers in which elevated curing temperature is obtained from heat of hydration of cement. The sealed containers also prevent moisture loss. Sampling and testing methods are the same as for normally cured specimens, USBR 4172 and 4039, respectively.

4.2 Important characteristics of the three procedures are given in table 1.

5. Significance and Use

5.1 The accelerated curing procedures provide, for a particular combination of materials at earliest practical time, an indication of potential strength of the concrete. They also provide information on the variability of the production process for use in process control.

5.2 Correlation between accelerated early strength of test specimens and strength at some later age, achieved

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[1] *Annual Book of ASTM Standards*, vols. 04.06, 08.01, 14.01.

[2] *Annual Book of ASTM Standards*, vol. 04.02.

Table 1. – Brief description of three accelerated curing procedures.

Procedure	Molds	Accelerated curing medium	Accelerated curing temperature °F (°C)	Age accelerated curing begins	Duration of accelerated curing	Age at testing
A. Warm water	Reusable or single use	Water	95 (35)	Immediately after casting	23.5 hours ± 30 min	24 hours ± 15 min
B. Boiling water	Reusable or single use	Water	Boiling	23 hours ±15 min after casting	3.5 hours ± 5 min	28.5 hours ±15 min
C. Autogenous	Single use	Heat of hydration	Initial concrete temperature augmented by heat of hydration	Immediately after casting	48 hours ±15 min	49 hours ± 15 min

by conventional curing methods, depends upon the materials comprising the concrete and the specific procedure employed. Any strength value provided by companion specimens, no matter how obtained, has a dubious relation to actual strength of the concrete inplace in the structure, and has value only as an indicator of a probability that desired load-bearing capability has been or can be obtained in the structure by use of a particular formulation. Therefore, there is no fundamental reason why the accelerated early strength obtained from any one of the three procedures cannot be used in the design and evaluation of concrete strengths in the same way that conventional 28-day strengths have been used in the past, with suitable changes in the expected numbers used to describe strength values. However, since the practice of using strength values obtained from standard-cured cylinders at 28 days is long established and widespread, it is recognized that many will wish to use the results of strength tests on specimens cured by accelerated methods to make "predictions" of strength that might be obtained at later ages. Such predictions should be limited to concretes using the same materials as those used for establishing the correlation.

5.3 The ratio of accelerated strength to conventionally obtained strength of test specimens at later ages increases with cement content and initial mixture temperature.

6. Apparatus

6.1 Required equipment are listed under each of the three procedures, sections 11, 12, and 13.

7. Precautions

7.1 Precautions against scalding or eye burns from steam are covered in note 6.

8. Calibration of Equipment

8.1 *Cylinder Molds.*-The 6- by 12-inch (152- by 305-mm) molds shall be checked for compliance with USBR 4031 and ASTM C 470.

8.2 *Slump Cone.*-The slump cone shall meet the requirements of USBR 4143.

8.3 *Air Meter.*-The air meter shall be checked for compliance with USBR 4231.

8.4 *Tamping Rod.*-The tamping rod shall be checked for compliance with USBR 4143.

8.5 *Vibrators.*-Vibrators shall comply with the requirements of USBR 4031.

8.6 *Mallet.*-The mallet, with a rubber or rawhide head, shall comply with the requirements of USBR 4231.

8.7 *Thermometers*:

8.7.1 Thermometers for verifying adequacy of thermostatically controlled electrical immersion heaters, as outlined under section 11.1.3.2, shall be accepted on certification of inspection by manufacturer.

8.7.2 Maximum or minimum recording thermometers (sec. 13) shall be accepted on certification of inspection by manufacturer.

8.8 *Electrical Potentiometer.*-The electrical potentiometer, as discussed under section 13.1.3.1, shall be accepted on certification of inspection by manufacturer.

9. Conditioning

9.1 *Procedure A-Warm Water Method*:

9.1.1 Cover top of specimen with a rigid plate as outlined in section 11.2.2.1.

9.1.2 Place specimen in curing tank immediately, with water temperature at 95±5 °F (35±2.8 °C). Temperature of curing water shall not drop more than

5 °F (2.8 °C) after immersion, and shall return to 95±5 °F within 15 minutes, as outlined under section 11.2.2.2.

9.1.3 Leave specimen in curing tank for 23.5 hours ±30 minutes, remove, and demold cylinder as outlined under section 11.2.2.4.

9.1.4 Ends of specimens shall be dry enough at time of capping to preclude formation of steam or foam pockets under or in cap.

9.1.5 Specimens shall be kept in a moist condition after capping by placing them in moist storage or wrapping with a double layer of wet burlap for a minimum of 30 minutes as outlined under section 11.2.3.3.

9.1.6 Test cylinder for strength at the age of 24 hours ±15 minutes as outlined under section 11.2.3.4.

9.2 *Procedure B–Boiling Water Method*:

9.2.1 Cover specimen and store in an area where the temperature is maintained at 70±10 °F (21.1±5.5 °C), and in accordance with section 12.2.2.

9.2.2 Place covered cylinder molds in water tank 23 hours ±15 minutes after molding. The water in tank shall be boiling at time of immersion and shall be returned to a boiling state within 15 minutes after cylinders are immersed, as outlined under section 12.2.3.1.

9.2.3 Leave specimen in boiling water for 3.5 hours ± 5 minutes, remove, demold, and allow to cool for not less than 1 hour at room temperature prior to capping as outlined under section 12.2.3.3.

9.2.4 Specimens shall be kept in a moist condition after capping by placing them in moist storage or wrapping with a double layer of wet burlap for a minimum of 30 minutes.

9.2.5 Test cylinder for strength at the age of 28.5 hours ±15 minutes as outlined under section 12.2.3.4.

9.3 *Procedure C–Autogenous Method*:

9.3.1 Immediately after molding, cover mold with a metal plate or tightly fitted cap and place in a heavy-duty plastic bag with as much entrapped air expelled as possible prior to tying the bag as outlined under section 13.2.2.1.

9.3.2 Place bagged specimen in autogenous container and secure container lid.

9.3.3 For at least 12 hours after molding, container shall not be moved, jarred, or subjected to any vibration, and shall be stored out of the sun, preferably at a temperature of 70±10 °F (21.1±5.5 °C) as outlined under section 13.2.2.4.

9.3.4 At an age of 48 hours ±15 minutes after molding, remove cylinder from container, demold, and allow to stand for 30 minutes at room temperature as outlined in section 13.2.2.5.

9.3.5 Ends of specimens shall be dry enough at time of capping to preclude formation of steam or foam pockets under or in cap.

9.3.6 Specimens shall be kept in a moist condition after capping by placing them in moist storage or wrapping with a double layer of wet burlap for a minimum of 30 minutes.

9.3.7 Test cylinder for strength at the age of 49 hours ±15 minutes as outlined under section 13.2.3.

10. Sampling

10.1 Sampling shall be done in accordance with USBR 4172.

11. Procedure A–Warm Water Method

11.1 *Apparatus*:

11.1.1 Equipment and small tools for fabricating specimens, measuring slump, and determining air content shall conform to the applicable requirements of USBR 4031 or 4192.

11.1.2 *Molds*:

11.1.2.1 Molds for specimens shall conform to the requirements for cylinder molds in USBR 4031 or 4192, except that cardboard molds shall not be used.

11.1.2.2 Single-use, light gauge, metal molds with lids shall conform to requirements of ASTM C 470.

11.1.2.3 When test specimens are to be used without capping, reusable molds having machined plates which can be securely connected to both top and bottom of mold shall be used. These plates shall provide bearing surfaces plane within 0.002 inch (0.05 mm), and shall also ensure that neither end of cylinder (when prepared for testing) shall depart from perpendicularity to the axis of specimen by more than 0.25° (approximately equivalent to 1/16 inch in 12 inches (1.6 mm in 305 mm). The mold assembly shall be sufficiently tight to permit filled mold to be turned from vertical filling position to a horizontal curing position without loss of mortar or damage to test specimen.

11.1.3 *Accelerated Curing Tank*:

11.1.3.1 The curing tank may be of any configuration suitable for number of cylinders to be tested, and cylinders may be arranged in any configuration provided a clearance of at least 2 inches (51 mm) between side of cylinder and side of tank and at least 4 inches (102 mm) between adjacent cylinders is maintained.

NOTE 2.–A number of different tanks have been used successfully; guidelines are shown in appendix X1.

11.1.3.2 The curing tank shall be capable of providing the specified water temperature. The temperature at any point in the water shall be maintained within ±5 °F (±2.8 °C) of that specified. Depending upon design features of tank and whether it is to be capable of use for Procedure B as well as Procedure A, insulation or mechanical agitation, or both, might be necessary to meet the specified temperature requirements. Electrical immersion heaters controlled by a thermostat are the most suitable form of heating elements (note 3). Thermometers or other temperature recording devices shall be used, independent of the thermostat, to check temperature of water.

NOTE 3.–For a particular procedure, the size of heating element required will depend upon size of tank and number of cylinders to be tested at one time. For controlling temperature, some household thermostats may be satisfactory but generally they are not sufficiently sensitive.

11.1.3.3 The plate supporting the cylinders shall have sufficient open perforations so as not to interfere with circulation of water.

11.1.3.4 A lid shall be provided when tank is to be capable of use for Procedure B as well as Procedure A. The water level shall be checked periodically and maintained at 4 inches (102 mm) above top of cylinders.

NOTE 4.-Provision for an overflow pipe is a convenience in controlling maximum depth of water.

11.2 *Procedure*:

11.2.1 *Preparation of Test Specimens*:

11.2.1.1 Take samples of concrete for test specimens in accordance with USBR 4172. Record location where sampled batch is used in structure.

11.2.1.2 Measure slump and air content, and mold specimens as required in USBR 4031 or 4192.

11.2.1.3 Test specimens shall conform to requirements for 6- by 12-inch (152- by 305-mm) cylinders in USBR 4031 or 4192.

11.2.2 *Curing*:

11.2.2.1 Cover top of specimen with a rigid plate to prevent loss of mortar to water bath (note 5).

11.2.2.2 Immediately place specimen into curing tank (note 5). The water at time of immersion and throughout the curing period shall be 95±5 °F (35±2.8 °C). Temperature of curing water after immersion of cylinders shall not drop more than 5 °F (2.8 °C) and shall return to 95±5 °F within 15 minutes.

11.2.2.3 Temperature of curing water should be continuously recorded or periodically measured throughout curing period.

11.2.2.4 After curing for 23.5 hours ±30 minutes, remove cylinder from tank and demold.

NOTE 5.-If cylinders are cast in molds meeting requirements of 11.1.2.3, they may be stored horizontally; otherwise, they are to be stored in curing tank with long axis vertical.

11.2.3 *Capping and Testing*:

11.2.3.1 Ends of specimens that are not plane within 0.002 inch (0.05 mm) or which depart from perpendicularity to center axis by more than 0.25° (approximately equivalent to 1/16 inch in 12 inches) (1.6 mm in 305 mm) shall be capped as specified in USBR 4617.

11.2.3.2 When tested in accordance with provisions of USBR 4617, capping material shall develop, at the age of 30 minutes, a strength equal to or greater than strength of cylinders to be tested.

11.2.3.3 Do not test specimens prior to 30 minutes after capping.

11.2.3.4 Test cylinder for strength at the age of 24 hours ±15 minutes in accordance with requirements of USBR 4039.

11.2.3.5 Figure 1 shows a typical data form.

12. Procedure B-Boiling Water Method

12.1 *Apparatus*:

12.1.1 The requirements for small tools and molds are the same as those stated in sections 11.1.1 and 11.1.2.

12.1.2 The curing tank shall conform to the requirements specified in section 11.1.3.

NOTE 6.-*Caution*. The use of boiling water imposes the need for safety measures to prevent scalding or eye burns resulting from the sudden escape of steam upon opening the cover and immersion of or dropping cylinders into the boiling water. Lifting tongs are suggested.

12.2 *Procedure*:

12.2.1 *Preparation of Test Specimens*.-Specimens shall be prepared in accordance with section 11.2.1.

12.2.2 *Initial Curing*.-Cover cylinder to prevent loss of moisture, and store so that cylinders will not be disturbed or subjected to vibration or jarring. In storage area, temperature adjacent to cylinders shall be maintained at 70±10 °F (21.1±5.5 °C). Protection and storage shall conform to requirements of USBR 4031 or 4192.

NOTE 7.-Strict attention to the protection and storage of cylinder during this initial period is necessary for meaningful results because of brief total curing period.

12.2.3 *Accelerated Curing*:

12.2.3.1 Place covered cylinder molds in water tank 23 hours ±15 minutes after molding. Water shall be boiling at time of immersion and throughout curing period (notes 5 and 8). Within 15 minutes after cylinders are immersed, water shall be returned to boiling.

NOTE 8.-In confined places, temperature of water may be kept just below boiling point to avoid excessive evaporation. The temperature at which water boils varies because of differences in elevation above sea level. Differences in strengths caused by these differences in temperature are not believed to be significant, but comparison of results among areas so affected should be supported by appropriate correlations and interpreted with the knowledge of the temperature variations.

12.2.3.2 Temperature of curing water should be continuously recorded, or measured at regular intervals throughout the curing period.

12.2.3.3 After curing for 3.5 hours ±5 minutes, remove cylinder from boiling water, remove mold, and allow cylinder to cool for not less than 1 hour at room temperature prior to capping.

12.2.3.4 *Capping and Testing*.-Cap and test cylinders in accordance with 11.2.3 except that age at time of test shall be 28.5 hours ±15 minutes.

12.2.3.5 Figure 1 shows a typical data form.

13. Procedure C-Autogenous Method

13.1 *Apparatus*:

13.1.1 The requirements for small tools and molds (note 9) are the same as those stated in sections 11.1.1 and 11.1.2.

13.1.2 *Autogenous Container*:

13.1.2.1 The autogenous container shall consist of thermal insulation that closely surrounds the concrete test cylinder and meets the heat retention requirements of 13.1.3.1.

13.1.2.2 The container shall be capable of being opened to permit insertion and withdrawal of mold containing test cylinder, and shall have an outer casing and an inner liner to prevent mechanical damage to insulating material.

NOTE 9.–Metal, reusable molds with end plates and clamps may be impracticable; consideration should be given to disposable molds. Cardboard molds shall not be used. All molds shall conform to requirements for cylinder molds in USBR 4031 or 4192.

13.1.2.3 The container shall have, as an integral part, devices capable of continuously monitoring minimum and maximum temperatures of test cylinder enclosed within.

13.1.2.4 Provision shall be made to keep container securely closed, and shall incorporate a resilient gasket-type heat seal.

NOTE 10.–Any configuration or method of container construction is acceptable providing container meets the requirements of 13.1.2 and 13.1.3. Information on suitable containers is included in appendix X1.

13.1.3 *Proving Test Requirements*:

13.1.3.1 *Heat Retention*.–Place a mold, for which the autogenous container has been designed, into container. If mold is not intrinsically watertight, a plastic bag may be used inside the mold to achieve watertightness. Fill mold to within 0.25 inch (6 mm) of top with water heated to 180 °F (82 °C). Insert a temperature sensing device into water to verify temperature and record reading. Remove temperature sensing device and close mold with a tight fitting cap, or close plastic bag liner securely. Then, close autogenous container. Store container in still air at 70±2 °F (21.1±1.1 °C) and compare temperature changes of water, using temperature sensing devices built into container (note 11), with the following tabulation:

Elapsed time, hours	° *F*	° *C*
12	152±5	67±3
24	136±6	58±3
48	114±7	45±4
72	100±8	38±4

NOTE 11.–The presumption is made that, at elapsed times shown in the tabulation, the temperature inside the mold is the same as the temperature just outside the mold.

13.1.3.2 *Tightness Test for Gasket-Type Heat Seal*.–When autogenous container is immersed in water to a depth of 6 inches (152 mm) above the joint between separable parts, no air shall escape through the heat seal within 5 minutes.

13.1.3.3 *Stability of Autogenous Container*.–The autogenous container, or any part thereof, shall not display embrittlement, fracturing, or distortion when maintained at an ambient temperature of −20 °F (−29 °C) for 72 hours, nor any softening or distortion when maintained at an ambient temperature of 140 °F (60 °C) for 72 hours. The gasket-type heat seal shall immediately fully recover its original thickness after 50 percent compression under these temperature conditions.

13.2 *Procedure*:

13.2.1 *Preparation of Test Specimens*.–Prepare specimens in accordance with section 11.2.1.

13.2.2 *Curing*:

13.2.2.1 Immediately after molding, cover mold with a moisture-tight plastic cap or place mold in a heavy duty plastic bag from which as much of the entrapped air as possible is expelled prior to tying neck of bag (using plastic bag and cap acceptable). The plastic bag should be of sufficient density and strength to resist punctures and serve as a lifting device for placing and removing test specimen from autogenous container.

13.2.2.2 Ensure the maximum-minimum temperature sensing devices are operating (reset if necessary) and secure autogenous container lid after specimen is in place.

13.2.2.3 Record time of molding to nearest 15 minutes and temperature of fresh concrete clearly on outside of container.

13.2.2.4 For at least 12 hours after molding, autogenous container shall not be moved, disturbed, or subjected to vibration or jarring, and shall be stored out of the sun, preferably at a temperature of 70±10 °F (21.1±5.5 °C).

13.2.2.5 At the age of 48 hours ±15 minutes after cylinder was molded, remove cylinder from autogenous container and demold. Allow to stand for 30 minutes at room temperature.

13.2.2.6 Record maximum and minimum temperatures in the container as indicated from the temperature sensing device.

NOTE 12.–Comparison of maximum and minimum temperatures with recorded temperature of fresh concrete will provide an indication of abnormal or interrupted curing, which may cause high or low strength results.

13.2.3 *Capping and Testing*.–Cap and test cylinders in accordance with 11.2.3 except that age at time of test shall be 49 hours ±15 minutes.

NOTE 13.–Capping and testing may be performed at ages different from those specified in 11.2.3. For convenience, some agencies have established relationships between test results at 24, 72, and 96 hours with those obtained by standard moist curing. However, at 24 hours, the relationship is less satisfactory than those obtained by accelerated autogenous curing for 48, 72, or 96 hours. Where the curing period is other than that specified in 13.2.2, the age at testing should be the curing period plus 1 hour. The tolerance of ±15 minutes would still apply.

13.2.4 Figure 1 shows a typical data form.

14. Interpretation of Results

14.1 Strength requirements in existing specifications and codes are not based upon accelerated curing; therefore, use of results from these procedures for the prediction of specification compliance of strengths at later ages must be applied with caution. As stated in section 16, variability of the procedures is the same or less than that from traditional methods. Thus, results can be used in rapid assessment of variability for process control and signaling the need for indicated adjustments. However, the magnitude of the strength values obtained is influenced by the specific combination of materials so that use of results from either conventional tests at any arbitrary age or those from these procedures must be supported by experience or correlations developed by the specific agency for the existing local conditions and materials. Factors influencing relationships between measured strengths and those of concrete inplace are no different from those affecting conventional strength tests.

15. Report

15.1 Figure 1 may also serve as a reporting form when used as an attachment to a cover letter. The report shall include:

- Identification number.
- Diameter (and length, if not standard), in inches (millimeters).
- Cross-sectional area, in square inches (square millimeters).
- Maximum load, in pounds-force (newtons).
- Compressive strength calculated to nearest 10 $\mathrm{lbf/in^2}$ or 0.05 MPa.
- Type of fracture, if other than usual cone.
- Defects in either specimen or caps.
- Age of specimens.
- Accelerated curing method used.
- Initial mix temperature to nearest °F (°C).
- Maximum and minimum temperature to nearest °F (°C) if Procedure C used.
- Method of transportation used for shipping specimens to laboratory.
- Ambient temperature of specimen or container during storage for Procedures B and C.

16. Precision and Bias

16.1 The single-laboratory coefficient of variation has been determined as 3.6 percent for a pair of cylinders cast from same batch. Therefore, results of two properly conducted strength tests by same laboratory on two individual cylinders made with same materials should not differ by more than 10 percent of their average.

16.2 The single-laboratory, multiday coefficient of variation has been determined as 8.7 percent for the average of pairs of cylinders cast from single batches mixed on 2 days. Therefore, results of two properly conducted strength tests each consisting of the average of two cylinders from same batch made in same laboratory on same materials should not differ by more than 25 percent of their average.

16.3 There is no currently known bias for this procedure.

Spec. or Solic. No. RESEARCH	Structure NONE	Tested by K. FORBES N. JOHNSON — Date 3-1 TO 3-29-84
Project NONE	Item ACC. CURING & COMP. DET. VS STD. LAB CURING Location DENVER LAB	Computed by K. FORBES — Date 3-1 TO 3-29-84
Feature NONE	Station ~ Offset ~ Depth ~ to ~	Checked by N. JOHNSON — Date 3-1 TO 3-29-84

MAKING, ACCELERATED CURING, AND TESTING OF CONCRETE COMPRESSION TEST SPECIMENS

Mix Ident.: CC 3345-3 : MSA 1½ inches ~~(mm)~~, 1½ to ¾ inches ~~(mm)~~ 35.5 %, ¾ to No.4 inches ~~(mm)~~ 31.5 %; Sand 33 %; Cement 414 lbm ~~(kg)~~, Pozzolan 103 lbm ~~(kg)~~, Water 233 lbm ~~(kg)~~, W/(C+P) Ratio 0.45, Slump 3 inches ~~(mm)~~, Air Content 5.0 %, Mix Temp. 67 °F ~~(°C)~~

Procedure	A, B, & C	B & C		A & B	A & B	A & B	B	A	C	A, B, & C		C	
		Conditioning Room During Immersion		Temperature of Curing Water						Temp. Range		Autogenous Container Heat Retainer	
Cylinder No.	Time at Completion of Molding	Before °F ~~(°C)~~	After °F ~~(°C)~~	At Time of Immersion °F ~~(°C)~~	Immed. After Immersion °F ~~(°C)~~	15 Min. After Immersion °F ~~(°C)~~	3.5 Hours ± 5 Min. °F ~~(°C)~~	23.5 Hours ± 30 Min. °F ~~(°C)~~	48 Hours ± 15 Min. °F ~~(°C)~~	Minimum °F ~~(°C)~~	Maximum °F ~~(°C)~~	Time, hours	Temp., °F ~~(°C)~~
1A	8:00 a.m.			97	85	95		96		85	97	12	155
1B	│	70	70	212	180	212	212			180	212	24	140
1C	│	70	70						107	67	107	48	117
1D	│											72	100
1E	│												
1F	│												
1G	↓												

Cylinder No.	D Diameter, inches ~~(mm)~~	L Length, inches ~~(mm)~~	L/D Ratio	Area $\pi D^2/4$, in² ~~(mm²)~~	Capping Time and Date	Break Time and Date	Break Age	Curing Method	Total Load, lbf ~~(kN)~~	Comp. Strength, lbf/in² ~~(MPa)~~	Type of Fracture	Remarks
1A	6	12	2.0	28.27	7:35am 3/2	8:05am 3/2	24 HRS 5 MIN	PROCED. A	46,650	1,650	CONE & SPLIT	SOME BREAK. AROUND AGG
1B	│	│	│	│	11:30am 3/2	12:00 Noon 3/2	28 HRS 0 MIN	PROCED. B	81,150	2,870	CONE & SHEAR	
1C	│	│	│	│	8:40am 3/3	9:10am 3/3	49 HRS 10 MIN	PROCED. C	77,200	2,730	CONE	
1D	│	│	│	│	7:30am 3/8	8:00am 3/8	7 DAYS	6-DAY FOG	80,300	2,840	CONE	
1E	│	│	│	│	7:30am 3/15	8:00am 3/15	14 DAYS	13-DAY FOG	107,700	3,810	CONE	
1F	│	│	│	│	7:30am 3/29	8:00am 3/29	28 DAYS	27-DAY FOG	132,000	4,670	CONE	
1G	↓	↓	↓	↓	7:35am 3/29	8:05am 3/29	28 DAYS	27-DAY FOG	132,300	4,680	CONE	

Figure 1. – Typical data and calculation form.

APPENDIX

X1. CURING APPARATUS
(Nonmandatory Information)

X1.1 Accelerated Curing Tank

X1.1.1 Curing tanks similar to the tank shown on figure X1.1 have been used successfully.

X1.1.2 Properly designed cabinets will ensure an almost uniform temperature throughout the curing tank without the need for a mechanical stirrer. The immersion heaters should be located centrally in plan, as near to bottom of tank as possible. The water above the heater will then be kept in circulation by convection currents.

X1.1.3 For a tank containing two or three cylinders, two coupled elements (1500 and 5000 W) have been found suitable for use with Procedure B. While smaller elements will maintain specified curing, the larger element is required as a booster to reestablish boiling within specified time after cylinders have been immersed. Where the tank is to be used only for Procedure A, the above heaters are also suitable; however, a single element (3000 W) has also been found to be suitable. With the 3000-W element, the tank, when used for Procedure A, may be of larger dimensions to hold more than two or three cylinders.

X1.1.4 The overflow pipe, closely fitting lid, and exterior insulation are not essential for curing tanks used only for Procedure A.

X1.2 Autogenous Curing Container

X1.2.1 A heat seal is required at the joint face between the separable parts of the container. This may be a labyrinth or a gasket-type seal, provided the requirements of 13.1.3.1, 13.1.3.2, and 13.1.3.3 are met. A suitable gasket is flexible polyurethane foam, 2 lbm/ft^3 (32 kg/m^3), maintained when closed at 50 percent compression.

X1.2.2 Foamed-in-place, closed-cell polyurethane having a density between 2 and 3 lbm/ft^3 (32 and 48 kg/m^3) and a thermal conductivity equal to or less than 0.15 Btu·in/(h·ft^2· °F) (0.02 W/(m·K)), in accordance with ASTM C 177, has been found to be a suitable insulating material at the thicknesses specified to meet the heat retention requirements of section 13.1.3.1.

X1.2.3 The maximum-minimum thermometer, if used, should cover a range from 20 to 150 °F (-7 to 66 °C) in 1° increments.

X1.2.4 A typical autogenous curing container is shown on figure X1.2.

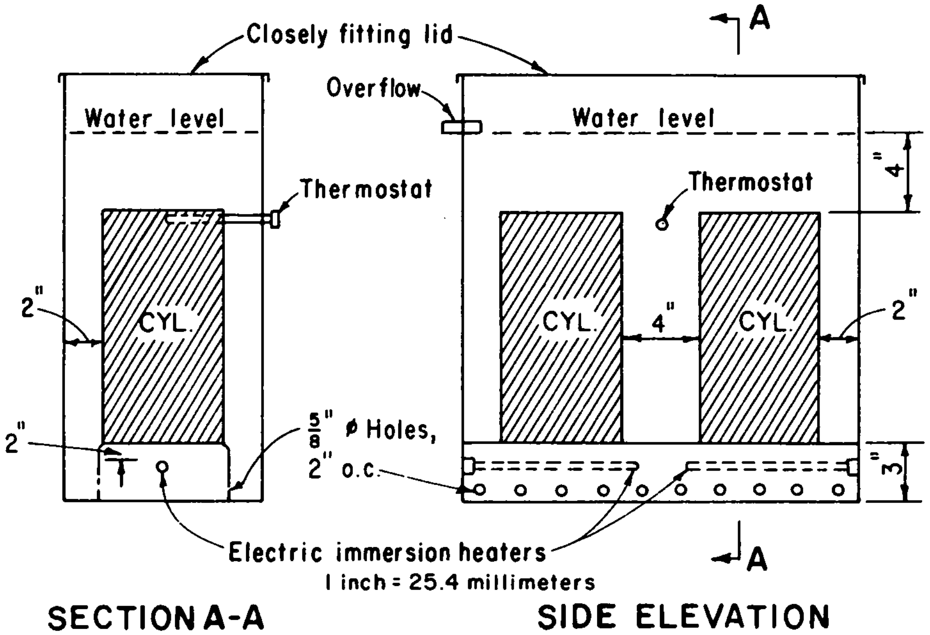

Figure X1.1. - Accelerated curing water tank.

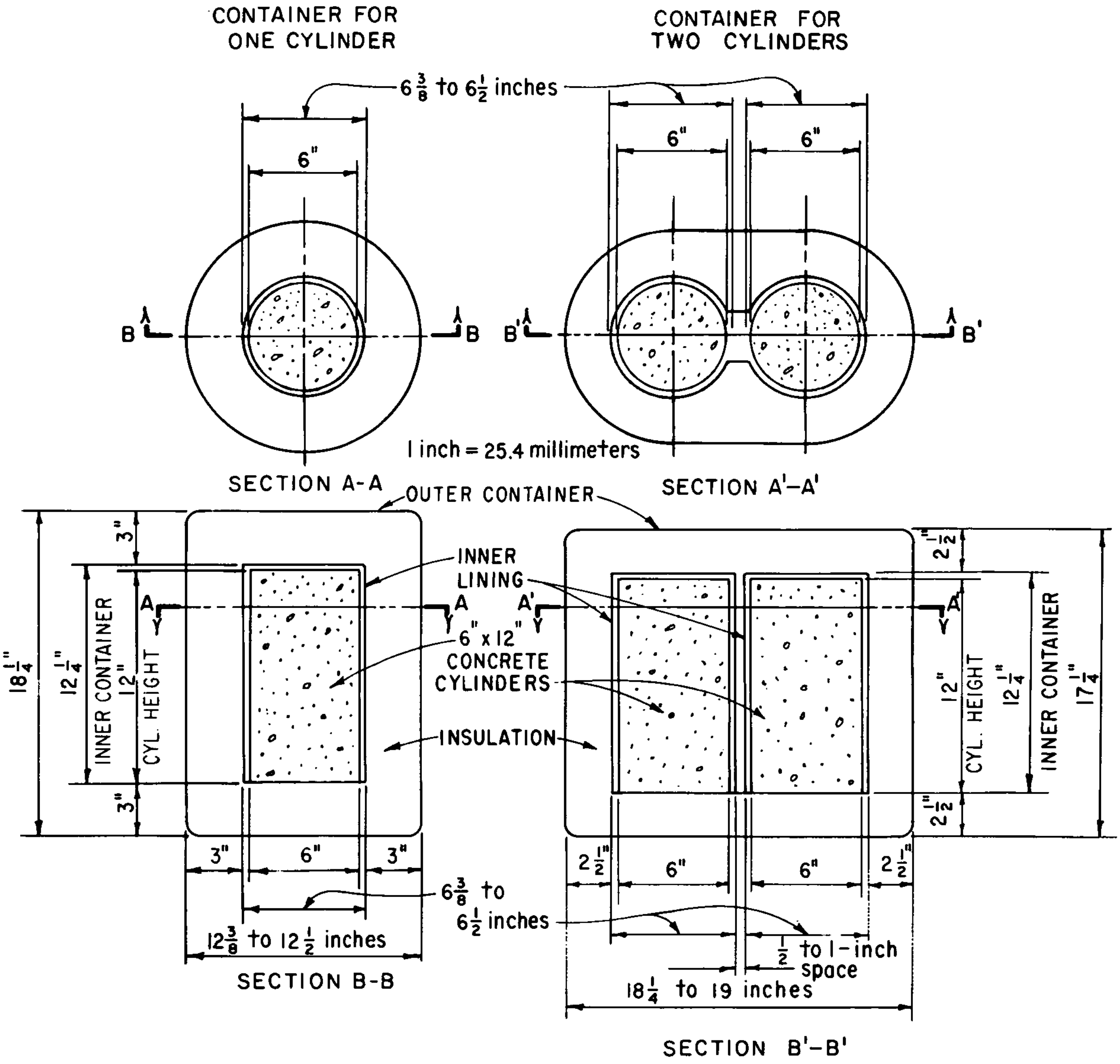

Figure X1.2. – Autogenous curing container for one or two cylinders (basic requirements).

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4702-92

PROCEDURE FOR

REDUCING FIELD SAMPLES OF AGGREGATE TO TESTING SIZE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4702; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 702-80.

1. Scope

1.1 This designation covers procedures for the reduction of field samples of aggregate to the appropriate size for testing by employing techniques that are intended to minimize variations in measured characteristics between test samples so selected and the field sample.

2. Applicable Documents

2.1 *USBR Procedures*:
4075 Sampling Aggregates
4128 Specific Gravity and Absorption of Fine Aggregate
2.2 *ASTM Standard*:
C 702 Standard Methods for Reducing Field Samples of Aggregate to Testing Size[1]

3. Significance and Use

3.1 Specifications for aggregates require sampling portions of the material for testing. Other factors being equal, larger samples will tend to be more representative of total supply. These procedures provide for reducing the large sample obtained in the field to a smaller, more convenient size for conducting a number of tests to describe the material and measure its quality in such a manner that smaller portion is most likely to be an excellent representation of field sample, and thus of total supply. The individual test methods provide for a minimum mass of material to be tested.

3.2 Under certain circumstances, reduction of the field sample size prior to testing is not recommended. Substantial differences between selected test samples sometimes cannot be avoided. For example, a certain aggregate might have relatively few large-size particles in the field sample, and these few particles may be unequally distributed among reduced-sized test samples. Similarly, if test sample is being examined for certain contaminants occurring as a few discrete fragments in only small percentages, caution should be used in interpreting results from a reduced-sized sample. Chance inclusion or exclusion of only one or two particles in the selected sample may incorrectly influence interpretation of characteristics of field sample. In these cases, entire field sample should be tested.

4. Selection of Method

4.1 *Fine Aggregate*.–Field samples of fine aggregate that are drier than the saturated-surface-dry condition (note 1) shall be reduced in size by a mechanical splitter according to method A (sec. 9). Field samples having free moisture on the particle surfaces may be reduced in size by quartering according to method B (sec. 10), or by treating as a miniature stockpile as described in method C (sec. 11).

4.1.1 If use of method B or C is desired and field sample does not have free moisture on particle surfaces, sample may be moistened to achieve this condition, thoroughly mixed, and sample reduction performed.

4.1.2 If use of method A is desired and field sample has free moisture on particle surfaces, entire field sample may be dried to at least the surface-dry condition, using temperatures that do not exceed those specified for any of the tests contemplated, and sample reduction then performed. Alternatively, if moist field sample is very large, a preliminary split may be made using a mechanical splitter having wide chute openings of 1-1/2 inches (38 mm) or more to reduce sample to not less than 11 lbm (5000 g). The portion so obtained is then dried, and reduction to test sample size is completed using method A.

NOTE 1.–In the size reduction of field samples for testing purposes, the loss of dust and fine particles must be avoided when splitting, quartering, or other handling of samples. The moisture condition of sample is very important if desired representative test samples are to be obtained. The SSD (saturated-surface-dry) condition is defined as the condition of aggregate particles when their permeable pores are filled with water and no water is present on exposed surfaces. Free or surface moisture is water carried on surfaces of aggregate particles and not contained in the pores as absorbed water. Fine aggregate particles will cling together when free moisture is present. In

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

the SSD condition, fine aggregate particles no longer cling together but will have just reached the free-flowing state without any moisture present to dampen the surfaces of a sample splitter and impede the flow as sample is fed to splitter chutes. When using quartering method, some free moisture on particle surfaces is desirable to avoid loss of fines. Methods of determining the SSD condition are described in USBR 4128. As a quick approximation, if the fine aggregate will retain its shape when molded in the hand, it may be considered to be wetter than SSD.

4.2 *Coarse Aggregates and Mixtures of Coarse and Fine Aggregates.*-Reduce sample using a mechanical splitter in accordance with method A (preferred method) or by quartering in accordance with method B. The miniature stockpile (method C) is not permitted for coarse aggregates or mixtures of coarse and fine aggregates.

5. Precautions

5.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6. Sampling

6.1 The field sample of aggregate shall be taken in accordance with USBR 4075, or as required by individual test methods. When tests for sieve analysis only are contemplated, the size of the field sample listed in USBR 4075 is usually adequate. When additional tests are to be conducted, the user shall determine how large the field sample should be to accomplish all intended tests.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

8. Conditioning

8.1 The only conditioning involved in these methods would be as discussed under sections 4.1.1 and 4.1.2.

9. Method A-Mechanical Splitter

9.1 *Apparatus*:

9.1.1 *Sample Splitter.*-Sample splitters shall have an even number of equal-width chutes, but not less than 8 for coarse aggregate or 12 for fine aggregate, which discharge alternately on each side of splitter. The minimum width of individual chutes shall be about 50 percent larger than largest particles in sample to be split (note 2). The splitter shall be equipped with two receptacles to hold the two halves of sample following splitting. Splitter shall also be equipped with a hopper or straightedged pan, which has a width equal to or slightly less than overall width of assembly of chutes, by which sample may be fed at a controlled rate to chutes. The splitter and accessory equipment shall be so designed that sample will flow smoothly without restriction or loss of material, see figure 1.

NOTE 2.-Mechanical splitters for dividing samples into representative halves are commonly available in sizes adequate for coarse aggregate having the largest particle not over 1-1/2 inches (37.5 mm). For fine aggregate, a splitter having 1/2-inch (13-mm) wide chutes will be satisfactory when entire sample will pass a 3/8-inch (9.5-mm) sieve. Mechanical splitters can be fabricated to divide samples into other than halves (e.g., one-quarter size fractions, three-quarter and one-quarter size fractions, etc.) provided samples obtained as the result of the size reduction process are representative of original field sample.

9.2 *Procedure.*-Place field sample in hopper or pan and uniformly distribute it from edge to edge so that when it is introduced into chutes, approximately equal amounts will flow through each chute. The rate sample is introduced shall be such as to allow free flowing through chutes into receptacles below. Reintroduce portion of sample in one receptacle into splitter as many times as necessary to reduce sample to size specified for intended test. The portion of material collected in the other receptacle may be reserved for reduction in size for other tests.

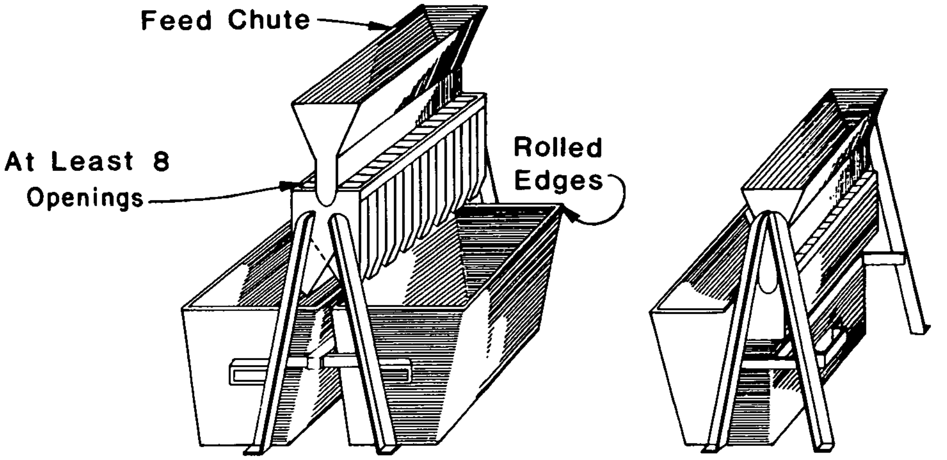
10. Method B-Quartering

10.1 *Apparatus.*-The apparatus shall consist of a straightedged scoop, shovel, or trowel; broom or brush; and a canvas blanket about 6 by 8 feet (2 by 2.5 m).

10.2 *Procedure.*-Use either the procedure described in section 10.2.1 or 10.2.2, or combination of both.

10.2.1 Place field sample on a hard, clean, level surface where there will be neither loss of material nor accidental addition of foreign material. Mix material thoroughly by turning entire sample over three times. With last turning, shovel entire sample into a conical pile by depositing each shovelful on top of preceding one. Carefully flatten conical pile to a uniform thickness and diameter by pressing down on apex with a shovel so that each quarter sector of the resulting pile will contain the material originally in it. The diameter should be about four to eight times the thickness. Divide flattened mass into four equal quarters with a shovel or trowel and remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean. Successively mix and quarter remaining material until sample is reduced to desired size (fig. 2).

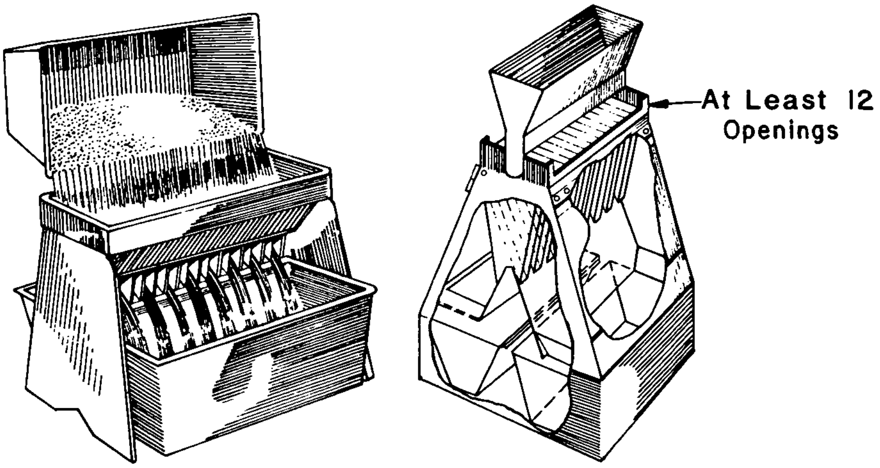
10.2.2 As an alternative to the method described in section 10.2.1 for when floor surface is uneven, the field sample may be placed on a canvas blanket and mixed with a shovel as described in 10.2.1, or by alternately lifting each corner of the blanket and pulling it over sample toward diagonally opposite corners causing material to be rolled.



Riffle Sample Splitter

Riffle Bucket and Separate Feed Chute Stand

(a) Large Riffle Samplers for Course Aggregate



Note–May be constructed as either closed or open type. Closed type is preferred.

(b) Small Riffle Sampler for Fine Aggregate

Figure 1. – Typical sample splitters..

Flatten and divide sample as described in 10.2.1, or if surface beneath blanket is uneven, insert a pipe or pole of some kind beneath blanket and under center of pile and then lift both ends of pipe, dividing sample into two equal parts. Remove pipe, leaving a fold of the blanket between divided portions. Insert pipe under center of pile, at right angles to first division, and again lift both ends of pipe, dividing sample into four equal parts. Remove two diagonally opposite quarters, being careful to clean fines from blanket. Successively mix and quarter remaining material until sample is reduced to desired size (fig. 3).

11. Method C–Miniature Stockpile Sampling

11.1 Method C is for damp, fine aggregate sampling only.

11.2 *Apparatus.*–The apparatus shall consist of a straightedged scoop, shovel, or trowel for mixing aggregate; and either a small sampling thief, small scoop, or spoon for sampling.

11.3 *Procedure.*–Place field sample of damp, fine aggregate on a hard, clean, level surface where there will be neither loss of material nor accidental addition of foreign material. Mix material thoroughly by turning entire sample over three times. With last turning, shovel entire sample into a conical pile by depositing each shovelful on top of preceding one. If desired, conical pile may be flattened to a uniform thickness and diameter by pressing down on apex with a shovel so that each quarter sector of resulting pile will contain material originally in it. Obtain a sample for each test by selecting at least five increments of material at random locations from miniature stockpile, using any of the sampling devices described in section 11.2.

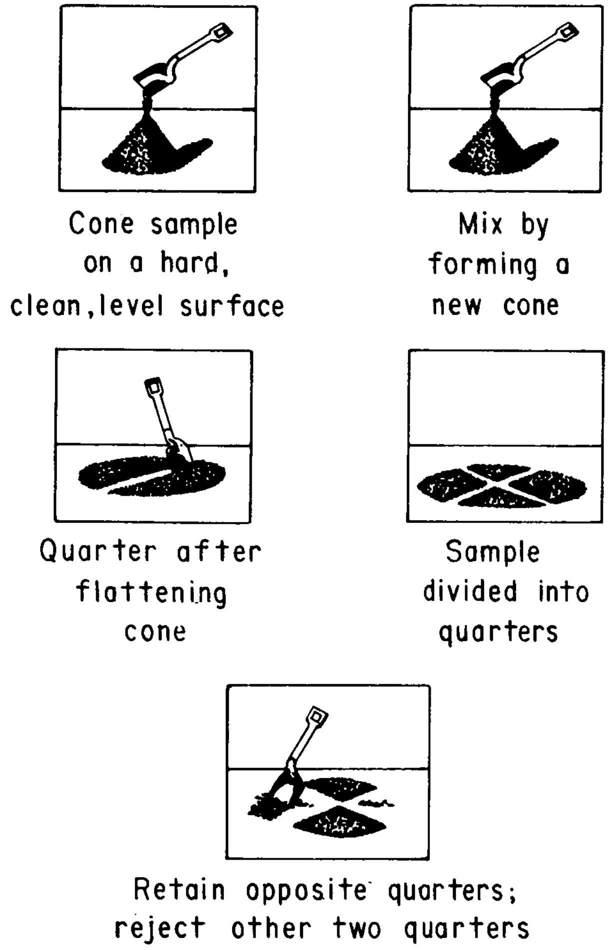


Figure 2. – Quartering a field sample on a hard, clean, level surface.

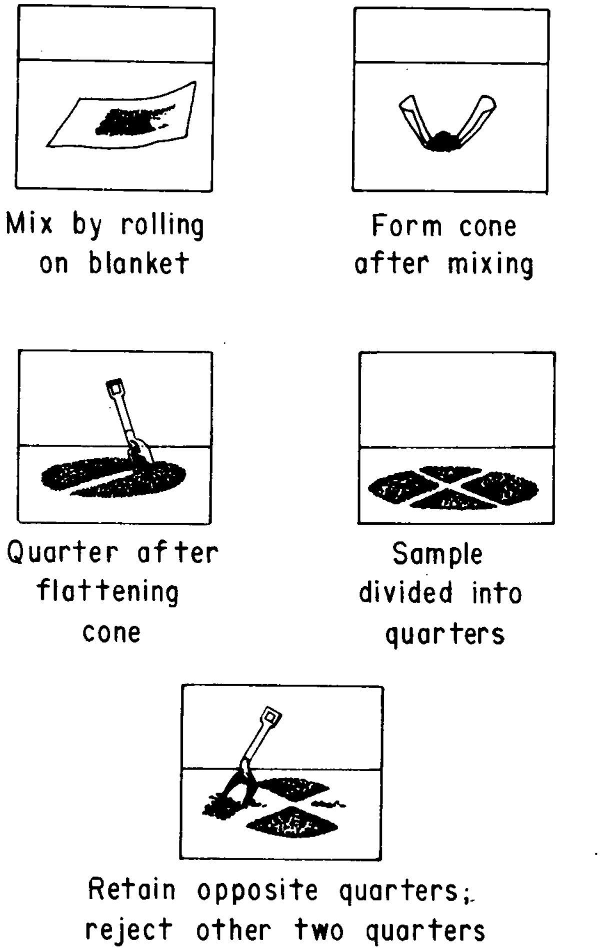


Figure 3. – Quartering a field sample on a canvas blanket.

12. Calculations

12.1 No calculations are involved in this procedure.

13. Report

13.1 No report is necessary for this procedure.

14. Precision and Accuracy

14.1 Since this procedure produces no numerical test results, determination of precision is not possible. However, failure to carefully follow the methods described herein could result in providing a biased sample to be used in subsequent testing.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4803-92

PROCEDURE FOR

PENETRATION RESISTANCE OF HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4803; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 803-82.

1. Scope

1.1 This designation covers the procedure for determination of resistance of hardened concrete to penetration by steel probes energized by a driving unit delivering a stated amount of energy. The penetration resistance of the concrete is determined by measuring exposed portion of probes.

2. Applicable Documents

2.1 *USBR Procedure*:
1000 Standards for Linear Measurement Devices
2.2 *ASTM Standards*:
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]
C 803 Standard Test Method for Penetration Resistance of Hardened Concrete[2]
2.3 *ANSI Standard*:
A 10.3 Safety Requirements for Powder Actuated Fastening Systems[3]

3. Summary of Procedure

3.1 A driving unit delivers a known amount of energy to several steel probes. The penetration resistance of the concrete is determined by measuring the exposed lengths of probes which have been driven into the concrete.

4. Significance and Use

4.1 This procedure may be used to assess uniformity of concrete, delineate zones of poor quality or deteriorated concrete in structures, and indicate strength development of concrete. This procedure is not an alternative for strength determination of concrete; however, it may be used as a supplement to strength determination.

4.2 For a given concrete and a given test apparatus, a relationship between penetration resistance and strength may be established and used to assess the inplace concrete strength. Such a relationship may change with curing and exposure conditions, type and size of aggregate, and level of strength developed in concrete.

NOTE 1.-Penetration resistance test results have been correlated with results of strength tests of drilled cores taken from same structure. The statistical correlation studies and additional penetration tests have then been used as the basis for estimating core strength of similar concrete in other locations in structure. References [1,2,3,4][4] describe procedures used and results obtained in such tests.

5. Apparatus

5.1 *Driving Unit.*-The driving unit shall be capable of driving probes into the concrete with an accurately controlled amount of energy so that probes will remain embedded for measurement of projecting portion.

NOTE 2.-A powder-actuated device has been successfully used.

5.1.1 For a specified energy loading, variation of the velocity of standard probes propelled by driving unit shall not have a coefficient of variation greater than 3 percent for any 10 specimen tests made by accepted ballistic methods.

NOTE 3.-A conventional counter chronograph and appropriate ballistic screens may be used to measure velocity 6.5 feet (or 2.0 m) from end of driving unit.

5.2 *Probe.*[5]-Each probe shall be a hardened alloy-steel device, cadmium- or zinc-plated, with a blunt conical end that can be inserted into driver unit and driven into concrete surface in such a manner that probe will remain firmly embedded so that length of projecting portion can be

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.
[4] Numbers in brackets refer to entries in References, section 14.
[5] Probes are available from Densicon, Inc., 371 Welton St., Hamden, CT 06511.

measured (note 4). Exposed end of probe shall be threaded to accommodate accessories designated to facilitate measurement and withdrawal (note 5).

NOTE 4.–Probes of 3-1/8-inch (79.4-mm) overall length and 5/16-inch (7.94-mm) diameter, with penetrating end diameter reduced to 1/4 inch (6.35 mm) for about 9/16 inch (14 mm) in length (sometimes described commercially as the Silver Probe Kit) have been found satisfactory for testing concrete having a density of 125 lbm/ft^3 (2002 kg/m^3) or greater. For concrete having a density less than 125 lbm/ft^3, use the same diameter and length of probe but without the penetrating end reduction (sometimes described commercially as the Gold Probe Kit). A change in section or shoulder for the probe has been found to be helpful in preventing rebound after setting.

NOTE 5.–If probes are to be removed from concrete, a device consisting of a nut that can be screwed onto end of probe and spacers that can be slipped over probe for nut to bear against will serve to remove probes.

5.3 *Measuring Equipment*:

5.3.1 A measuring instrument such as a vernier caliper, depth gauge, or other measuring device; and associated equipment that will permit measurement of exposed length of probe to nearest 0.025 inch (or 0.5 mm) is required.

5.3.2 Measuring equipment shall include a reference baseplate or other device which is supported on concrete surface at three equally spaced points at least 2 inches (51 mm) from probe to be measured.

NOTE 6.–The reference baseplate shall have a hole in it so that baseplate can be slipped over probe and rest firmly on surface of concrete. To hold baseplate against surface of concrete when measurements in a horizontal direction or in the bottom of an overhead concrete surface are being made, a plate retainer consisting of a spring and a nut that can be screwed onto threaded end of probe may be used.

5.4 *Positioning Device.*–A device to be placed on surface of concrete for positioning and guiding probe and driver unit during firing.

5.5 *Holding Device.*–A device for holding 6- by 12-inch (152- by 305-mm) concrete cylinders, furnished by some suppliers, is called a Vee Press for probe testing cylinders. The cylinders may also be probed by initiating a load with the compression testing machine.

NOTE 8.–This may be a single-positioning device (fig. 1) or a triangular device with holes at the three corners to permit firing of three probes in a triangular pattern.

NOTE 9.–A type of driving unit described as a Windsor Probe, furnished by some suppliers, includes a scratch hardness kit for identifying the Mohs Hardness for aggregate. This scale is rated as softest at (1) to hardest at (10). Identifiers are as follows:

(1) Talc
(2) Gypsum
(3) Calc-spar or Calcite
(4) Fluorspar or Fluorite
(5) Apatite
(6) Feldspar
(7) Quartz
(8) Topaz
(9) Sapphire or Corundum
(10) Diamond

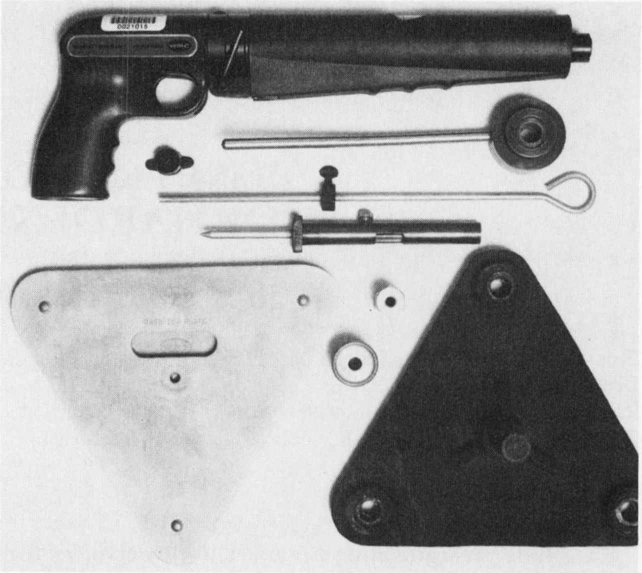


Figure 1. – Single-positioning device.

Minerals less than 2.5 on the scale will leave a mark on paper. Helpful identifiers are as follows:

2.5: equivalent to a fingernail
3.0: equivalent to a copper coin
5.5: equivalent to a knife blade or window glass
6.5: equivalent to a steel file

A table or graph is furnished with the driving unit that compares the exposed length of probe to a compressive strength based on the Mohs Hardness Scale in the range of Mohs Hardness Nos. 3 through 7. Within this range, one unit of Mohs Hardness can vary from 350 to 915 lbf/in^2 (2.41 to 6.31 MPa). Consequently, the Bureau does not use the table or graph but establishes its own calibration curves.

6. Precautions

6.1 These test procedures may involve hazardous materials, operations, and equipment, and do not claim to address all safety problems associated with their use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 Care shall be exercised in the operation of any ballistic device to ensure against unexpected or inadvertent discharge, or propulsion of a probe into free flight with its attendant danger.

6.3 The driving unit shall incorporate features to prevent firing when not properly placed in positioning device on concrete surface.

6.4 Personnel shall wear safety goggles and other appropriate protective attire when such devices are being used.

6.5 The driving unit, if powder actuated, shall conform to applicable requirements of ANSI Standard A 10.3.

7. Test Area Location

7.1 The concrete to be tested must have reached a sufficient degree of resistance to penetration so that probe will not penetrate more than one-half the thickness of the concrete, but will remain firmly embedded. No probe shall be located less than 7 inches (178 mm) from any other probe nor less than 4 inches (102 mm) from edge of a concrete surface.

7.2 A minimum of three firmly embedded test probes in a given test area shall constitute one test.

NOTE 10.-Number of tests to be made depends on intended use of results.

8. Calibration and Standardization

8.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

8.2 Calibrate the measuring equipment in accordance with USBR 1000.

8.3 The calibration curves for the penetration resistance that compares the exposed length of probe to a compressive strength need to be developed. These curves may be developed by several different methods:

- On cylinders fabricated from a mix representing the structure to be investigated, either standard laboratory cure or field cure.
- On cylinders fabricated from a mix representing a test slab for purposes of providing replicate cores and/or cubes for providing test readings as well as those physically broken in a compression machine.
- On the structure itself from which cores may be taken; the cores will also be subjected to both methods of compressive strength determinations.

8.4 Refer to figures 2 and 3 for typical calibration data and curves.

9. Conditioning

9.1 The concrete surface should be reasonably smooth. Surfaces coarser than a broom finish shall be stoned or ground over an area larger than that which will be covered by positioning device and measuring baseplate.

10. Procedure

10.1 Place positioning device on surface of concrete at location to be tested. Mount a probe in driving unit, position driver and probe in positioning device, and fire or otherwise drive probe into concrete following directions supplied with driving unit.

10.2 Remove positioning device and tap probe on its exposed end for firmness of embedment and to ensure it has not rebounded. Reject any probe that is not firmly embedded.

10.3 Place measuring baseplate over probe and position plate so that it bears firmly on surface of concrete without rocking or other movement. If surface of concrete has been raised around base of probe, the crushed concrete shall be removed to allow reference plate to lie flat. Install probe measuring cap and plate retainer, as appropriate, and measure distance from reference plate to end of probe or to upper surface of measuring cap to nearest 0.025 inch (or 0.5 mm). If probe is slanted with respect to surface of concrete, make four measurements equally spaced around and parallel to probe and average them to get measurement.

10.4 Provision shall be made to decrease amount of energy delivered to probe by driving unit or to increase dimensions of probe when tests are to be made on concrete having a density less than 125 lbm/ft^3 (2002 kg/m^3) or a strength less than 2,500 lbf/in^2 (17.2 MPa).

11. Calculations

11.1 Figures 2 and 4 show typical calculation forms.

12. Report

12.1 Figure 4 may also be used as a typical reporting form. The report shall include:

- Driving unit identification and energy level used
- Structure identification
- Location of test area
- Description of test area
- Description of concrete including type of aggregate and surface finishing technique
- Approximate thickness of concrete tested
- Dimensions of probes
- Exposed length of all probes
- Description of all other pertinent test conditions including probes rejected for data analysis

13. Precision and Bias

13.1 The precision of probe measurements has been found to vary with the maximum size of coarse aggregate. The indexes of precision shown in table 1 apply to measurements on same concrete, made with same materials, procedures, equipment, and curing conditions which are obtained by a single operator using same instrument.

13.2 The bias for this procedure has not been established.

14. References

[1] Arni, H.T., *Impact and Penetration Tests of Portland Cement Concrete*, Report No. FHWA-RD-73-5, Federal Highway Administration, Offices of Research and Development, Washington, DC, 1973.

[2] Bowers, D.G.G., *Assessment of Various Methods of Test for Concrete Strength*,Connecticut Department of Transportation/Federal Highway Administration, available from National Technical Information Service, NTIS No. PB 296317, Springfield, VA, December 1978.

[3] Malhotra, V.M., *Testing Hardened Concrete: Nondestructive Methods*, ACI Monograph No. 9, Iowa State University Press/ACI, Detroit, MI, 1976.

[4] Strong, H., *In-Place Testing of Hardened Concrete With the Use of the Windsor Probe*, Idaho Test Method T-128-79.

Table 1. - Precision[1].

Maximum size of aggregate	1S Limit,[2] inch (mm)	Maximum range of three individual measurements,[3] inch (mm)	D2S Limit,[4] inch (mm)	Maximum difference between two averages of three measurements,[5] inch (mm)
No. 4 (4.75 mm) (mortar)	0.08 (2.0)	0.26 (6.6)	0.23 (5.8)	0.13 (3.3)
1 inch (25.0 mm)	0.10 (2.5)	0.33 (8.4)	0.28 (7.1)	0.16 (4.1)
2 inches (50 mm)	0.14 (3.6)	0.46 (11.7)	0.40 (10.2)	0.22 (5.6)

[1] These values represent indexes of precision as described in ASTM C 670.

[2] These values are single-operator standard deviations for concrete made with maximum size aggregate shown in column 1.

[3] These values are maximum allowable ranges for groups of three individual measurements made close together, either as individual measurements or by using triangular positioning device. If range of three measurements exceeds limit given, measurements should not be averaged. In this case, a fourth probe should be fired and the one that deviates the most from the average of the four measurements should be discarded. If the three remaining measurements still do not meet limit given, device should be moved to a different area and three new measurements should be made.

[4] These values are maximum difference between two individual measurements (D2S limits). These indexes should not be used if measurements are being obtained in groups of three and averaged.

[5] A difference larger than values given indicates a high probability that there is a significant difference in the concrete in the two areas represented by the two groups of three measurements each.

PENETRATION RESISTANCE OF HARDENED CONCRETE

Instrument Ident.: Driver Unit Model WINDSOR 532CF-1 , ☒ Single Probe Locating Template ☐ Triple Probe Locating Unit
Direction of Test VERTICALLY DOWNWARD, Thickness of Structure 6 inches ~~(mm)~~
Finish: ☒ Form ☐ Screed ☐ Wood Float ☐ Steel Trowel ☐ Broom ☐ Ground

Mix Ident.: FP2650-3A(4½"), Design Strength (f'_c) 3,000 lbf/in² ~~(MPa)~~, Req'd. Strength (f_{cr}) at 28 days 3,560 lbf/in² ~~(MPa)~~
Cement: TYPE II LA, IDEAL, PORTLAND, CO, 470 lbm/yd³ ~~(kg/m³)~~, Specific gravity 3.15
Pozzolan: CLASS F, LADUE, MO , 94 lbm/yd³ ~~(kg/m³)~~, Specific gravity 2.50
Sand: 26 %, Specific Gravity 2.65 , FOUNTAIN SAND & GRAVEL, PUEBLO, CO
Aggregate: 27 %, No. 4 to 3/4 inch ~~(mm)~~, Sp. Gr. 2.63 ; 27 %, 3/4 to 1½ inch ~~(mm)~~, Sp. Gr. 2.61
25 %, 1½ to 3 inch ~~(mm)~~, Sp. Gr. 2.60 ; 24 %, 3 to 4½ inch ~~(mm)~~, Sp. Gr. 2.60
MSA 4½ inch ~~(mm)~~; WRA PDA-25
Mix Properties: Density, minus 1½ inch ~~(mm)~~ 145.2 lbm/ft³ ~~(kg/m³)~~, Total Mix 148.6 lbm/ft³ ~~(kg/m³)~~
Air Content, minus 1½ inch ~~(mm)~~ 3.9 %
Total Mix 3.6 %, W/(C + P) 0.50 ; Mohs Hardness 5 TO 7
Temp.: Ambient 70 °F ~~(°C)~~, Concrete 73 °F ~~(°C)~~, Moisture Condition: 24 HOURS IN HEAT-CONTROLLED MOLD—REST STD. LAB CURE

Age 3 Hours [✓ Days] Months Years				
Power Load Breech Plug ☒ Yes ☐ No Probe Kit: ☐ Silver ☒ Gold				
12 x 24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in² ~~(MPa)~~	
	Ind.	Avg.	Ind.	Avg.
CYL.				
1A	1.125		1,200	
1B	1.100		1,160	
1C	1.150		1,230	
		1.125		1,200
1D	1.150		1,330	
1E	1.175		1,500	
1F	1.150		1,330	
		1.158		1,390

Age 7 Hours [✓ Days] Months Years				
Power Load Breech Plug ☒ Yes ☐ No Probe Kit: ☒ Silver ☐ Gold				
12 x 24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in² ~~(MPa)~~	
	Ind.	Avg.	Ind.	Avg.
CYL.				
2A	1.325		1,750	
2B	1.350		1,870	
2C	1.325		1,730	
		1.335		1,780

Age 14 Hours [✓ Days] Months Years				
Power Load Breech Plug ☒ Yes ☐ No Probe Kit: ☒ Silver ☐ Gold				
12 x 24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in² ~~(MPa)~~	
	Ind.	Avg.	Ind.	Avg.
CYL.				
3A	1.425		2,450	
3B	1.425		2,550	
3C	1.400		2,360	
		1.415		2,450

Age 28 Hours [✓ Days] Months Years				
Power Load Breech Plug ☐ Yes ☒ No Probe Kit: ☒ Silver ☐ Gold				
12 x 24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in² ~~(MPa)~~	
	Ind.	Avg.	Ind.	Avg.
CYL.				
4A	1.775		3,550	
4B	1.775		3,690	
4C	1.750		3,420	
		1.767		3,550

Figure 2. - Calibration and utilization of Windsor Probe (sheet 1 of 2).

PENETRATION RESISTANCE OF HARDENED CONCRETE																			
Age 90 Hours [✓ Days] Months Years					Age 180 Hours [✓ Days] Months Years					Age 1 Hours Days Months [✓ Years]					Age ___ Hours Days Months Years				
Power Load Breech Plug ☐ Yes ☒ No Probe Kit: ☒ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☒ No Probe Kit: ☒ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☒ No Probe Kit: ☒ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☐ No Probe Kit: ☐ Silver ☐ Gold				
12x24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in^2 ~~(MPa)~~		12x24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in^2 ~~(MPa)~~		12x24 Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in^2 ~~(MPa)~~		Test Ident.	Exposed Probe inches (mm)		Press Strength lbf/in^2 (MPa)	
	Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.
CYL.					CYL.					CYL.									
5A	1.850		4,240		6A	1.950		5,030		7A	1.975		5,270						
5B	1.850		4,130		6B	1.925		4,810		7B	1.975		5,210						
5C	1.825		4,000		6C	1.950		4,900		7C	1.975		5,130						
		1.842		4,120			1.940		4,910			1.975		5,200					

Figure 2. – Calibration and utilization of Windsor Probe (sheet 2 of 2).

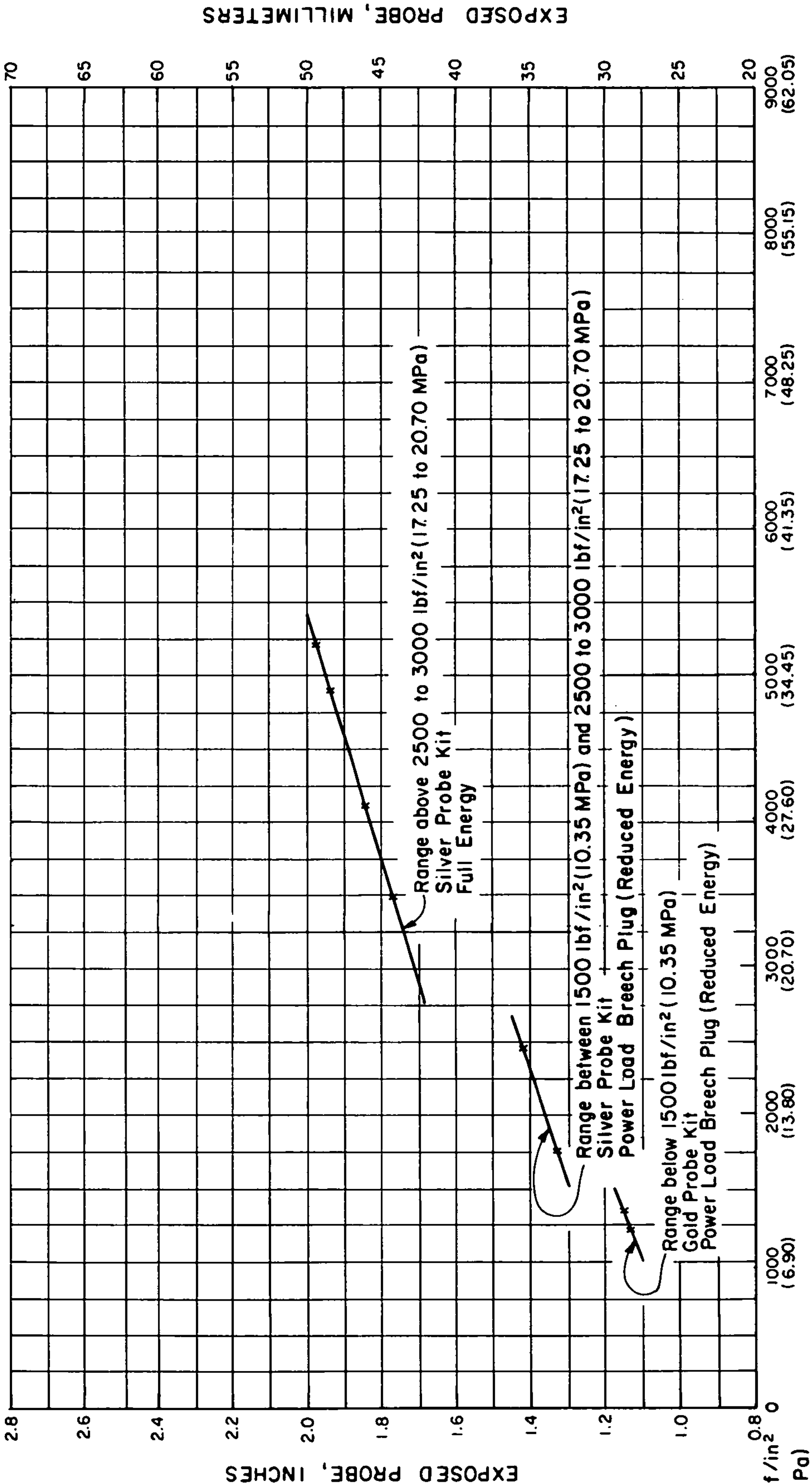
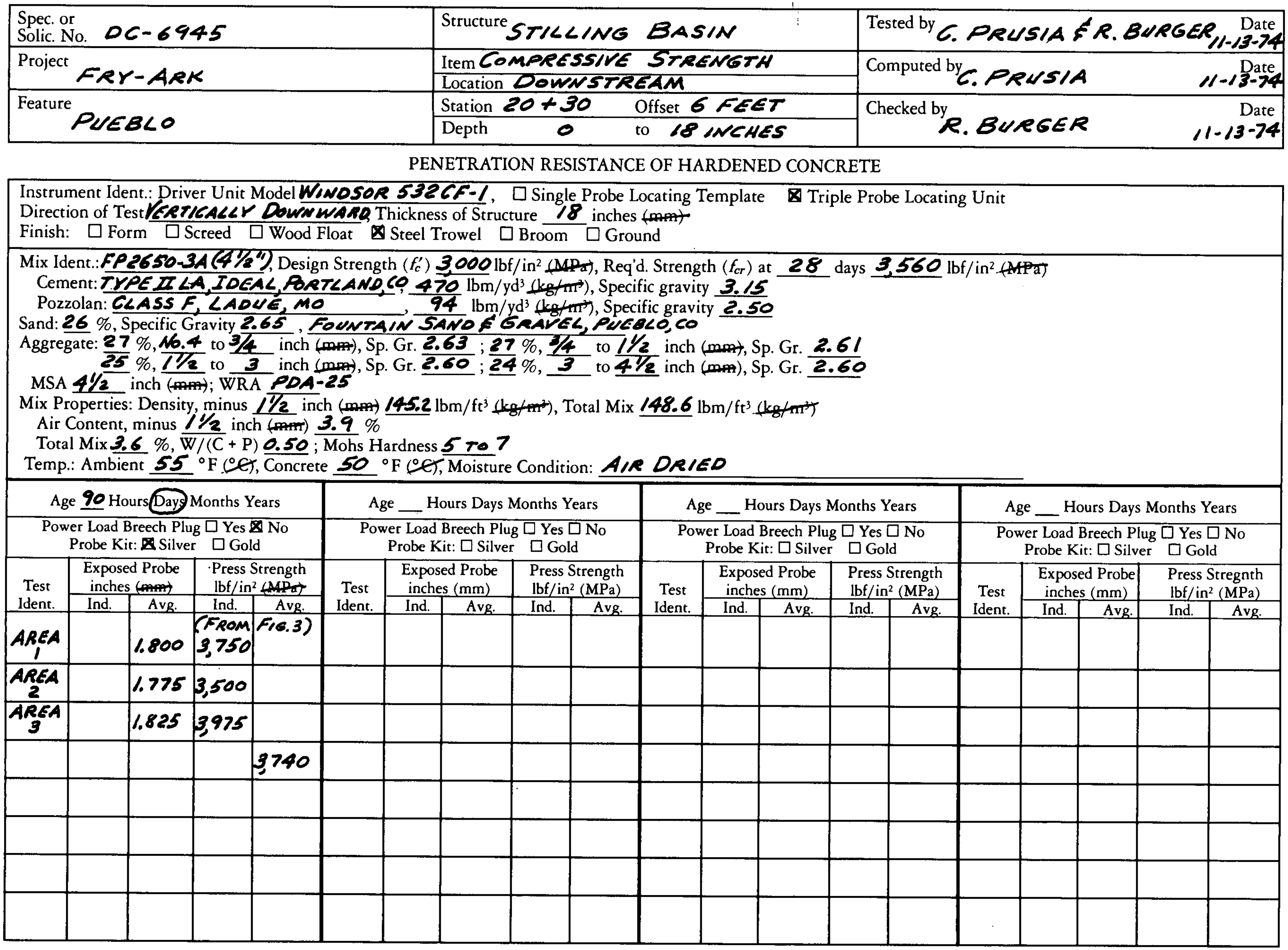


Figure 3. – Typical calibration curve.



Spec. or Solic. No. DC-6945	Structure STILLING BASIN	Tested by C. PRUSIA & R. BURGER Date 11-13-74
Project FRY-ARK	Item COMPRESSIVE STRENGTH Location DOWNSTREAM	Computed by C. PRUSIA Date 11-13-74
Feature PUEBLO	Station 20+30 Offset 6 FEET Depth 0 to 18 INCHES	Checked by R. BURGER Date 11-13-74

PENETRATION RESISTANCE OF HARDENED CONCRETE

Instrument Ident.: Driver Unit Model WINDSOR 532CF-1, ☐ Single Probe Locating Template ☒ Triple Probe Locating Unit
Direction of Test VERTICALLY DOWNWARD Thickness of Structure 18 inches ~~(mm)~~
Finish: ☐ Form ☐ Screed ☐ Wood Float ☒ Steel Trowel ☐ Broom ☐ Ground

Mix Ident.: FP2650-3A (4½"), Design Strength (f'_c) 3,000 lbf/in^2 ~~(MPa)~~, Req'd. Strength (f_{cr}) at 28 days 3,560 lbf/in^2 ~~(MPa)~~
Cement: TYPE II LA, IDEAL, PORTLAND, CO 470 lbm/yd^3 ~~(kg/m^3)~~, Specific gravity 3.15
Pozzolan: CLASS F, LADUE, MO, 94 lbm/yd^3 ~~(kg/m^3)~~, Specific gravity 2.50
Sand: 26 %, Specific Gravity 2.65, FOUNTAIN SAND & GRAVEL, PUEBLO, CO
Aggregate: 27 %, No. 4 to ¾ inch ~~(mm)~~, Sp. Gr. 2.63 ; 27 %, ¾ to 1½ inch ~~(mm)~~, Sp. Gr. 2.61
25 %, 1½ to 3 inch ~~(mm)~~, Sp. Gr. 2.60 ; 24 %, 3 to 4½ inch ~~(mm)~~, Sp. Gr. 2.60
MSA 4½ inch ~~(mm)~~; WRA PDA-25
Mix Properties: Density, minus 1½ inch ~~(mm)~~ 145.2 lbm/ft^3 ~~(kg/m^3)~~, Total Mix 148.6 lbm/ft^3 ~~(kg/m^3)~~
Air Content, minus 1½ inch ~~(mm)~~ 3.9 %
Total Mix 3.6 %, W/(C + P) 0.50 ; Mohs Hardness 5 TO 7
Temp.: Ambient 55 °F ~~(°C)~~, Concrete 50 °F ~~(°C)~~, Moisture Condition: AIR DRIED

Age 90 Hours [✓ Days] Months Years					Age ___ Hours Days Months Years					Age ___ Hours Days Months Years					Age ___ Hours Days Months Years				
Power Load Breech Plug ☐ Yes ☒ No Probe Kit: ☒ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☐ No Probe Kit: ☐ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☐ No Probe Kit: ☐ Silver ☐ Gold					Power Load Breech Plug ☐ Yes ☐ No Probe Kit: ☐ Silver ☐ Gold				
Test Ident.	Exposed Probe inches ~~(mm)~~		Press Strength lbf/in^2 ~~(MPa)~~		Test Ident.	Exposed Probe inches (mm)		Press Strength lbf/in^2 (MPa)		Test Ident.	Exposed Probe inches (mm)		Press Strength lbf/in^2 (MPa)		Test Ident.	Exposed Probe inches (mm)		Press Stregnth lbf/in^2 (MPa)	
	Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.		Ind.	Avg.	Ind.	Avg.
AREA 1		1.800	(FROM 3,750	FIG. 3)															
AREA 2		1.775	3,500																
AREA 3		1.825	3,975																
				3,740															

Figure 4. – Relative compressive strength by Windsor Probe.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4805-92

PROCEDURE FOR

REBOUND NUMBER OF HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4805; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 805-79.

1. Scope

1.1 This designation covers a procedure for determination of a rebound number for hardened concrete using a spring-driven steel hammer.

2. Applicable Documents

2.1 *ASTM Standards*:
C 805 Standard Test Method for Rebound Number of Hardened Concrete[1]
E 177 Standard Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[2]

3. Significance

3.1 The rebound number determined by this procedure may be used to assess uniformity of inplace concrete, delineate zones or regions (areas) of poor quality or deteriorated concrete in structures, and to indicate changes with time in characteristics of concrete such as those caused by hydration of cement, which provides useful information for determining when forms and shoring may be removed.

3.2 This procedure is not intended as an alternative for strength determination of concrete.

4. Apparatus

4.1 *Rebound Hammer*.-The rebound hammer consists of a spring-loaded steel hammer which, when released, strikes a steel plunger in contact with concrete surface. The hammer must travel with a fixed and reproducible velocity. The rebound distance of the hammer from the steel plunger is measured on a linear scale attached to frame of instrument. Figure 1 shows a typical device.

NOTE 1.-Several types and sizes of rebound hammers are commercially available to accommodate testing of various sizes and types of concrete construction. One known source is Schmidt Test Hammers, Inc., 502 North Tacoma Avenue, Tacoma, WA 98403.

4.2 *Abrasive Stone*.-Consists of medium-grain texture, silicon carbide or equivalent material.

5. Test Area

5.1 *Selection of Test Surface*.-Concrete members to be tested shall be at least 4 inches (102 mm) thick, or fixed within a structure. Smaller specimens must be rigidly supported. Areas exhibiting honeycombing, scaling, rough texture, or high porosity should be avoided. Concretes should be about the same age and have about the same moisture condition to be compared. Dry concretes have higher rebound numbers than wet concrete, and the surface layer of concrete may be carbonated, yielding higher rebound numbers [1].[3] The form material against which concrete was placed should be similar (note 2). Troweled surfaces generally exhibit higher rebound numbers than screeded or formed finishes. If possible, structural slabs should be tested from underside to avoid finished surfaces.

NOTE 2.-Where formed surfaces were ground, overall increases in rebound numbers of 2.1 for plywood formed members and 0.4 for high-density plywood formed surfaces have been noted [2].

6. Precautions

6.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Calibration and Standardization

7.1 Rebound hammers require periodic servicing and verification: semiannually for hammers in heavy use, annually for hammers used less frequently, or whenever there is reason to question a hammer's proper operation. Metal anvils are available for verification and are recommended. However, verification on an anvil will not guarantee that different hammers will yield same results at other points on rebound scale. Some users compare

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 14.02.

[3] Numbers in brackets refer to entries in References, section 14.

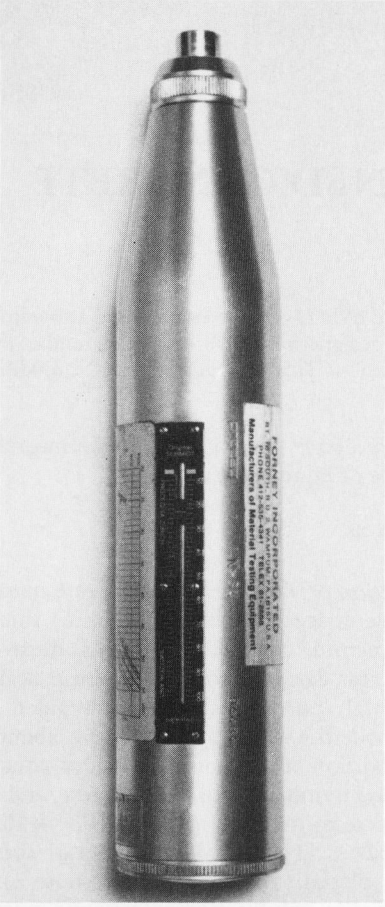

Figure 1. - Concrete test hammer.

several hammers on concrete surfaces encompassing the usual range of rebound values encountered in field.

8. Conditioning

8.1 The test area shall be at least 6 inches (152 mm) in diameter. Heavily textured, soft, or surfaces with loose mortar shall be ground smooth with abrasive stone described in section 4.2. Surfaces coated with curing compounds or other sealants should be scraped to remove all soft coating. Smooth-formed or troweled surfaces shall be tested without grinding. The effect of drying and carbonation can be minimized by thoroughly wetting surfaces for 24 hours prior to testing. Concretes over 6 months old may require grinding to a depth of 1/4 inch (6 mm) if they are to be compared to markedly younger concretes. Grinding to this depth is not feasible without power equipment. An automobile body shop grinder works well for these situations. Ground and unground surfaces should not be compared.

8.2 Other factors that may affect results of test are as follows:

8.2.1 Concrete at 32 °F (0 °C), or less, may exhibit very high rebound values. Concrete should be tested only after if has thawed.

8.2.2 Temperatures of rebound hammer itself may affect rebound number.

NOTE 3.–Rebound hammers at 0 °F (–18 °C) may exhibit rebound numbers reduced by as much as 2 or 3 [3].

8.2.3 For readings to be compared, the direction of impact (horizontal, downward, upward, etc.) must be the same.

8.2.4 Different hammers of same nominal design may give rebound numbers differing from 1 to 3 units and therefore, tests should be made with same hammer to compare results. If more than one hammer is to be used, a sufficient number of tests must be made on typical concrete surfaces to determine magnitude of differences to be expected.

9. Procedure

9.1 Firmly hold instrument in a position that allows plunger to strike perpendicularly to surface tested. Gradually increase pressure on plunger until hammer impacts. After impact, record rebound number to two significant digits. Take 10 readings from each test area. No two impact tests shall be closer together than 1 inch (25 mm). Examine impression made on surface after impact, and disregard reading if impact crushes or breaks through a near-surface air void.

10. Calculation

10.1 Discard readings differing from the average of 10 readings by more than 7 units and determine average of remaining readings. If more than two readings differ from the average by 7 units, discard entire set of readings.

10.2 Figure 2 shows a typical calculation form.

11. Use and Interpretation of Rebound Hammer Results

11.1 Rebound numbers should be correlated with core testing information. Due to the difficulty of acquiring appropriate correlational data in a given instance, the rebound hammer is most useful for rapidly surveying large areas of similar concretes in the construction under consideration.

12. Report

12.1 Figure 2 may also serve as a reporting form. The report shall include the following information for each test area:

- Structure identification.
- Location of test area.
- Description of test area, e.g., wood-floated surface, dry, and ground with abrasion stone.
- Description of concrete:

  (a) Composition, if known, such as aggregates, cement content, water-cement ratio, air content, and admixtures used;

(b) Design strength;
(c) Age;
(d) Curing conditions and any unusual conditions related to test area; and
(e) Type of forms used for test area, if known or discernible.

- Average rebound number for each test area.
- Values and locations of discarded rebound numbers.
- Hammer type and serial number.

13. Precision and Bias

13.1 The single-specimen, single-operator, machine, day precision is 2.5 units, (1S) as defined in ASTM E 177.

13.2 There is no known bias.

14. References

[1] Zoldners, N. G., "Calibration and Use of Impact Test Hammer," *Proceedings*, American Concrete Institute, vol. 54, pp. 161-165, August 1957.

[2] Gaynor, R. D., "In-Place Strength of Concrete-A Comparison of Two Test Systems," and "Appendix to Series 193," National Ready Mixed Concrete Association, TIL No. 272, November 1959.

[3] National Ready Mixed Concrete Association, TIL No. 260, April 1968.

Spec. or Solic. No. DC-6945	Structure STILLING BASIN	Tested by C. PRUSIA R. BURGER — Date 11-13-74
Project FRY-ARK	Item COMPRESSIVE STRENGTH Location DOWNSTREAM	Computed by C. PRUSIA — Date 11-13-74
Feature PUEBLO DAM	Station 20+30 Offset 6 FEET Depth 0 to 18 INCHES	Checked by R. BURGER — Date 11-13-74

REBOUND NUMBER OF HARDENED CONCRETE

Instrument Identification: IMPACT HAMMER ; Model: SCHMIDT CT320, NO. 1 ; Thickness of Structure 18 inches ~~(mm)~~
Finish: ☐ Form, Type ____ ☐ Screed ☐ Wood Float ☒ Steel Trowel ☐ Broom ☐ Ground
Direction of Test: VERTICALLY DOWNWARD

Mix Ident.: FP2650-3A (4.5 INCHES), Design Strength (f_c') 3,000 lbf/in² ~~(MPa)~~, Req'd. Strength (f_{cr}) at 28 days 3,560 lbf/in² ~~(MPa)~~
Cement: TYPE II LA, IDEAL-PORTLAND, CO, 470 lbm/yd³ ~~(kg/m³)~~, Specific Gravity 3.15
Pozzolan: CLASS F-LADUE, MO, 94 lbm/yd³ ~~(kg/m³)~~, Specific Gravity 2.50
Sand: 26 %, Specific Gravity 2.65, FOUNTAIN SAND & GRAVEL, PUEBLO, CO
Aggregate: 27 %, NO. 4 to 3/4 inch ~~(mm)~~, Specific Gravity 2.63 ; 27 %, 3/4 to 1½ inch ~~(mm)~~, Specific Gravity 2.61 ;
25 %, 1½ to 3 inch ~~(mm)~~, Specific Gravity 2.60 ; 24 %, 3 to 4½ inch ~~(mm)~~, Specific Gravity 2.60
MSA 4½ inches ~~(mm)~~; WRA PDA-25
Mix Properties: Density, minus 1½ inches ~~(mm)~~ 145.2, Total Mix 148.6 lbm/ft³ ~~(kg/m³)~~; Air Content, minus 1½ inches ~~(mm)~~ 3.9 %,
Total Mix 3.6 %, W/(C + P) 0.50 ; Mohs Hardness NA ; Temp.: Ambient 55 °F ~~(°C)~~, Concrete 50 °F ~~(°C)~~
Moisture Condition: AIR DRIED

Impact Number	Area No. 1			Area No. 2			Area No.			Area No.		
	Reading	Reading	Reading	Reading	Reading	Reading	Reading	Reading	Reading	Reading	Reading	Reading
1	20 OUT	25	29	29	27	26 OUT						
2	26	22	28	35	39	36						
3	30	25	30	29	41 OUT	44 OUT						
4	22	30	27	31	28	34						
5	28	28	26	35	39	42						
6	35 OUT	22	33	41	28	38						
7	28	23	29	31	37	30						
8	33	30	30	35	30	32						
9	24	23	27	41	31	40						
10	27	28	28	35	29	28						
Total	273	256	287	342	329	350	CONTROL AREA 2 33.7 AVG					
Avg. of 10	27.3	25.6	28.7	34.2	32.9	35.0	QUESTIONABLE AREA 1 27.2 AVG					
Avg. of 3		27.2			34.0			DIFF.	6.5	FROM MFTR'S. GRAPH, THIS IS ABOUT 1,200 lbf/in² LESS		
Avg. of X	8/27.3	10/25.6	10/28.7	10/34.2	9/32.0	8/35.0						

Figure 2. – Relative compressive strength by the Schmidt impact hammer.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4823-92

PROCEDURE FOR

EXAMINATION AND SAMPLING OF HARDENED CONCRETE IN CONSTRUCTION

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730,Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4823; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 823-83.

1. Scope

1.1 This designation outlines procedures for visual examination and sampling of hardened concrete in construction. Reference is made to the examination and sampling of concrete in prefabricated building units, precast products, and laboratory specimens.

NOTE 1.-The procedures are not directly applicable to inplace concrete that does not harden in a normal manner or that is observed not to develop strength sufficient to allow removal of forms or temporary supports or to sustain required loads. Under such circumstances, actions to be taken are dictated by considerations for safety and requirements for continuation of construction operations.

2. Applicable Documents

2.1 *USBR Procedures*:

4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4215 Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens
4295 Petrographic Examination of Aggregate for Concrete
4457 Microscopical Determination of Air-Void Content and Parameters of Air-Void System in Hardened Concrete
4597 Pulse Velocity Through Concrete
4803 Penetration Resistance of Hardened Concrete
4805 Rebound Number of Hardened Concrete
4856 Petrographic Examination of Hardened Concrete

2.2 *ASTM Standards*:

C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]
C 823 Standard Practice for Examination and Sampling of Hardened Concrete in Constructions[2]
E 105 Standard Recommended Practice for Probability Sampling of Materials[3]
E 122 Standard Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process[3]
E 141 Standard Recommended Practice for Acceptance of Evidence Based on the Results of Probability Sampling[3]

2.3 *ACI Publications*:

ACI 201.1R Guide for Making a Condition Survey of Concrete in Service[4]

3. Significance and Use

3.1 The examination may provide a basis for planning the inplace testing of the concrete.

3.2 The sampling can provide materials for petrographic examination (USBR 4856), chemical or physical analytical procedures, or any of a wide variety of destructive or nondestructive tests to determine physical, mechanical, or structural properties of the concrete.

3.3 The results of examination and sampling carried out in accordance with this procedure may be used for a variety of purposes and to serve a variety of objectives, some of which are discussed in section 6 and ACI 201.1R.

4. Terminology

4.1 *Concrete Construction*.-Any object, unit, or structure that has been built of hydraulic cement concrete.

4.2 *Category of Concrete*.-A specified level of quality in concrete that is observed to be in a definable range of condition as a result of service or test exposure. This level is as distinguished from concrete in the same or related construction that is either of differing specified quality or of the same specified quality but in observably different condition at the time of examination. It is also used to refer to concrete having a certain attribute (see sec. 11).

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[2] *Annual Book of ASTM Standards*, vol. 04.02.

[3] *Annual Book of ASTM Standards*, vol. 14.02.

[4] *ACI Manual of Concrete Practice*, part 1.

5. Qualifications and Instruction of Personnel

5.1 *Qualifications.*–It is assumed that the examination, formulation of sampling plan, and sampling procedures will be performed by personnel qualified by education and experience to carry out such work; and to operate equipment employed, record and interpret observations, and report on sampling plan and its execution. Technicians and laborers may be required to assist in these operations, but appropriate training and supervision are mandatory.

5.2 *Instructions to Employees.*–This practice may be used by personnel employed directly by those for whom the examination and sampling program are conducted. The employer should inform the personnel, in as much detail as necessary, on the purposes and objectives of the examination, nature of information sought, and extent of examination and sampling desired. Pertinent background information should also be made available. If the person to perform the work is highly experienced, the employer should seek his or her advice in delineating the investigation. The nature, extent, and objectives of the examination and sampling plan should be recorded, and the record may appropriately include items listed in the agreement (sec. 5.3).

5.3 *Agreements with Consultants.*–This practice may be the basis for establishing arrangements between a purchaser of a consulting service and the consultant. The purchaser and consultant should jointly determine the nature, extent, and objectives of the examination and sampling program to be made, and should record their agreement in writing. The agreement may stipulate specific determinations to be made, observations to be reported, number and nature of samples to be taken, level of reliability required for results of tests, portions of the construction to be sampled, funds to be obligated, time schedule for investigation, or a combination of these and other conditions.

EXAMINATION OF CONCRETE IN CONSTRUCTION

6. Procedural Plan

6.1 *Objective.*–The objective of the examination of concrete is to provide information that can be used to evaluate the condition of the concrete and the construction, and to corroborate observed satisfactory performance or document and explain distress or failure. The examination of concrete in service or under test should be undertaken in accordance with a scope, objective, and systematic procedure, all agreed upon by the responsible parties. The extent of the investigation and procedures that are most appropriate for the examination depend upon a decision as to the objectives of the investigation and the level of reliability required for the resulting test data. This decision may stipulate an authorized budget and time schedule for completion of various stages of the investigation. The budget and time schedule can be modified following preliminary investigations and adjusted periodically as data accumulates.

6.2 *Purpose.*–Investigations on the condition of concrete in service are usually undertaken to:

- Determine ability of concrete to perform satisfactorily under anticipated conditions of future service
- Identify processes or materials causing distress or failure
- Determine conditions that caused or contributed to satisfactory performance or failure
- Establish methods for repair or replacement without the possibility of recurrence of the distress
- Determine conformance with construction specifications requirements
- Develop data to aid in fixing the financial and legal responsibility for cases involving failure or unsatisfactory service
- Evaluate performance of components used in the concrete

6.2.1 It is assumed that the manager of the investigation would begin with one or more working hypotheses, derived from information received or gathered, that would explain the reasons for the condition of the concrete, and that would be continuously revised and redefined as more information is received. The intent is that, at the end of the investigation, an explanation will have been produced that is the best obtainable from the investigation of the available evidence concerning the mechanisms that operated to produce the condition of the construction.

6.3 *Scope of Investigation.*–The scope of an investigation on concrete in service may be limited to only isolated areas displaying deterioration; or may be concerned with general distress, such as excessive deflection or collapse of structural members. The scope may also involve study of the dislocation of entire structures or large portions of structures. The investigation may be confined to the study of the concrete, or it may require substantial research into other circumstances such as foundation conditions, conditions of service, construction practices, and comparisons with other structures.

7. Preliminary Investigations

7.1 *Purpose.*–The purpose of preliminary investigations is to verify the existence of an unsatisfactory condition, describe its nature, and estimate its extent and possible effect upon the performance, service life, and safety of the structure. An investigation of failure or inadequate performance of concrete in construction is predicated upon a conclusion, usually by the owner or his representatives, that an unsatisfactory condition exists or is imminent. Such a conclusion may be in error if the observed condition is insignificant or if the full extent of the actual distress of inadequacy has not been detected.

7.2 *Methods.*–The preliminary investigation may include visual inspection of the structure, review of plans and specifications for the work, examination of available reports by project engineers and inspectors, compilation of available data on service conditions, petrographic examination in accordance with USBR 4856, and the testing of a few selected samples of concrete and secondary chemical deposits in or on the concrete. The deflection, expansion, or shrinkage of typical portions of a structure might appropriately need to be measured. The condition of the concrete can be estimated using nondestructive testing procedures, such as impact devices, see USBR 4803 and 4805, and ultrasonic methods, see USBR 4597. Selected critical portions of structures may be probed and sampled by drilling (USBR 4042). The concrete cores may be tested in accordance with USBR 4215. Borehole cameras and viewing devices have been found to be helpful in specific instances [1,2,3][5].

7.3 *Conclusions.*–The findings of the preliminary investigation may remove all concern with respect to the condition of the concrete. In certain cases, the findings may be adequate for a final conclusion on the significance of observed distress. Otherwise, care should be taken to assure that the preliminary investigation provides the information necessary to delineate a plan for further investigations as discussed in sections 8 through 14.

8. Assembly of Records

8.1 *Reports and Legal Documents.*–The investigation of concrete performance should be preceded or accompanied by the assembly and critical review of records pertaining to the project specifications, construction contract, construction operations, concrete-making materials, weather conditions during and after construction, and the actual conditions of service. Such records should establish specified requirements for the materials and completed work, and may reveal circumstances or conditions that caused or contributed to the distress of the concrete. Records of operation and maintenance may describe the beginning and progress of unsatisfactory performance.

8.2 *Interviews.*–Interviews with contractors, engineers, inspectors, tradespeople, and suppliers should be conducted to obtain pertinent information that is not included in the written record. Owners, occupants, and users of the construction should be questioned concerning the onset and progress of evident distress, especially with respect to the possible relationship to any change of the conditions of use and service.

9. Detailed Investigations of Concrete in Construction

9.1 *Procedures.*–A detailed investigation of concrete in construction should include all procedures required to achieve approved scope and objectives within the authorized budget and time schedule. After the preliminary investigation to establish the general condition of the concrete and extent of any unsatisfactory performance, the detailed investigation may include:

- A thorough examination of the concrete construction
- Surveys and field tests to define and evaluate condition of inplace concrete and safety of the construction
- Acquiring samples for examination and testing by laboratory procedures

9.2 *Scope of Field Examination.*–A detailed visual examination should be made by personnel familiar with concrete and concrete construction. This examination should locate and describe all categories of the concrete. All affected construction or portions thereof should be identified and the external aspects of failure should be described as quantitatively as possible. The examination may be extended to aggregate sources in accordance with the procedures described in USBR 4295. Photographs of pertinent features of the construction, their environs, and the manifestations of failure are valuable and should be obtained.

9.3 *Observations.*–Specific features of the concrete to be noted include:

- Nature and extent of cracking and fractures
- Evidence of volume change, deflection, or dislocation of construction or portions thereof, which may include closing or opening of joints, tilting, shearing, or misalignment of structural elements and shifting or misalignment of machinery
- Conditions of exposed surfaces, such as spalling, popouts, unusual weakness, disintegration, excessive wear, or discoloration
- Evidence of cement-aggregate reactions
- Secondary deposits on surfaces, in cracks, and in voids
- Presence and extent of repair work and quality of its bond to original concrete

9.3.1 Other properties of the concrete requiring observation would include:

- Thoroughness of consolidation
- Whether the concrete is air-entrained
- Evidence of segregation and bleeding
- Indications of extremely high, low, or normal water content
- For reinforced concrete, condition of steel and its location in section
- Nature and condition of other embedded items

9.3.2 Any phenomena indicating distress of the concrete should be studied in relation to possible causative or contributory factors, such as varying conditions of exposure over the area of the construction; sequence of placing operations; conditions prevailing during construction; sources of supply of concrete and concrete-making materials; identifiable problems of handling, placing, and finishing; conditions of curing and early protection; and adequacy of structural design and conformance to plans. Varying conditions of exposure over the area of construction during and after construction may include the following:

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[5] Numbers in brackets refer to entries in References, section 22.

- Differences in thermal exposure to solar heating; shaded portions usually are subjected to the lowest range of daytime thermal cycles.
- Differences in exposure to moisture which may arise by orientation of the construction with respect to prevailing winds during times of rainfall or snowfall, and which will be affected by the daytime thermal cycles.
- Differences in mineral composition of subgrade so that part of the construction is located on a foundation containing swelling clay or containing unstable sulfides or sulfates.
- Differences in moisture content of subgrade during or after construction.

9.3.3 The foundation and subgrade materials and conditions should also be carefully examined if there is a possibility of their involvement in the serviceability of the concrete.

9.3.4 The observations made, together with relevant information developed as described in section 8 and the results of the preliminary investigations described in section 7, shall be assembled, as may be appropriate, into a report which shall either be submitted to those for whom the study was conducted or prepared for incorporation into a more comprehensive document covering other phases of an investigation of broader scope.

SAMPLING HARDENED CONCRETE

10. Requirements

10.1 Sampling each category of concrete should be done objectively so that the set of samples taken is not weighted with unusually poor or unusually sound concrete. Samples may be taken to exemplify unusual or extreme conditions or features to aid in the identification of causes of distress or failure of concrete, but these samples should be kept apart from samples that are taken to exemplify statistically the properties of the inplace concrete. Thus, the samples may be of two types: (1) those that are intended to be representative of the variability of the inplace concrete, and (2) those that display specific features of interest but are not intended to be representative of any substantial proportion of the inplace concrete. The samples should include portions of both near-surface concrete and concrete at depth because the concrete may vary substantially with depth in the development of cracking, deterioration of the cement paste, progress of cement-aggregate reactions, and other features. The samples should also be sufficient in size and number to permit application of all necessary laboratory procedures upon different samples or portions of samples than those used for other tests, except as noted in section 12.3. Therefore, the sampling program should be arranged with foreknowledge of the laboratory testing program to be covered by the plan of investigations. The samples secured for each test procedure should be sufficient in number to provide an estimate that is of acceptable reliability (sec. 11.2 and 11.3).

11. Sampling Plan

11.1 Representative samples should be taken in accordance with a prearranged plan that will meet the requirements of section 10. The plan should also conform with the recommendations of sections 4 and 5 of ASTM E 105. For guidelines in the application of statistical methods to a small number of samples, see reference [4]. Two sampling situations may occur, as described in sections 11.1.1 and 11.1.2.

11.1.1 *Situation 1.*-The preliminary examination and other information indicate that all of the concrete is in similar condition and quality, or that it is infeasible, without taking and testing samples, to determine whether the concrete is essentially uniform. For this situation, sampling locations should be spread randomly or systematically over the area of interest. For large structures or substantial areas of pavement, the sampling sequence should be repeated at some predetermined frequency, such as for each 500, 1,000, or 5,000 ft^2 (46, 93, 465 m^2) of exposed concrete, as may be appropriate. Any method for determining sampling locations may be employed provided the locations are established without bias.

11.1.2 *Situation 2.*-The preliminary examination and other information indicate the concrete is in two or more categories (see sec. 4.2) or comprises two or more portions that are, or are likely to be, of differing composition or quality. For this situation, samples may be taken for comparison with respect to several categories of performance by using the Chi-Square Test [5].

11.2 *Recommended Sampling Method.*-Prepare to scale an outline sketch or obtain scaled large photographs of the surface from which the representative samples are to be extracted. Subdivide the entire area, that includes all of the separate surfaces, into at least 10 equal or approximately equal sections but not less than the number of separate areas included in the investigation. Designate each section by a number or letter. Choose sections to be sampled by drawing numbered or lettered slips of paper at random from a container or by using a list of random numbers or letters. Take the samples, in accordance with section 13, at locations that are marked at random on the sketch of each indicated section (note 2).

11.2.1 In an investigation of test specimens or concrete products, the units to be examined and tested should be selected randomly by methods similar to those of section 11.1.

11.2.2 Prefabricated products of large dimension, such as building units, pipe, and piling, can be sampled by the recommended method as it is applied to structures and pavements.

11.2.3 The sampling method should be modified as appropriate to provide for sampling concrete members or elements that have been removed from construction for investigation.

NOTE 2.-If it is necessary to avoid critical reinforcement, embedded hardware, or other construction features, move the sampling location the minimum necessary distance to the north (up on vertical surfaces). If such a move is not feasible, move east, south, or west (right, down, or left), alternatively considered, in that order.

11.3 *Sample Size.*-For samples to be subjected to tests yielding a numeric value, the number of samples should be determined in accordance with the recommendations of ASTM E 122, based upon the degree of confidence desired to be placed in the resulting numerical value. The quantity of concrete and the dimensions of pieces secured in the sampling operation should conform with the stipulations of the applicable method of test.

11.4 *Evaluation of Test Results.*-Test results from samples obtained in accordance with situation 1, section 11.1.1 are evaluated on the basis of statistics computed as follows:

$$\bar{X} = \frac{\Sigma X_i}{n} \tag{1}$$

where:

$\bar{X}$ = average of mean values,
X_i = an individual test result,
n = average number of test results, and

$$s = \sqrt{\frac{\Sigma(X_i - \bar{X})^2}{n - 1}} \tag{2}$$

where:

s = standard deviation of individual values

11.4.1 *Evaluation of Test Results on Basis of Variability.*-Variability of test results within a group is indicated by the variable s in equation (2) in section 11.4. Whether these statistics are excessively large can only be determined by comparing them with some prior knowledge of what the variability ought to be. The best information for this variability knowledge is contained in the precision statement of the test method being used. Directions for obtaining an acceptable range for the average number of test results n, equation (1), and an acceptable difference between the averages of two groups of tests from the same category of concrete are given in ASTM C 670.

11.4.2 *Evaluation on Quality of Concrete.*-Quality of the concrete in question can be assessed by comparing the average of test measurements from a group within the category of questionable quality with the average obtained from a category of good quality. A "student's t test" [6] may be applied to the difference between the two averages to make the decision as to whether the difference is significant or not. Before conducting the "t" test, other considerations must be kept in mind. These include the nature and intent of the construction, material properties relevant to successful concrete in the construction, nature of any distress, economics of maintenance, need for repair (if any), and the desired service life of the structure.

11.4.3 For situation 2 (sec. 11.1.2), each separate category of exposed surface of the concrete construction, or each category of test specimen or concrete product, should be treated individually, as described for situation 1 (sec. 11.1.1). This is to establish sampling locations and number of samples, and to select particular specimens or product units for examination. For example, completely scaled, partially scaled, and unscaled areas of pavement concrete of a specified level of quality should be sampled separately so that three sets of samples are secured. Each set would be comprised of concrete of a specific category conforming with the recommendations of ASTM E 105 and E 122. Any number of sets of samples may be required for the proper investigation of concrete that is within the scope of an approved plan so as to adequately evaluate concrete of differing specified levels of quality, and in differing condition following service exposure.

12. Sampling for Compliance With Construction Specifications

12.1 To determine the compliance of hardened concrete with requirements of codes or contract specifications, each sample should be sufficient in quantity and dimensions to permit performance of the applicable test procedure in accordance with the stipulations of the test method.

12.2 The number of samples to be taken from each category of concrete should be established in accordance with ASTM E 105 and E 122 so as to provide a reliable estimate of the standard deviation and average value of the test results. The level of reliability required and the criteria for acceptance of the results, as set forth in ASTM E 141, should be established as part of the construction specifications or, if not, as a part of the sampling plan. In the event that no such stipulation has been established, no less than five samples shall be taken from each category for each test procedure stipulated in the procedural plan.

12.3 In some instances, two or more tests may be performed on a sample provided the tests initially do not modify the properties of the concrete to be evaluated by subsequent tests. Any such reuse or successive use of samples shall be stipulated in detail beforehand in the sampling plan so as to specify the nature of tests that may be performed successively, sequence of testing, and precautions to be taken in performing the tests and handling the sample during testing. Three examples of permissible successive testing are: (1) a density test followed by a compression test; (2) an air void content test (USBR 4457) followed by a petrographic examination; and (3) a compression test followed by a chemical test for cement content, provided care is taken to avoid loss of fragments of the specimen.

12.4 For purposes of engineering surveys and research programs, the number of samples and their characteristics may be established by responsible personnel in accordance with the scope and objectives of the investigation.

13. Sampling Procedures

13.1 In general, samples of hardened concrete from construction, concrete products of large size, or large test specimens should be secured in accordance with USBR 4042. Specimens of hardened concrete may be obtained by coring, sawing, or otherwise removing portions of the concrete (note 3). Sawing or coring by rotary drilling (note 4) is preferred for samples subjected to tests for physical properties or petrographic examination. Caution should be used to avoid or minimize fracturing the concrete or contamination of the sample with foreign substances. Use of sledges, chisels, and similar tools should be avoided because their possible effects on the integrity of the sample would have to be considered during examination and testing of the samples.

NOTE 3.–Care should be taken to avoid cutting critical sections of reinforcement, conduit, and ductwork.

NOTE 4.–A diamond-drilled core is preferred to a shot-drilled core because the resulting outer surface of the core is smoother and reveals the composition and fabric of the concrete more clearly.

13.2 Samples for examination may be secured from small beam or slab specimens or from small prism-shaped or columnar concrete products by sawing across the entire width and depth; for example, at the third-points and middle of the length. Samples from vertically cast concrete cylinders should be secured from top and bottom halves; from top, middle, and bottom portions; or by sawing the specimen longitudinally. These samples will represent any variability arising as a consequence of placing and compaction procedures, segregation, or bleeding. Similar procedures and precautions should be employed in securing samples from other types of test specimens and concrete products. Methods for obtaining portions of samples for testing purposes are outlined in section 13 and table 1.

13.3 If feasible, samples should be taken perpendicular to the layers in which the concrete was deposited. The samples should include the exposed surface, near surface concrete, any concrete in contact with aggressive substances, and concrete at depth. Samples of isolated spalls or popouts should include representative examples of same and the underlying and adjacent concrete. For sampling various common types of concrete construction, recommended minimum depths or thicknesses across which samples should be taken are shown in table 1. Deeper drilling may be required to determine the extent of cracking, condition of construction joints, extent of any cement-aggregate reactions, condition of concrete in contact with subgrade material, and variability of the concrete.

13.4 Samples should be identified and oriented by painted or inked markings on the material itself. The samples should also be wrapped and sealed, as may be appropriate, to preserve the moisture content representative of the structure at the time of sampling; and be packed so as to be properly protected from freezing or damage in transit or storage.

14. Information to Accompany Samples

14.1 The supervisory personnel responsible for the laboratory tests, analyses, and/or the examinations of the samples should receive complete information on the identity and source of each sample and on the problem being investigated. In particular, they should be advised and consulted about specific questions on the objectives of the investigation.

14.2 Specific items of information that should be available to the supervisor or consultant are:

- Location of source of each sample, orientation of sample, depth from which sample was taken, and sampling procedures.
- Photographs of the samples and of the sampling locations should be provided, if possible.

Table 1. – Minimum depth of concrete samples for testing purposes.[1]

Type of construction	Thickness of section, feet (m)	Minimum depth to be sampled, feet (m)
Slabs, pavements, walls, linings, foundations, and structural elements accessible from one side only	1.0 (0.3) or less 1.0 (0.3) or greater	Entire depth 1.0 (0.3)
Suspended slabs,[2] walls, conduits, foundations, structural elements exposed to atmosphere on two or more sides, and concrete products	0.5 (0.15) or less 0.5-2.0 (0.15-0.6)	Entire depth One half thickness or 0.5 (0.15), whichever is greater
Massive sections	2.0 (0.6) or greater	2.0 (0.6)

[1] The requirements shown in this table may not provide the quantities or dimensions of samples that are required by the stipulations of sections 11 and 12. In such cases, the necessary additional quantity of concrete in pieces of appropriate minimum size should be taken at each sampling location in accordance with the requirements of section 13.

[2] When suspended slabs are cored, it is desirable to leave the lower 1 inch (25 mm) uncored so as not to lose the core by its falling from the barrel and to make it easier to patch the core hole.

- Report on both the preliminary and detailed field investigations including a description of the performance of the concrete in service and the results of the concrete field examination. Surveys, field tests, and other pertinent information on construction, source of concrete, and concrete-making materials should also be included.
- Results of any tests or analyses that were performed on the concrete or concrete-making materials.

15. Precautions

15.1 This test procedure may involve the use of hazardous materials, operations, and equipment. It is the responsibility of the user of this procedure to establish appropriate safety practices and to determine the applicability of regulatory limitations prior to use.

16. Calibration and Standardization

16.1 The calibration and standardization of equipment used in obtaining and/or testing specimens is covered under the referenced applicable documents of section 2.

17. Conditioning

17.1 The conditioning of the specimens used for testing is covered under the referenced applicable documents of section 2.

18. Procedure

18.1 The overall procedure is covered in sections 6 through 13.

19. Calculations and Interpretation of Results

19.1 No specific forms or sample calculations are included with this procedure because they are covered under the referenced applicable documents of section 2. Depending upon the scope and magnitude of the investigations, applicable forms will have to be devised at the time if appropriate forms are not available.

19.2 Interpretation of results are covered in section 11.4.

20. Reports

20.1 No typical report is included with this procedure because of its wide variability. Suggestions on items to be covered in a report are given in section 14.

21. Precision and Bias

21.1 The precision ana bias for this test procedure have not been established.

22. References

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UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4856-92

PROCEDURE FOR

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4856; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 856-83.

1. Scope

1.1 This designation covers a procedure that outlines the petrographic examination on samples of hardened concrete. The samples may be taken from concrete construction, may be concrete products or portions thereof, or may be concrete or mortar specimens that have been exposed in natural environments, exposed to simulated service conditions, or subjected to laboratory tests. The term "concrete construction" is intended to include all types of units or structures that are made of hydraulic cement concrete.

NOTE 1.-Photographs of materials, phenomena, and reaction products discussed in sections 8, 9, 10, and 12; and tables 1, 2, 3, 5, 6, and 7 are available as associated material.[1]

1.2 The petrographic methods described are applicable to the examination of samples of all types of hardened hydraulic cement mixtures including concrete, mortar, grout, plaster, stucco, and terrazzo. In this procedure, the material for examination is designated as "concrete" even though the commentary may be applicable to other mixtures, unless the reference is specifically to a media other than concrete.

2. Applicable Documents

2.1 *USBR Procedures*:
1000 Standards for Linear Measurement Devices
1020 Calibrating Ovens
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4215 Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens
4295 Petrographic Examination of Aggregate for Concrete
4457 Microscopical Determination of Air-Void Content and Parameters of Air-Void System in Hardened Concrete
4597 Pulse Velocity Through Concrete
4803 Penetration Resistance of Hardened Concrete
4805 Rebound Number of Hardened Concrete
4823 Examination and Sampling of Hardened Concrete in Construction

2.2 *ASTM Standards*:
C 294 Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates[2]
C 452 Standard Test Method for Potential Expansion of Portland Cement Mortars Exposed to Sulfate[3]
C 856 Standard Practice for Petrographic Examination of Hardened Concrete[2]
E 3 Standard Methods of Preparation of Metallographic Specimens[4]
E 883 Standard Practice for Metallographic Photomicrography[4]

2.3 *CRD Method*:
C 52 Method of Test for Resistance of Concrete Surfaces to Abrasion (Rotating Cutter Method) [1][5]

3. Qualifications of Petrographers

3.1 It is assumed that the examination will be made by personnel qualified by education and experience to operate equipment used and to record and interpret results obtained. In some cases, the petrographer will have had adequate experience to provide detailed interpretation of the materials' performance with respect to the engineering and other consequences of the observations. Alternatively, the interpretation will be made in part by engineers, scientists, or others qualified to relate to the observations.

3.2 This procedure may be used by a petrographer employed directly by those for whom the examination is made. The Government shall inform the petrographer, in as much detail as necessary, of the purposes and objectives of examination, kind of information needed, and extent of examination desired. Pertinent background information,

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[1] Glossy prints, which are frequently of use to the petrographer, are available at a nominal charge from ASTM Headquarters, 1916 Race St., Philadelphia PA 19103. Request adjunct No. 12-308560-00.

[2] *Annual Book for ASTM Standards*, vol. 04.02

[3] *Annual Book of ASTM Standards*, vol. 04.01.

[4] *Annual Book of ASTM Standards*, vol. 03.03.

[5] Numbers in brackets refer to entries in References, section 14.

including results of prior testing, should be made available. If petrographer is highly experienced, his advice and judgment should be sought regarding extent of examination and on the information discussed in section 3.3.

3.3 This procedure may form the basis for establishing arrangements between the Government and a consulting service. In such a case, both parties should determine the kind, extent, and objectives of examination and analyses to be made; and should record their agreement in writing. The agreement may stipulate specific determinations to be made, observations to be reported, funds to be obligated, or a combination of these or other conditions.

4. Purposes of Examination

4.1 Examples of purposes for which a petrographic examination of concrete is used are given in sections 4.2 through 4.5. The probable usefulness of a petrographic examination in specific instances may be determined by discussion with an experienced petrographer on the objectives of the investigation.

4.2 *Concrete from Construction.*–A petrographic examination on concrete from construction could include:

- A detailed determination on condition of concrete in a construction.
- Determination on causes of inferior quality, distress, or deterioration of concrete in a construction.
- Determination on probable future performance of concrete.
- Determination on whether concrete in a construction was or was not as specified; other tests may be required in conjunction with petrographic examination.
- Description of cementitious matrix including qualitative determination on type of hydraulic binder used, degree of hydration, degree of carbonation if present, evidence of unsoundness of cement, presence of a mineral admixture, nature of hydration products, adequacy of curing, and unusually high water-cement ratio of paste.
- Determination on whether alkali-silica or alkali-carbonate reactions, cement-aggregate reactions, or reactions between contaminants and matrix have taken place and their effects on the concrete.
- Determination on whether concrete has been subjected to and affected by sulfate attack, other chemical attack, early freezing, or to other harmful effects of freezing and thawing.
- Part of a survey on safety of a structure for a present or proposed use.
- Determination on whether concrete subjected to fire is essentially undamaged, or moderately or seriously damaged.
- Investigation on performance of coarse or fine aggregate in structure, or determination of composition of aggregate for comparison with aggregate from approved or specified sources.
- Determination of factors that caused a given concrete to serve satisfactorily in the environment in which it was exposed.
- Determination on presence and nature of surface treatments such as dry shake applications on concrete floors.

4.3 *Test Specimens from Actual or Simulated Service.*–A petrographic examination may be conducted on concrete or mortar specimens that have been subjected to actual or simulated service conditions for most of the purposes listed in section 4.2.

4.4 *Concrete Products.*–A petrographic examination can be used for investigation of concrete products of any kind including masonry units, precast structural units, piling, pipe, and building modules. The products or samples of those submitted for examination may be from current production, from elements in service in a construction, or from elements that have been subjected to tests or to actual or simulated service conditions. The examination could include:

- Determination of features listed in section 4.2.
- Determination on effects of manufacturing processes and variables such as methods for mixing, molding, demolding, consolidation, curing, and handling.
- Determination on effects of use of different concrete-making materials, forming and molding procedures, types and amounts of reinforcement, and embedded hardware.

4.5 *Laboratory Specimens.*–The purposes of a petrographic examination on laboratory specimens of concrete, mortar, or cementitious paste are usually to investigate effects of the test on the specimen or on one or more of its constituents to provide examples of the effects of a process, and to provide petrographer with visual evidence on examples of reactions in a specimen of known materials, proportions, age, and history. Specific purposes may include:

- Determine if alkali-silica reaction has taken place, what aggregate constituents were affected, what evidence of reaction exists, and effects of reaction on concrete.
- To establish whether one or more alkali-carbonate reactions have taken place, which aggregate constituents were affected, what evidence of reaction exists, and effects of reaction on concrete properties.
- Determine if any other cement-aggregate reaction has taken place. In addition to alkali-silica and alkali-carbonate reactions, other reactions are hydration of anhydrous sulfates, rehydration of zeolites, wetting of clays; and reactions involving solubility, oxidation, sulfates, and sulfides [2,3,4].
- Establish whether an aggregate used in a test has been contaminated by a reactive constituent when, in fact, aggregate was not reactive.
- To establish effects of a freezing and thawing test or other physical or mechanical exposure of concrete on aggregate and matrix.
- Determine extent of a reaction, nature of reaction products, and effects of reaction produced in exposure

to a chemically aggressive environment, such as in ASTM C 452.

- To determine characteristics of moist-cured concrete that has not been subjected to chemical attack, to a cement-aggregate reaction, or to freezing and thawing.
- By comparison with appropriate laboratory specimens, a petrographer may be able to substantiate existence of a particular reaction in concrete, or determine that reaction cannot be detected.

5. Apparatus

5.1 The apparatus and equipment used in making petrographic examinations of hardened concrete depend on the methods required. This section includes equipment generally used; equipment required for field sampling is not listed. Any other useful equipment may be added.

5.2 *Equipment for Specimen Preparation*:

5.2.1 *Diamond Saw*.-A slabbing saw with an automatic feed and blade large enough to make at least a 7-inch (178-mm) cut in one pass.

5.2.2 *Cutting Lubricant*.-Required for diamond saw.

5.2.3 *Horizontal Lap Wheel*.-A steel, cast iron, or other metal lap wheel at least 16 inches (406 mm) in diameter and large enough to grind at least a 4- by 6-inch (102- by 152-mm) area.

5.2.4 *Free Abrasive Machine*.-This machine uses abrasive grit in lubricant, and has sample holders on a rotating table. This type of grinding machine increases speed of preparation of finely ground surfaces.

5.2.5 *Polishing Wheel*.-This wheel should be at least 8 inches (203 mm) in diameter, and should preferably be a two-speed or vibratory polisher.

5.2.6 *Hot Plate or Oven*.-Should be thermostatically controlled to permit drying and impregnating specimens with resin or wax for preparation of thin sections, ground surfaces, and polished sections.

5.2.7 *Prospector's Pick or Bricklayer's Hammer*.-One or both of these tools may be needed.

5.2.8 *Abrasives*.-Silicon carbide grits: No. 100 (150 μm), No. 220 (63 μm), No. 320 (31 μm), No. 600 (16 μm), No. 800 (12 μm); optical finishing powders such as M-303, M-204, and M-309; and polishing powders as needed.

5.2.9 *Plate-Glass Squares*.-These plate-glass squares should be from 12 to 18 inches (305 to 457 mm) on an edge and at least 3/8 inch (10 mm) thick for hand-finishing specimens.

5.2.10 *Suitable Medium or Media*.-For impregnating concrete and mounting thin sections. Canada balsam, Lakeside 70 cement, and flexibilized epoxy formulations have been found to be successful. Should also have an appropriate solvent.

NOTE 2.-*Caution*: Flexibilized epoxies form strong bonds but have higher indexes of refraction than Canada balsam or Lakeside 70. These epoxies are toxic and should not be allowed to touch skin. Plastic gloves should be worn when using, and work should be done under a hood so as not to breathe fumes.

5.2.11 *Microscope Slides*.-Clear, noncorrosive, glass slides about 1 inch (25 mm) wide and at least 1-3/4 inches (44 mm) long. Thickness of slides may need to be specified to fit some thin-section machines.

5.2.12 *Cover Glasses*.-Noncorrosive cover glasses of No. 1 (0.18 mm) thickness (preferred).

5.3 *Equipment for Specimen Examination*:

5.3.1 *Stereomicroscope*.-This microscope should provide magnifications in the range from 7X to 70X, or more.

5.3.2 *Dollies*.-Small, wheeled dollies with flat tops, with a portion of the top curved to hold a section of core to assist in manipulating concrete specimens under the stereomicroscope.

5.3.3 *Polarizing Microscope*.-For examinations in transmitted light, with mechanical stage; low-, medium-, and high-power objectives such as 3.5X, 10X, and 20X to 25X; 43X to 50X with a numerical aperture of 0.85 or more; assorted eyepieces having appropriate corrections and magnifications for use with each of the objectives; micrometer eyepiece; condenser adjustable to match numerical aperture of objective with highest numerical aperture to be used; full- and quarter-wave compensators, quartz wedge, and other accessories.

5.3.4 *Metallographic Microscope*.-With vertical illuminator; mechanical stage; metallographic objectives of low, medium, and high magnification; and appropriate eyepieces to provide a range of magnifications from about 25X to 500X. Reflected polarized light should be available and appropriate compensators provided. Some polarizing microscopes can be equipped with accessories for metallographic examination if the tube can be raised or the stage lowered to give adequate clearance for vertical illuminator and thicker specimens usually used. For more information on metallographic photomicrography, refer to ASTM E 883.

5.3.5 *Eyepiece Micrometer*.-Eyepiece micrometers calibrated using a stage micrometer are useful for measuring particles of aggregate, cement grains, calcium hydroxide, and other crystals; and for measuring widths of cracks.

5.3.6 *Stage Micrometer*.-For calibrating eyepiece micrometers.

5.3.7 *Microscope Lamps*.-Many modern polarizing microscopes have built-in illuminators which are convenient and satisfactory if, with the condenser, they can be adjusted to fill the back lens of the objective of highest numerical aperture with light. If microscope requires a separate illuminator, tungsten ribbon-filament bulbs in suitable adjustable housings are satisfactory. Several types of illuminators are available for stereomicroscopes, some can be mounted on the microscope while some stand on their own bases. The choice is a question of adequacy of illumination for tasks intended. Focusable illuminators are preferred.

5.3.8 *Needleholders and Points*.-In addition to pin vises and needles from laboratory supply houses, a No. 10 sewing needle mounted in a handle or a selection of dissecting needles from size 00 to size 4 are useful for prying out reaction products.

5.3.9 *Bottles with Droppers*.-For applying acid, water, and other reagents during examination.

5.3.10 *Assorted Forceps*.-Preferably stainless steel, including fine-pointed watchmaker's forceps.

5.3.11 *Refractometer and Immersion Media*.-Covering the range of refractive indexes from 1.410 to at least 1.785, in intervals not larger than 0.005. Stable immersion media, calibrated at a known temperature and of known thermal coefficient, are preferable and should be used in a temperature-controlled room. A thermometer graduated in tenths of a degree Fahrenheit, or Celsius, should be used to measure air temperature near microscope stage so that thermal corrections of refractive index can be made if needed.

5.3.12 *Miscellaneous Equipment*.-Other equipment needed includes linear measurement devices, ovens, and lens paper.

6. Selection and Use of Apparatus

6.1 Laboratories should be equipped to provide photographs, photomacrographs, and photomicrographs to illustrate significant features of the concrete. While ordinary microscope lamps are sometimes satisfactory for photomicrography in transmitted and reflected light, lamps providing intense point or field sources, such as tungsten ribbon-filament bulbs or zirconium or carbon arcs, are more desirable.

6.2 The minimum equipment required for a petrographic examination of concrete, where both specimen preparation and examination are completed within the laboratory, consists of a selection of apparatus and supplies for specimen preparation; a stereomicroscope, preferably on a large stand so that 6-inch (152-mm) diameter cores can be conveniently examined; polarizing microscope and accessories; lamps for each microscope; and a stable, calibrated, immersion media of known thermal coefficient. Specimens for petrographic examination may be obtained by sending samples to individuals or firms that offer custom services in preparing thin or polished sections and finely-ground surfaces. However, it is more convenient to prepare specimens in-house if possible.

6.3 X-ray diffraction, X-ray emission, differential thermal analysis, thermogravimetric analysis, analytical chemistry, infrared spectroscopy, and other techniques may be useful in obtaining quick and definite answers to relevant questions where microscopy will not do so. Some undesirable constituents of concrete, some hydration of products of cementitious materials, and some reaction products that are useful in defining effects of different exposures, and many contaminating materials may not be identified unless techniques that supplement light microscopy are used [5,6].

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7.2 Specific precautions are given in note 2 of section 5.2.10 on the toxicity of certain materials.

8. Samples

8.1 Cores shall be obtained in accordance with USBR 4042. The minimum size of sample should be at least one core; preferably 6 inches (152 mm) in diameter and 12 inches (305 mm) long for each mixture, condition, or category of concrete; except that for pavement, the full depth of pavement shall be sampled with a 4- or 6-inch (102- or 152-mm) core. Broken fragments of concrete are usually of doubtful use in a petrographic examination because damage to concrete cannot be clearly identified as a function of sampling technique or representative of real condition of concrete. Cores smaller than 6 inches in diameter can be used if aggregate is small enough. In deteriorated concrete, core recovery is much poorer with a 2-1/8-inch (54-mm) diameter core than with a 6-inch diameter core.

8.2 *Samples from Construction*.-The most useful samples for petrographic examination of concrete from construction are diamond-drilled cores with a diameter at least two times, preferably three times, the maximum size of the coarse aggregate in the concrete. If 6-inch (150-mm) aggregate is used, a core at least 10 inches (254 mm) in diameter is desirable.

8.2.1 The location and orientation of all cores, including cores or core lengths not sent to laboratory, should be clearly shown. Each core should be properly labeled. For vertically drilled cores, the elevation or depth at top and bottom of each section should be shown, and any core loss and fractures prior to the drilling should be marked. For cores taken horizontally or obliquely, direction of vertical plane and tops and bottoms should be marked. A field log similar to the log shown on figure 1 should be provided.

8.2.2 Broken pieces of concrete from extremely deteriorated structures, or pieces removed while preparing for repair work, are sometimes used for the petrographic examination. The samples will be more useful if their original locations in the structure are clearly described or indicated on a sketch or photograph.

8.2.3 Figure 1 also shows a typical form for sample information, which should include:

- Location and original orientation of each specimen, see USBR 4823.
- Mixture proportions of concrete.
- Sources of concrete-making materials, and results of any testing on these materials.
- Description of mixing, placing, consolidation, and curing methods.
- Age of structure or, for a structure that required several years to complete, dates of placement of concrete sampled.

- Conditions of operation and service exposure.
- Reason for and objectives of examination.
- Symptoms believed to indicate distress or deterioration.
- Results of field tests such as measurements of Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens (USBR 4215); Pulse Velocity (USBR 4597); Rebound Hammer (USBR 4805); or Probe Readings (USBR 4803).

8.3 *Samples from Test Specimens from Natural Exposures, Concrete Products, and Laboratory Specimens*:

8.3.1 Information on these types of samples should include materials used, mixture proportions, curing, age of concrete when placed in service or test, orientation in exposure, present age, condition surveys during exposure, characteristics of natural or laboratory exposure, and method of manufacture of the concrete products. Large concrete products may be sampled similar to those from construction (sec. 8.2), and smaller concrete products may be represented by one or more samples showing range of condition from service or fabrication, or both.

8.3.2 The exposure of laboratory specimens should be described with the test results in addition to age at test and available test results on aggregates, hydraulic binders, and admixtures used. This information should accompany test specimens from natural exposures and concrete products or samples therefrom, if available.

8.3.3 Figure 1 may also serve as a typical form for reporting the information required on these samples.

9. Examination of Samples

9.1 *Choice of Method.*-Specific techniques and methods used in examination of a sample depend on purpose of examination and nature of sample. The method to be used should be selected after questions that examination is intended to answer have been clearly formulated. The method should answer those questions as unequivocally and economically as possible. Details that need to be resolved will be dictated by objectives of examination and will vary for different situations. Consequently, selection and location of specimens from samples submitted for examination should be guided by objectives of study. For relevant subjects not described in this procedure, refer to USBR 4295 and 4457 and ASTM C 294.

9.2 *Visual Examination and Outline of Additional Examination.*-A petrographic examination of concrete, mortar, or cementitious paste should begin with a review of all available information about the specimen, followed by a visual examination of each sample. An outline of the information that can be obtained from the visual examination is given in table 1. The visual exam should be followed by an examination using a stereomicroscope, see table 2 and section 12.1. In some cases, further study is unnecessary and a final report can be prepared. In other cases, specimens are selected during the visual and stereomicroscope examinations for further processing and additional stereomicroscope study, more detailed examination using the petrographic or metallographic microscopes or by X-ray diffraction and other instrumental methods, and for other chemical or physical tests. Methods for specimen preparation are outlined in section 10. Tables 2, 3, 4, and 5 summarize characteristics of concrete conveniently observed with the stereomicroscopic, petrographic, and metallographic microscopes. During each examination, the petrographer should note specific examinations to be subsequently made in detail, and may recognize the need to reexamine specimens. Possible observations using different types of microscopes are shown in table 6, and properties of some relevant compounds are listed in table 7.

9.3 *Photography.*-It is frequently desirable to maintain a photographic record as illustrations for the report and for future reference. The following sections describe the types of photographs that may be useful.

9.3.1 Overlapping close-up photographs of a core laid out in sequence, including a dimensional scale, are often useful. It is convenient to use a view camera at a constant distance with same lighting in all photographs.

9.3.2 Photographs and photomacrographs of features of interest on a core surface, ground surface, or an old or new crack surface at magnifications of 0.7X to 3X are particularly useful if specimen will be destroyed during subsequent examinations. A camera equipped with a long extension bellows, lenses of focal length from 2.9 to 6.5 inches (73.7 to 165.1 mm), and a ground-glass back is desirable.

9.3.3 Photomacrographs at magnifications of at least 3X to 10X and sometimes higher, may be used to illustrate reaction products or growths on specimen or significant crack patterns. Black and white photographs, such as 4 by 5 inches (102 by 127 mm) taken at 1X magnification on fine-grained film with a long gray scale, convey a great deal of information and may be more useful than a photograph taken at a higher magnification on a smaller format. As a general guide, subject should be illuminated by oblique lighting at a low angle if relief on subject surface is low, and at a higher angle if relief is high. The object of the oblique illumination is to show detail and contrast without obscuring features by long shadows. Details can also be enhanced by using colored filters, such as Wratten G or other yellow filters. Cross lighting from two sides is sometimes successful in showing detail and obliterating confusing shadows.

9.3.4 Photomicrographs of thin sections, immersion mounts, and polished sections at magnifications from 2X to an upper limit appropriate to the subject and dependent on quality of equipment and skill of photographer may be used to illustrate textures, compounds, and crack patterns.

9.3.5 The range of photographic techniques used should be adequate to provide a good selection of illustrations for the report and record. The subjects for illustrations are usually selected during the visual and stereomicroscopic examinations.

10. Specimen Preparation and Conditioning

10.1 *Preparation for Visual and Stereomicroscope Examination*:

10.1.1 Diamond-drilled cores, formed or finished surfaces, freshly broken surfaces, or old crack surfaces should be examined in condition received. It is sometimes helpful to have drilled, formed, and finished surfaces wetted to increase contrast.

10.1.2 Diamond saw cuts should be oriented with relation to significant features of the concrete; either normal to bedding directions in conventional concrete, normal to a formed or finished surface, or normal to a crack or crack system; in order to reveal structure and fabric of the concrete and extent of alteration outward from crack.

10.1.3 It is useful to prepare at least one sawed surface by grinding it with progressively finer abrasives (as described in USBR 4457) until a smooth matte finish is achieved, and to select areas on matching opposing surface for preparation of thin sections and specimens for optical, chemical, X-ray diffraction, or other examinations.

10.1.4 Specimens obtained by diamond drilling are not ordinarily damaged in the process; however, weak concrete damaged by chemical attack, an alkali-aggregate reaction, freezing and thawing, or any combination thereof, will result in poor core recovery with many fractures if core is drilled with a 2-1/8-inch (54-mm) diameter bit and barrel. However, if drilled with a 6-inch (152-mm) diameter bit and barrel, essentially complete recovery results. This difference is particularly important in petrographic examinations made during condition surveys of old structures. Weakened concrete may also break during sawing. The removal and preparation of specimens for laboratory studies usually involves the application of force and sometimes the application of heat to specimen.

10.1.5 The effects of force can be minimized during specimen preparation by using thicker slices and making only one cut parallel to long axis of a core section. Fractured or fragile concrete can be supported by partially or completely encasing it in plaster, epoxy resin, or other reinforcing media before sawing.

10.1.6 Heat used while impregnating concrete with thermoplastic wax or resin will cause cracking if concrete is heated while it is wet, and will also alter the optical properties of some compounds, such as ettringite. As a result, artifacts may be produced and compound identification made difficult. These artifacts may be mistaken as original features, so care must be used in evaluating a particular feature and indexing it as original in the specimen when the feature may have been produced during removal of specimen from structure or during laboratory processing.

10.1.7 When alkali-carbonate reactions are suspected and rims around crushed carbonate aggregate are observed, it is useful to etch a sawed or ground surface in 6 *N* (normal) or weaker hydrochloric acid to see if peripheral rims on coarse aggregate particles are more or less susceptible to etching than interior of particle. Because etching destroys the surface, this step should not be taken until all other examinations of the surface have been completed. Etching the ground surface for 30 seconds in 10-percent hydrochloric acid is an appropriate procedure.

10.2 *Preparation of Immersion Mounts.*-Secondary products of nondeleterious and deleterious chemical processes may be observed during the stereomicroscopic examination. Finely-pointed probes may be used to excavate and transfer these products to microscope slides. The material is then covered with a cover glass, immersed in a refractive index liquid, and examined using a polarizing microscope to determine optical characteristics of the product such as index of refraction, birefringence, and optical character.

10.3 *Preparation of Thin Sections.*-A detailed description of thin-section preparation is beyond the scope of this procedure. There are many laboratories that provide this service if in-house facilities are not available. Preparation includes slicing the concrete into 1/16-inch (2-mm) thick wafers if concrete is strong, and thicker slices if concrete is weak. It may be necessary to impregnate the concrete with a resin before slicing to prevent disintegration. Diluted flexibilized epoxy or thermoplastic resins have been used successfully. The thin concrete slices are then mounted on glass slides using flexibilized epoxy, Canada balsam, or Lakeside 70 and ground on laps using progressively finer abrasive until a thickness of 1181 microinches (30 μm) or less is obtained; a thickness not greater than 787 microinches (20 μm) is required for detailed examination of paste in transmitted light. It is usually necessary to check thickness of section using birefringent colors of common minerals in the aggregate, such as quartz or feldspar, during final grinding stages. A cover glass is placed on the cleaned, prepared section and secured with Canada balsam or other media.

10.3.1 Semiautomatic thin-section machines are available which prepare original surface of the blank for mounting, trims, excess thickness of blank after mounting, and grinds the section to 1968 to 3937 microinches (50 to 100 μm) leaving little thickness to be removed by hand lapping.

10.4 *Preparation for Examination by Metallographic Microscope*:

10.4.1 The preparation of specimens for examination by the metallographic microscope is described in ASTM E 3, the methods described in this procedure are intended as guides only. Methods should be used that are appropriate to the varieties of microscopical techniques used, and to specimen condition and composition. It is impossible to provide instructions to cover every possible situation.

11. Calibration and Standardization

11.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

11.2 Linear measurement devices shall be calibrated in accordance with USBR 1000.

11.3 Ovens shall be calibrated in accordance with USBR 1020.

11.4 Thermometers shall be checked against thermometers certified by the manufacturers.

11.5 The eyepiece micrometer shall be calibrated with a stage micrometer in accordance with section 5.3.5.

11.6 The stable immersion media shall be calibrated to meet requirements of section 5.3.11.

12. Procedure

12.1 *Visual and Stereomicroscope Examination*:

12.1.1 If there is more than one specimen, arrange them in logical order to represent position in structure and differences in material, proportions, and exposure, or any combination thereof. Photographs and sketches of significant features should be made before specimens are altered. Tables 1 and 2 list some features to be observed during examination.

12.1.2 *Concrete from Construction* (Core Log):

12.1.2.1. Fit fragmented cores together to determine if any pieces are missing. Measure cores to verify field data and prepare a diagramatic log of each core, if necessary. The log should be made to a scale to show relevant features. The log may be used to show fresh and old fractures, reacted particles, reaction products, changes in size or type of coarse and fine aggregates, distribution of coarse aggregate, honeycomb, segregation of components, cold joints or lift or course boundaries, location and direction of steel or other embedded material, changes in color or paste, and other significant features. Notes should be made and suitably referenced in log. If cores have been suitably packed to preserve the moisture content as drilled, which may or may not be the actual inplace moisture content, specimens should be carefully handled to preserve moisture content and avoid breakage. Tests that may be made on specimens in the as-received moisture condition include compressive strength, static or dynamic modulus of elasticity, air content by high-pressure meter, permeability, and freezing and thawing.

12.1.2.2 During the visual examination, a general comparison of cores representing different conditions, materials, and extent and nature of deterioration should be made and recorded. Specimens should be sorted into comparable groups based on conditions or location of regions designated for more detailed examination. In some cases during the visual or stereomicroscope examinations, one or more specimens from each group may be selected for more detailed studies. If a reduced number of specimens is to be selected for detailed examination, selection should be made after careful visual and stereomicroscope examinations have been made to define one or more factors that characterize each group.

12.1.3 *Specimens from Natural Exposures*.-These specimens should be laid out in logical order-either by materials, proportions, age, or any combination thereof, and compared with respect to composition and condition. Significant features for more detailed examination should be marked and noted. Table 3 shows features of fire-damaged concrete.

12.1.4 *Concrete Products*:

12.1.4.1 The concrete product samples may consist of complete units when they have relatively small dimensions, such as tile, block, or brick, or portions removed from units by coring or sawing. Samples should be organized and oriented in a manner appropriate to objectives of examination. For example, portions taken from a single product unit should be grouped together, and each sample should be described by visual observation and measurement of dimensions in relation to markings or labels. The following information should be recorded or clearly marked on the samples: location in product unit (top, side, end, interior, etc.); vertical and horizontal directions as cast or molded; outer and inner ends; position in product unit during curing period; position of sample relative to highly stressed portions of concrete adjacent to tendon anchorages; and location in unit as placed in the construction. Sketches or photographs of pertinent features should be recorded to show conditions such as cracking, staining, chemical deposits, presence of foreign matter, segregation, and surface defects.

12.1.4.2 Methods described in sections 12.1.1 and 12.1.2 are applicable in the examination of concrete products. The investigation may be directed toward features resulting from the specific manufacturing operations involved such as mixing, molding, demolding, curing, and any prestressing methods. For example, lack of uniformity might originate in incomplete mixing, improper consolidation during molding, or incomplete or nonuniform curing. Surface defects and poor appearance may result from improper application of form-release agents, which may cause inhibition of hydration of the cement in a near-surface zone. Such features can be detected and described by visual and microscopical examinations of formed or molded surfaces, sawed and lapped surfaces, or fracture surfaces across the sample.

12.1.5 *Laboratory Specimens*.-These specimens should be laid out in logical order and compared with respect to composition and condition, and to features influenced or expected to be influenced by testing.

12.1.6 *Stereomicroscope Examination*.-The stereomicroscope examination reveals additional details at magnifications from 5X to 150X, see tables 1 and 2. The visual and stereomicroscope examinations are often performed alternately. Examinations at low magnifications reveal characteristics of formed, finished, deteriorated, broken, sawed, or ground surfaces. Old cracks may be opened and their surfaces examined to detect reaction products and secondary alteration. These cracks are frequently of different color than mass of the concrete, and appear blurred by secondary deposits.

12.1.6.1 Freshly broken surfaces may follow structural weaknesses, and may reveal significant features that have not been masked by secondary alteration.

12.1.6.2 Sawed and ground surfaces are examined to detect fine cracks and trace networks of cracks that are not perceptible on drilled or sawed surfaces, filling and partial filling in voids and cracks, and to detect rims on aggregate particles that may indicate chemical reaction between cement and aggregate. Rims on gravel or natural sand should be presumed to be a result of weathering in the deposit unless samples of aggregates used are available and show that rims were not present before aggregate was used in concrete. Rims produced in the concrete on particles of sand and gravel are absent or relatively thin and faint at locations where particles are in contact with an air void. Rims produced by weathering may mask rims produced by alkali-silica reaction. Rimmed crushed stone in concrete usually indicates an alteration in the concrete from alkali-silica or alkali-carbonate reactions [7,8,9]. Pale rims in mortar bordering coarse aggregate [6,11] and pale areas in mortar may be gel-soaked paste [10] or highly carbonated paste adjoining carbonate aggregate that has undergone an alkali-carbonate reaction.

12.1.6.3 Deposits in old cracks may include calcite, ettringite, calcium hydroxide, or more unusual crystalline substances, and occasionally include sand, silt, clay, and freshwater or saltwater organisms. Such organisms may provide evidence that part of a structure that is not ordinarily submerged has been submerged.

12.1.6.4 Quantitative determination of concrete constituents can be made by microscopical point-count or linear-traverse methods in general accord with requirements of USBR 4457. A total analysis may include proportional amounts of coarse aggregate, fine aggregate, cementitious matrix, and air voids. The differentiation of coarse and fine aggregate is not accurate unless the two fractions are distinquishable lithologically because maximum dimension of particles usually is not intersected by prepared surface. Similarly, the proportion of individual rock types can be determined quantitatively by these methods, such as the content of unsound or reactive constituents in the coarse or fine aggregate, or both; proportions of lightweight and normal weight aggregate; and abundance of granular contaminating substances.

12.2 *Polarizing Microscope Examination*:

12.2.1 *Characteristics of Good Concrete Thin Sections*.–Features that characterize good, thin sections of concrete or mortar include: (1) mounted lower surface is free of abrasive and has been ground to a smooth matte finish normally obtained by finishing surface with optical alumina or equivalent, (2) lower surface of blank is entire, (3) air voids have complete peripheries, (4) there is a sharp boundary between void and surrounding mortar, (5) deposits in voids are preserved, and (6) aggregate that has been observed under stereomicroscope to be entire when blank was selected has remained entire and microfractures have not been produced in sectioning. It is very difficult to avoid production of microfractures when aggregate is principally quartzite and quartz if it is desired to reduce section to a thickness of 1181 microinches (30 μm) so that brightest birefringence color of quartz is of first-order white. Some cracks will be formed and some loss of paste that is softer than quartz aggregate will occur.

12.2.1.1. The desirable thickness of the thin section ranges from about 787 to 1575 microinches (20 to 40 μm). Thinner sections may be required for detailed examination of the cement paste matrix. It is sometimes necessary to abandon the normal thickness and use a thicker section to preserve fragile deposits in voids such as alkali-silica gel, ettringite, calcium hydroxide, calcite, aragonite, or thaumasite. When it is desired to preserve contact between mortar and coarse aggregate, it may be preferable to have the section thicker than normal with the highest birefringence color of the quartz a pale first-order yellow. In normal concrete, material bordering the aggregate consists of amorphous cement gel, with calcium hydroxide crystals evenly distributed but with slight concentrations along undersides of fine and coarse aggregate if section is cut parallel to placement direction. For an alkali-silica reaction, there is usually a zone depleted in or free of calcium hydroxide surrounding reacted aggregate particles. Gel is occasionally present surrounding the aggregate or soaking the paste so that it is completely dark with crossed polars and brown grading hazily to a more normal paste in plane polarized light. Gel-soaked paste is fairly easy to recognize, and it is possible to recognize depleted calcium hydroxide around a reacted aggregate particle if the fine aggregate of any crusher dust present does not contain much colorless mica. Thin flakes of muscovite can be confused with thin tablets of calcium hydroxide when both are viewed on edge; they can be distinquished if the higher index of the mica is observed.

12.2.1.2 It is sometimes preferable to lose part of the section or crack the quartz in order to distinguish among quartz (birefringence 0.009), calcium hydroxide (birefringence 0.027), and calcite (birefringence 0.172). When these three materials occur together, the quartz particles will be shaped like sand grains or rock fragments while the calcium hydroxide will be present either as tablets tangential to aggregate or as poikilitic crystals in the paste enclosing residual cement grains or areas of gel. The birefringence of calcium hydroxide is three times that of quartz, birefringence of calcite is 6.4 times that of calcium hydroxide, and birefringence of aragonite is 5.7 times that of calcium hydroxide. While aragonite is fairly uncommon in concrete, calcite is common as a product of carbonation and as an ingredient of aggregate. At the normal thickness of 1181 microinches, (30 μm) the highest birefringence of calcium hydroxide viewed parallel to the cleavage is bright first-order yellow with an occasional orange or first-order red. Calcite in the same section has high-order white birefringence except in very minute grains where it is very thin, approximately rhombic in shape, and birefringence is first-order white. The birefringence relationships discussed in this section are the basis that makes possible much of the interpretation of concrete thin sections.

12.2.2.2 *Choice of Areas for Thin Sections of Concrete*.–Areas from which thin sections are to be prepared usually should be chosen after examining the sawed or sawed and ground surface with a stereomicroscope. Selection of the area may depend on the directed examination features, or selection may be affected by the presence of highly deteriorated concrete and the desire to choose a volume strong enough to endure sectioning even after impregnation. In this case, an area of mortar with coarse aggregate at corners or along sides may be the best selection. If it is desired to compare the aggregate with an aggregate of known source to establish whether both came from the same source, coarse aggregate should be selected in sufficient quantity to cover the range of varieties present and their physical condition. If concrete has been subjected to alkali-silica or alkali-carbonate reactions, areas selected for sectioning should include coarse aggregate with cracks inside the periphery but surrounding the center and cracks in middle of particle, which narrow toward the border and which may or may not contain gel, in the case of alkali-silica reaction. Reaction-rimmed particles may be chosen for sectioning for either type of reaction, but it is usually futile to do so because rims distinct to the naked eye or to the lower power of the stereomicroscope may not be visible in thin section. Features visible in the examination of thin sections of concrete are shown in table 5.

12.3 *Metallographic Microscope Examination*[12].– There are two advantages of examining concrete with a metallographic microscope: (1) only one prepared surface is required, and (2) the polished surface enhances and allows etching the residual cement. When the objective of the petrographic examination is particularly concerned with the composition and characteristics of the cementitious materials, polished sections that are produced by grinding and polishing a sawed piece of concrete are particularly useful in detecting unusual amounts of free calcium oxide, magnesium oxide, or their hydration products and other cementitious constituents. Although the coarser relict cementitious grains may be far from a representative sample, they can reveal characteristics that, if correlated with behavior and history of concrete, can be extremely helpful in interpreting behavior. Table 6 lists constituents of concrete visible, after preparation, using different microscopes. Table 7 is a list of substances reported as occurring in concrete.

13. Report

13.1 Figure 1 may serve as a typical reporting form along with a cover letter. The report for the petrographic examination should include:

- Location and orientation of samples in the construction, products, or types of specimens.
- History of samples (as available).
- Physical and chemical tests made on the samples, with results.
- Description of samples and a report on mixture proportions (if available or estimated), workmanship, construction practice, and original quality of concrete in the construction (as available).
- Interpretation of nature of materials, and chemical and physical events that contributed to success or distress of the concrete.

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Table 1.– Visual examination of concrete[4].

COARSE AGGREGATE	+ FINE AGGREGATE	+ MATRIX	+ AIR	+ EMBEDDED ITEMS
Composition:				
Maximum dimension[1], in inches or mm, in the range > d > Type: 1. Gravel 2. Crushed stone 3. Mixed 1 and 2 4. Other (name) 5. Mixed, 1 and/or 2 and/or 4 If type 1, 2, or 4, homogeneous or heterogeneous. Lithologic types	Type: 1. Natural sand 2. Manufactured sand 3. Mixed 4. Other (name) 5. Mixed, 1 and/or 2 and/or 4 If type 1, 2, or 4, homogeneous or heterogeneous.	Color, by comparison with National Research Council Rock Color Chart (1963). Color Distribution: 1. Mottled 2. Even 3. Gradational changes.	More than 3% of total, predominantly in spherical voids? Less than 3% of total, abundant nonspherical voids? Color differences between voids and mortar?	Type, size, and location; kinds of metal and other items.
Coarse aggregate more than 20, 30, 40, or 50% of total.			Voids empty, filled, lined, or partly filled	
Fabric:				
Shape Distribution Packing Grading (even, uneven, excess, or deficiency of size or sizes) Parallelism of flat sides or long axes of exposed sections, Normal to direction of placement and/or parallel to formed and finished surfaces.[2]	Distribution[3] Particle shape[3] Grading[3] Preferred orientation[3]	Distribution	Shape Distribution Grading[3] Parallelism of long axes of irregular voids or sheets of voids with each other, or with flat sides or long axes of coarse aggregate.	Voids below horizontal or low-angle reinforcement.
Condition:				
Does it ring when hit lightly with a hammer, or give a dull flat sound? Can you break it with your fingers? Cracks? How distributed? Through or around coarse aggregate? With cores or sawed specimens, did aggregate tear in drilling or sawing? Crack fillings? Surface deposits? If air dry, are there unusually wet or dry looking areas? Rims on aggregate?				Clean or corroded? Are cracks associated with embedded items?

[1] A substantial portion of the coarse aggregate has maximum dimensions in the range shown as measured on sawed or broken surfaces.

[2] Sections sawed or drilled close to and parallel to formed surfaces appear to show local turbulence as a result of spading or rodding close to the form. Sections sawed in plane of bedding (normal to direction of placement) are likely to have inconspicuous orientation. Sections broken normal to placement, in conventionally placed concrete with normal bond, tend to have aggregate knobs abundant on bottom of upper piece as cast and sockets abundant on top of lower piece as cast.

[3] As perceptible.

Table 2.–Outline for examination of concrete with a stereomicroscope [4].

COARSE AGGREGATE	FINE AGGREGATE	MATRIX	VOIDS
Lithologic types and mineralogy, as perceptible.	Lithologic types and mineralogy, as perceptible.	Color	Grading
Surface texture.		Fracture around or through aggregate	Proportion of sphereical to nonspherical.
Within piece: Grain shape	Shape	Contact of matrix with aggregate: Close, no opening visible on sawed or broken surface; aggregate not dislodged with fingers or probe; boundary openings frequent, common, rare.	Nonspherical, ellipsoidal, irregular, disk-shaped.
Grain size extreme range observed, inch (mm)	Surface texture		
Median within range ____ to ____ inch (mm)			Color change from interior surface to matrix.
Textureless (too fine to resolve)	Grading		
Uniform or variable			
From piece to piece:	Distribution	Width	Interior surface luster like rest of matrix, dull, shining.
Intergranular bond Porosity and absorption[1]		Empty	
If concrete breaks through aggregate, through how much of what kind?		Filled	Linings in voids absent, rare, common (in most); complete, partial, colorless, colored, silky tufts, hexagonal tablets, gel, other.
If boundary voids, along what kind of aggregate? All? All of one kind? More than 50% of one kind? Several kinds?		Cracks present, absent, result of specimen preparation, preceding specimen preparation.	Underside voids or sheets of voids uncommon, small, common, abundant.
		Mineral admixtures[2]	
Segregation		Contamination	
		Bleeding	

Condition Note.–When examined at 6× to 10× under good light, the freshly broken surface of a concrete in good physical condition, that still retains most of its natural moisture content, has a luster that in mineralogical terms is subtranslucent glimmering vitreous [24]. Thin edges of splinters of the paste transmit light; reflections appear to come from many minute points on surface, and quality of luster is like that from broken glass but less intense. Concrete in poor physical condition is more opaque on a freshly broken surface, and luster is dull, subvitreous going toward chalky. A properly cured laboratory specimen from a concrete mixture of normal proportions, cured 28 days, has shown normal compressive or flexural strength, and that is broken with a hammer and examined on a new break within a week after time it has finished curing, should provide an example of concrete in good physical condition. Under the same conditions of examination, when there is reasonable assurance that concrete does not contain white portland cement or slag cement, color of matrix of concrete in good physical condition is definitely gray or definitely tan, except adjoining old cracks or original surfaces.

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[1] Pore visible to the naked eye, or at ____ × or sucks in warer that is dropped on it.

[2] Dark solid spheres or hollow-centered spheres of glass or magnetite, or some of glass and some of magnetite, recognizable at magnification of 9× on sawed or broken surfaces. Other mineral admixtures with characteristic particles visible at low magnification are recognizable. Ground surface of concrete containing portland blast-furnace slag cement are unusually white near free surfaces but retain greenish or blue-greenish patches, and slag particles can be seen with stereomicroscope or polarizing microscope.

Table 3. – Effects of fire on characteristics of concrete.

CHARACTERISTIC	CAUSES AND EFFECTS	INVESTIGATION METHODS
Surface Hardness	Dehydration to 212 °F (100 °C) removes free water; dehydration is essentially complete at 1004 °F (540 °C); calcium hydroxide goes to calcium oxide between 842 and 932 °F (450 and 500 °C). Paste expands with thermal coefficient effect and then shrinks, cracks, decrepitates, and becomes soft [21].	Beneath the softened concrete, which can be tested in accordance with USBR 4805, concrete is probably normal if it has not undergone color change. Establish by coring for for compressive tests, by wear tests (CRD-C 52) [21], and by scratching with a knife.
Cracking	Perpendicular to face and internal, where heating or cooling caused excess tensile stresses. In some new concrete, resembles large-scale shrinkage cracking; may penetrate up to 3.9 inches (100 mm) but may heal autogenously [21].	Examination of surface, ultrasonic tests, coring, and petrographic examination [21].
Color Change.–When concrete has not spalled, observe depth of pink color to estimate fire exposure.	Concrete made with sedimentary or metamorphic aggregate shows permanent color change on heating. Color normal to 446 °F (230 °C); goes from pink to red between 554 and 1094 °F (290 and 590 °C); between 1094 and 1652 °F (590 and 900 °C), color changes to gray and then to buff [21]. For temperatures up to about 932 °F (500 °C), temperature distribution is little affected by using carbonate rather than siliceous aggregate [22]. At 1063 °F (573 °C), low quartz inverts to high with a 0.85-percent increase in volume, producing popouts. Spalling over steel to expose one-fourth of bar at 1454 °F (790 °C); white-powdered decomposed hydration products at 1652 °F (900 °C). Surface cracking at about 554 °F (290 °C); deeper cracking at about 1004 °F (540 °C).	Color change is the factor most useful to investigator; permits recognizing how deeply a temperature of about 572 °F (300 °C) occurred [22].
Aggregate Behavior.–Aggregate behavior affects strength, modulus, spalling, cracking, surface hardness, and residual thermal strains [21].	Aggregates differ in thermal diffusivity, conductivity, and coefficient of expansion. Heat transmission decreases from concrete made with highly siliceous aggregate, sandstone, traprock, limestone, and lightweight aggregates [21].	Changes upon heating are often accompanied by a volume change [21].
Spalling	Occurs subparallel to free face; followed by breaking off of saucer-like pieces especially at corners and edges [21].	
Compressive Strength and Elastic Modulus.–For concrete at least 1-year old, strength will increase after cooling from 572 °F (300 °C) if design strength was attained [22].	Reduction in strength of concrete containing siliceous gravel after heating, then cooling and testing: Heated to temperature, °F (°C) — Reduction, percent 356 (180) — 25 698 (370) — 50 1058 (570) — 80 Reduction in modulus temperature, °F (°C) — Reduction, percent 392 (200) — 25 806 (430) — 50 1400 (760) — 70	Determinations by compressive tests and static modulus of cores; USBR 4805 for qualitative determination; USBR 4597 [21].

Table 4. – Common types of concrete deterioration.

TYPE OF DETERIORATION	COMMON EVIDENCE	OCCURRENCE
Alkali-aggregate reaction	Silica Gel	Generally clear and colorless or white and porcelaneous; generally hard and desiccated; occurs in voids, fractures, rock sockets, porous aggregate particles, and cementitious paste and as an exudation on exposed surfaces.
	Reaction Rims	Often clarified; occur around reactive aggregate particles; incipient fractures associated with reaction rims may occur within aggregate particles.
	Fractures	Generally occur in paste and around or through aggregate particles; pattern cracking occurs on exposed surfaces; generally associated with reactive aggregate particles and formation of silica gel; often filled with silica gel.
	Concrete Appearance	Generally dull, white, and chalky paste.
Sulfate attack	Sulfate Minerals (gypsum, ettringite, etc.)	Generally white, fibrous, subspherulitic, or platy crystals; occurs in voids, fractures, and rock sockets.
	Fractures	Generally occur in paste; pattern cracking occurs on exposed surfaces; generally associated with formation of sulfate minerals; often filled with sulfate minerals.
	Concrete Appearance	Generally dull, white, porous, and chalky paste.
Freeze-thaw	Carbonation	Generally white, calcium carbonate deposits; occurs in voids, fractures, rock sockets, and paste.
	Fractures	Generally occur in paste and around aggregate particles near and parallel to exposed surfaces; may also occur within absorptive, clayey, and/or poor quality aggregate particles; associated with formation of ice crystals in concrete or aggregate particles due to freezing; often filled with calcium carbonate.
	Popouts	Generally absorptive, clayey, and/or poor quality aggregate particles near exposed surfaces; results in pitting of exposed surfaces.

Table 5. – Outline for examination of concrete in thin sections.

COARSE AND FINE AGGREGATE	RELICT CEMENTITIOUS GRAINS AND HYDRATION PRODUCTS	CHARACTERISTICS OF CEMENT PASTE
Mineralogy, texture, fabric, variable or homogeneous. Grading: Excess or deficiency of sand sizes is to be judged after examination of a series of thin sections. Grain size and nature of internal boundaries in aggregate. Classification of coarse and fine aggregate. Natural mineral aggregate or crushed stone; natural or manufactured fine aggregate. Bond with matrix; peripheral cracks inside borders of aggregate grains; internal cracks. General microfractures if established that they existed before thin sectioning. *Alkali-Carbonate Reactions.*–If coarse aggregate is a carbonate rock or rocks, are there rims or partial rims depleted in calcium hydroxide? Partly dolomitic rocks that have reacted are occasionally bordered with paste free from calcium hydroxide along dolomitic portion while paste along limestone portion is normal. See other comments in column 3. *Alkali-Silica Reaction.*–Does aggregate contain particles of types known to be reactive (chert, novaculite, acid volcanic glass, cristobalite, tridymite, opal, bottle glass)? If quartzite, metamorphosed subgraywacke, argillite, phyllite, or any of the reactive types noted in first question, are there internal cracks inside periphery of aggregate? Has aggregate been gelatinized so that it has pulled off during sectioning leaving only a peripheral hull bonded to mortar? (This last phenomenon also occurs in concrete with air-cooled slag aggregate, where it indicates reaction between cement and slag). Cracks that appear to be tensile and to narrow from center toward border of particle are also evidence of alkali-silica reaction. [10].	For concrete over 2 years old and normally cured, the only residual cement grains are those that were largest, which may be composed of several constituents or be of alite or belite (substituted C_3S and C_2S). The latter two may be bordered by one or two layers of gel having different indexes of refraction, or by a layer of calcium hydroxide. The largest relict grains may be truly unhydrated and retain the low (dark gray) birefringence of alite in distorted quasi-hexagonal sections and the visible birefringence to first-order yellow of the lamellar twins in rounded grains of belite. Interstitial aluminoferrite appears as prismatic grains ranging in color from brown to greenish-brown to reddish-brown, and having a high refractive index and pleochroism masked by color of grain. Tricalcium aluminate is usually not recognized in thin sections because cubic form is isotropic or because it hydrates early in hydration history of concrete forming submicroscopic ettringite or tetracalcium aluminum sulfate hydrate or other tetracalcium aluminum hydrates with or without other anions. These may be visible in voids in older concrete but are best discriminated by X-ray diffraction. Cements from different sources have different colors of aluminoferrite; and calcium silicates have pale green, yellow, or white shades. It should be possible to match cements from one source.	Normal cement paste consists, in plane transmitted light, of pale tan matter varying somewhat in index of refraction and containing relict unhydrated cement grains. In concrete sectioned at an early age or not adequately cured, paste contains unhydrated cement grains ranging from a few micrometers in maximum size to as large as 100 μm in maximum diameter if cement was ground in open-circuit mills or was deliberately ground to a low surface area to reduce heat of hydration. With crossed polars, normal paste is black or very dark mottled gray with scattered anhedral poikilitic crystals or small segregations of calcium hydroxide and scattered relict grains of cement. In concrete of high water-cement ratio and siliceous aggregate, calcium hydroxide crystals are as large as the maximum size of residual cement grains, about 100 μm. In concrete of lower water-cement ratio, higher cement content, and either siliceous or carbonate aggregate, maximum size of calcium hydroxide crystals is considerably smaller. Regardless of water-cement ratio and type of aggregate, calcium hydroxide crystals occupy space tangential to undersides of aggregate particles. Where all aggregate is carbonate rock, maximum size of calcium hydroxide is smaller than in comparable concrete with siliceous aggregate. (Calcium hydroxide is probably epitaxial on calcite). Cement paste in concrete that has been subjected to prolonged acid leaching is low in calcium hydroxide, which is present as recrystallized virtually anhedral grains precipitated near exterior surfaces. For concrete over 2 or 3 years old and made with type I, II, or III cement, some ettringite is to be expected as rosettes in air voids; this is a normal phenomenon. To demonstrate sulfate attack, it must be established chemically that the SO_3 content of concrete is greater than would be supplied by original sulfate content of cement. Ettringite in voids is not ettringite that has damaged concrete although it may accompany submicroscopic ettringite in the paste that has damaged the concrete.

Table 6. - Characteristics of concrete observed using microscopes.

Characteristic		Type of Microscope	
	Stereomicroscope	Petrographics	Metallographic
Aggregate:			
Shape	X	X	X
Grading	X	-	-
Distribution	X	-	-
Texture	X	X	X
Composition	X	X	-
Rock types	X	X	-
Alteration	X	X	-
degree	X	X	
products	X	X	
Coatings	X	X	-
Rims	X	X	-
Internal cracking	X	X	X
Contamination	X	X	-
Concrete:			
Air-entrained or not	X	X	X
Air voids	-	-	-
shape	X	X	X
size	X	X	X
distribution	X	-	-
Bleeding	X	-	-
Segregation	X	-	-
Aggregate-paste bond	X	X	X
Fractures	X	X	X
Embedded items			
size	X	-	-
shape	X	-	-
location	X	-	-
type	X	-	-
Alteration			
degree and type	X	X	X
reaction products			
location	X	X	X
identification	X[1]	X	-
Nature and condition of surface treatments	X	X	-
Paste:			
Color	X	X	-
Hardness	X	-	X
Porosity	X	-	X
Carbonation	X	X	-
Residual cementitious			
distribution	-	X	X
particle size	-	X	X
abundance	-	X	X
composition	-	X	X
Mineral admixtures	X[2]	X	X
size	-	X	X
abundance	X	X	X
identification	X	X	X
Compounds in hydrated cement	X[3]	X	X
Contamination			
size	X	X	X
abundance	X	X	X
identification	-	X	X[4]

[1] Secondary ettringite can sometimes be recognized by crystal habit and silky luster.

[2] Fly ash can be detected by color and shape when dark spheres are present. In concrete that has not oxidized, presence of slag may be inferred from green or blue color of paste.

[3] Ettringite and calcium hydroxide in voids may be recognized by their crystal habits.

[4] Magnesium oxide and calcium oxide should be identifiable in polished section.

Table 7. - Secondary deposits in concrete.[1]

COMPOUND AND MINERAL EQUIVALENT	INDEXES OF REFRACTION	FORM AND OCCURRENCE
$CaCO_3$ (calcium carbonate); calcite	$\omega = 1.658$ $\epsilon = 1.486$	Fine-grained, white or gray masses or coatings in cementitious paste, in voids, along fractures, or on exposed surfaces; very common.
$CaCO_3$ (calcium carbonate); aragonite	$\alpha = 1.530$ $\beta = 1.680$	Minute, white prisms or needles in voids or fractures in concrete; rare.
$CaCO_3$ (calcium carbonate); vaterite	$o = 1.544–1.550$ $E = 1.640–1.650$	Spherulitic, form-birefringent, white encrustations on moist-stored laboratory specimens (vaterite A); also identified in sound concrete from structures by X-ray diffraction (α - vaterite); common [11].
$Ca_6[Al(OH_6)]_2{\cdot}24H_2O\ (SO_4)_3{\cdot}2H_2O$ (6-calcium aluminate trisulfate-32 hydrate) [23]; ettringite.[2]	$\omega = 1.464–1.469$ $\epsilon = 1.458–1.462$	Fine, white fibers or needles or spherulitic growths in voids, in cement paste, or in fractures; very common [4,11].
$3CaO{\cdot}Al_2O_3{\cdot}CaSO_4{\cdot}12H_2O$ (tetracalcium aluminate monosulfate-12-hydrate)	$\omega = 1.504$ $\epsilon = 1.49$	White to colorless, minute, hexagonal plates in voids and fractures; very rare [11].
$Ca_4Al_2\ (OH)_{14}{\cdot}6H_2O$ (tetracalcium aluminate-13-hydrate)	$\omega = 1.53$ $\epsilon = 1.52$	Micalike, colorless, pseudohexagonal, twinned crystals in voids; very rare [14].
$Na_2O{\cdot}CO_2{\cdot}H_2O$ (hydrous sodiumcarbonate); thermonatrite	$\alpha = 1.420$ $\beta = 1.506$ $\gamma = 1.524$	Minute inclusions in alkali silica gel; rare [11].
$2Al_2O_3{\cdot}SO_3 15H_2O$ (hydrated aluminum sulfate); paraluminite	$\alpha = 1.463 \pm 0.003$ $\beta = 1.471$ $\gamma = 1.471$	Occurring in cavities in intensely altered concrete; very rare [14].
$CaSO_4{\cdot}2H_2O$ (calcium sulfate dihydrate); gypsum	$\alpha = 1.521$ $\beta = 1.523$ $\gamma = 1.530$	White to colorless crystals in voids, in cement paste, or along surfaces of aggregate particles in concrete or mortar affected by sulfate or seawater attack; unusual.
$Ca(OH)_2$ (calcium hydroxide); portlandite	$\omega = 1.574$ $\epsilon = 1.547$	White to colorless, hexagonal plates or tablets in cement paste, in voids, along fractures; ubiquitous in concrete.
$Mg(OH)_2$ (magnesium hydroxide); brucite	$\omega = 1.559$ $\epsilon = 1.580$	White to yellow, fine-grained encrustations and fillings in concrete attacked by magnesian solutions or seawater; unusual [15,16].
$SiO_2{\cdot}n\ H_2O$ (hydrous silica); opal	$\eta = 1.43$ (varies with water content).	White to colorless, finely divided, amorphous; resulting from intense leaching or carbonation of cementitious paste, unusual in recognizable proportions.
$Na_2O{\cdot}K_2O{\cdot}CaO{\cdot}SiO_2$ (alkalic silica gel)	$\eta = 1.46–1.53$	White, yellowish, or colorless; viscous, fluid, waxy, rubbery, hard; in voids, fractures, exudations, aggregate; common [8,18].
$Fe_2O_3{\cdot}nH_2O$ (hydrated iron oxides); limonite	opaque or nearly so.	Brown stain in fracture and on surfaces; common.
$Ca_6[Si(OH_6)]_2{\cdot}24H_2O(SO_4)_2(CO_3)_2$ (thaumasite)[2] [20]	$\omega = 1.504$ $\epsilon = 1.468 \pm 0.002$	Prismatic, hexagonal; capable of growing in continuity with ettringite; in sewer pipe subject to sulfate attack, in grout, in some pavement [20].
$K_2Ca(SO_4)_2){\cdot}H_2O$ (syngenite)	$\alpha = 1.501$ [23] $\beta = 1.51$ $\gamma = 1.51$	Found in cavities and zones peripheral to slate particles, in fibrous form [17].
$Mg_{3/4}Al_{1/4}(OH)_2(CO_3)_{1/8}(H_2O)_{1/2}$ (hydrotalcite) [20].	$\omega = 1.510 \pm 0.003$ $\epsilon = 1.495 \pm 0.003$	Foliated platy to fibrous masses [13,20].

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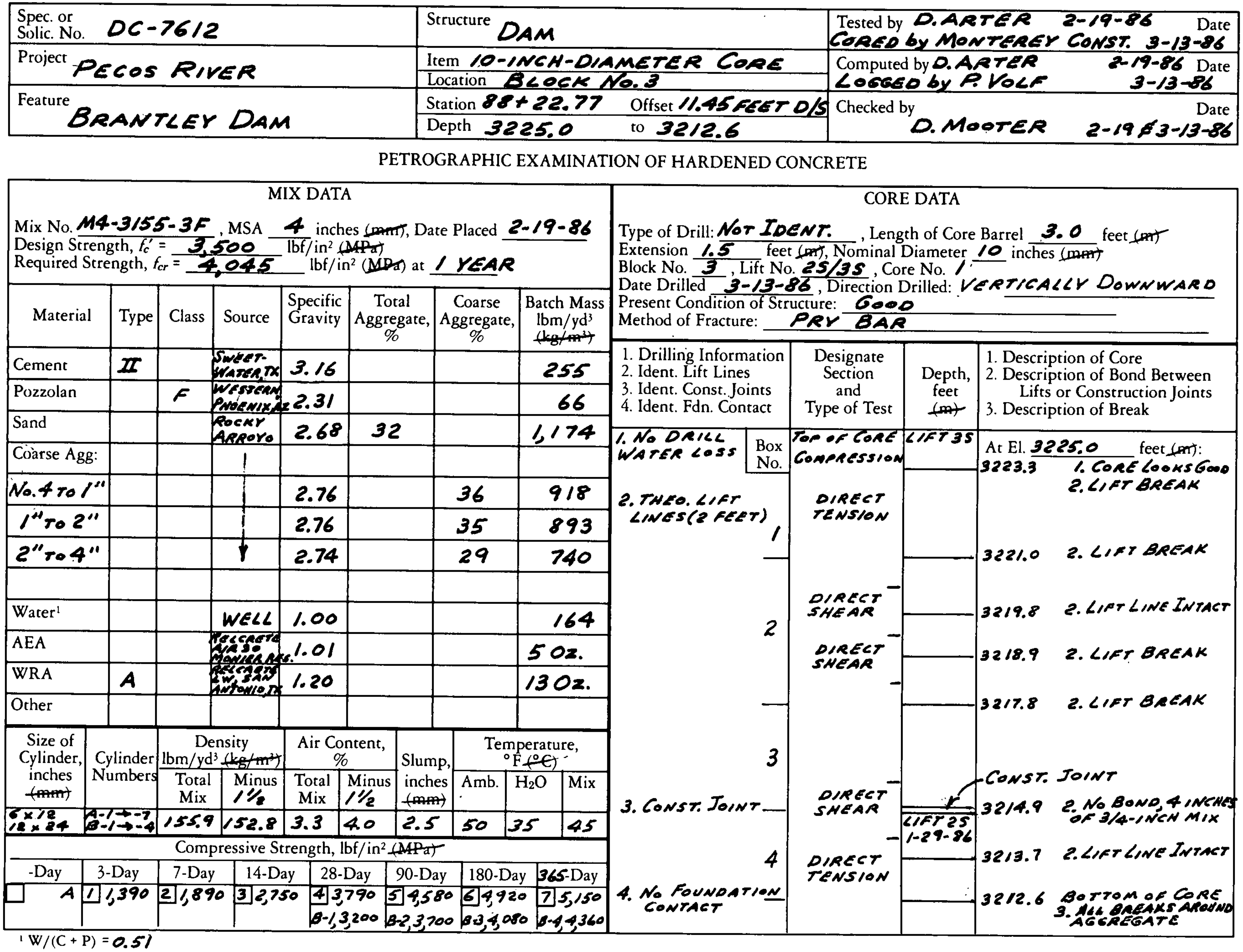
[1] The literature and private reports include data on many unidentified secondary compounds in concrete; these are not included in this table. Indexes of refraction of common mineralogic types are taken from standard works on mineralogy.

[2] Higher and lower indexes of refraction have been recorded for naturally occurring ettringite [23] and thaumasite [19], but it is not known that naturally occurring minerals and compounds found in hydrated cement are of same composition.



Spec. or Solic. No. DC-7612	Structure DAM	Tested by D. ARTER 2-19-86 Date CORED by MONTEREY CONST. 3-13-86
Project PECOS RIVER	Item 10-INCH-DIAMETER CORE Location BLOCK No. 3	Computed by D. ARTER 2-19-86 Date LOGGED by P. VOLF 3-13-86
Feature BRANTLEY DAM	Station 88+22.77 Offset 11.45 FEET D/S Depth 3225.0 to 3212.6	Checked by Date D. MOOTER 2-19 & 3-13-86

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE

MIX DATA

Mix No. M4-3155-3F, MSA 4 inches ~~(mm)~~, Date Placed 2-19-86
Design Strength, f_c' = 3,500 lbf/in² ~~(MPa)~~
Required Strength, f_{cr} = 4,045 lbf/in² ~~(MPa)~~ at 1 YEAR

Material	Type	Class	Source	Specific Gravity	Total Aggregate, %	Coarse Aggregate, %	Batch Mass lbm/yd³ ~~(kg/m³)~~
Cement	II		SWEET-WATER, TX	3.16			255
Pozzolan		F	WESTERN, PHOENIX, AZ	2.31			66
Sand			ROCKY ARROYO	2.68	32		1,174
Coarse Agg:			↓				
No. 4 TO 1"			↓	2.76		36	918
1" TO 2"			↓	2.76		35	893
2" TO 4"			↓	2.74		29	740
Water[1]			WELL	1.00			164
AEA			RELCRETE AIR 30 MONIER RES.	1.01			5 Oz.
WRA	A		RELCRETE LW, SAN ANTONIO, TX	1.20			13 Oz.
Other							

Size of Cylinder, inches ~~(mm)~~	Cylinder Numbers	Density lbm/yd³ ~~(kg/m³)~~ Total Mix	Density Minus 1½	Air Content, % Total Mix	Air Content, % Minus 1½	Slump, inches ~~(mm)~~	Temperature, °F ~~(°C)~~ Amb.	H₂O	Mix
6 x 12 12 x 24	A-1 → -7 B-1 → -4	155.9	152.8	3.3	4.0	2.5	50	35	45

Compressive Strength, lbf/in² ~~(MPa)~~

-Day	3-Day	7-Day	14-Day	28-Day	90-Day	180-Day	365-Day
☐ A	1 1,390	2 1,890	3 2,750	4 3,790	5 4,580	6 4,920	7 5,150
				B-1 3,200	B-2 3,700	B-3 4,080	B-4 4,360

[1] W/(C + P) = 0.51

CORE DATA

Type of Drill: NOT IDENT., Length of Core Barrel 3.0 feet ~~(m)~~
Extension 1.5 feet ~~(m)~~, Nominal Diameter 10 inches ~~(mm)~~
Block No. 3, Lift No. 25/35, Core No. 1
Date Drilled 3-13-86, Direction Drilled: VERTICALLY DOWNWARD
Present Condition of Structure: GOOD
Method of Fracture: PRY BAR

1. Drilling Information 2. Ident. Lift Lines 3. Ident. Const. Joints 4. Ident. Fdn. Contact	Box No.	Designate Section and Type of Test	Depth, feet ~~(m)~~	1. Description of Core 2. Description of Bond Between Lifts or Construction Joints 3. Description of Break
1. No DRILL WATER LOSS		TOP OF CORE COMPRESSION	LIFT 35	At El. 3225.0 feet ~~(m)~~:
2. THEO. LIFT LINES (2 FEET)	1	DIRECT TENSION		3223.3 1. CORE LOOKS GOOD 2. LIFT BREAK
				3221.0 2. LIFT BREAK
	2	DIRECT SHEAR		3219.8 2. LIFT LINE INTACT
		DIRECT SHEAR		3218.9 2. LIFT BREAK
				3217.8 2. LIFT BREAK
3. CONST. JOINT	3	DIRECT SHEAR		CONST. JOINT 3214.9 2. No BOND, 4 INCHES OF 3/4-INCH MIX
			LIFT 25 1-29-86	3213.7 2. LIFT LINE INTACT
4. No FOUNDATION CONTACT	4	DIRECT TENSION		3212.6 BOTTOM OF CORE 3. ALL BREAKS AROUND AGGREGATE

Figure 1. - Mix data, properties, and log of concrete core (sheet 1 of 2).

Spec. or Solic. No. DC-7612	Structure DAM	Tested by CORED by MONTEREY CONST. Date 3-14&17-86
Project PECOS RIVER	Item 10-INCH-DIAMETER CORE Location BLOCK No. 3	Computed by LOGGED by P. VOLF Date 3-14&17-86
Feature BRANTLEY DAM	Station 33+47.77 Offset 20.08 FT D/S Depth 3225.0 to 3212.9	Checked by D. MOOTER Date 3-17-86

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE

CORE DATA

Type of Drill: NOT IDENT., Length of Core Barrel 3.0 feet ~~(m)~~
Extension 1.5 feet ~~(m)~~, Nominal Diameter 10 inches ~~(mm)~~
Block No. 3, Lift No. 25/35, Core No. 2
Date Drilled 3-14&17-86, Direction Drilled: VERTICALLY DOWNWARD
Present Condition of Structure: GOOD
Method of Fracture: PRY BAR

1. Drilling Information 2. Ident. Lift Lines 3. Ident. Const. Joints 4. Ident. Fdn. Contact	Box No.	Designate Section and Type of Test	Depth, feet (m)	1. Description of Core 2. Description of Bond Between Lifts or Construction Joints 3. Description of Break
1. NO DRILL WATER LOSS		TOP OF CORE	LIFT 35	At El. 3225.0 feet ~~(m)~~:
2. THEO. LIFT LINES (2 FT)	1	DIRECT SHEAR		3222.2 1. CORE LOOKS GOOD 2. LIFT LINE INTACT
		DIRECT SHEAR		3220.0 2. LIFT BREAK
				3218.9
	2	COMPRESSION		
		DIRECT SHEAR		3217.2 2. LIFT BREAK
3. CONST. JOINT	3	DIRECT SHEAR	LIFT 25 1-29-86	CONSTRUCTION JOINT 3215.2 2. GOOD BOND, 4 INCHES OF 3/4-INCH MIX
4. NO FOUNDATION CONTACT				3212.9 BOTTOM OF CORE 3. ALL BREAKS AROUND AGGREGATE

CORE DATA

Type of Drill: ________, Length of Core Barrel ______ feet (m)
Extension ______ feet (m), Nominal Diameter ____ inches (mm)
Block No. ____, Lift No. ______, Core No. ______
Date Drilled ________, Direction Drilled: ____________
Present Condition of Structure: ____________
Method of Fracture: ____________

1. Drilling Information 2. Ident. Lift Lines 3. Ident. Const. Joints 4. Ident. Fdn. Contact	Box No.	Designate Section and Type of Test	Depth, feet (m)	1. Description of Core 2. Description of Bond Between Lifts or Construction Joints 3. Description of Break
				At El. ________ feet (m):

Figure 1. - Mix data, properties, and log of concrete core (sheet 2 of 2).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4900–92

PROCEDURE FOR

PULLOUT STRENGTH OF HARDENED CONCRETE OR SHOTCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4900; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: C 900-82.

1. Scope

1.1 This designation covers the procedure for determination of the pullout strength of hardened concrete or shotcrete in test specimens or structures by measuring the force required to pull an embedded metal insert and the attached truncated cone of concrete from a concrete mass.

2. Applicable Documents

2.1 *USBR Procedures*:
1104 Load Verification of Testing Machines
1430 Calibrating the Loading Device for Permeability Tests
4039 Compressive Strength of Cylindrical Concrete Specimens

2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 900 Standard Test Method for Pullout Strength of Hardened Concrete[1]

3. Summary of Procedure

3.1 A metal insert is embedded in fresh concrete or shotcrete; after either has hardened, the pullout strength is determined by measuring the maximum force required to pull insert from the mass. The configuration of the embedded insert and bearing ring of the loading system affects shape of pullout fracture within the mass and the measured pullout strength.

4. Significance and Use

4.1 For a given concrete or shotcrete and test apparatus, the pullout strength is related to other strength test results. Such strength relationships depend on configuration of embedded insert, bearing ring dimensions, depth of embedment, and level of strength development in the concrete or shotcrete. This relationship must be established for each system and each new combination of concreting or shotcreting materials prior to testing. Such relationships tend to be less variable where both pullout and other test specimens are of consistent size and cured under similar conditions. The references given in section 15 present experiences by different researchers on the use of pullout test equipment.

4.2 Pullout tests are used to determine when the inplace strength of the concrete or shotcrete has reached a specified level so that, for example, post-tensioning may proceed, forms and shores may be removed, or winter protection and curing may be terminated.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125.

6. Apparatus

6.1 The apparatus requires three basic subsystems: (1) a pullout insert, (2) a loading system, and (3) a load-measuring system (fig. 1).

NOTE 1.–A center-pull hydraulic jack with a suitable pressure gauge and bearing ring have been used satisfactorily.

6.1.1 The pullout insert shall be made of metal, and shall consist of a cylindrical head to be embedded in the fresh concrete or shotcrete, and a shaft firmly attached to the head.

6.1.2 For tests where the conic fracture intersects the exposed surface of the concrete or shotcrete, the loading system shall consist of a bearing ring to be placed against hardened surface concentrically around pullout insert shaft, and a loading apparatus with necessary load-measuring devices that can be readily attached to pullout shaft. For embedded tests where conic fracture surface does not intersect exposed surface, a bearing ring shall be provided on the concrete or shotcrete by using a highly compressible

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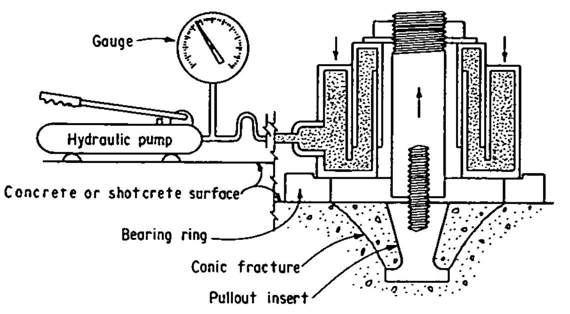
[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.



Note - Concrete or shotcrete surface may be top or bottom of slab or vertical or inclined wall.

Figure 1. - Apparatus for pullout test.

material to form a cylindrical void concentric with pullout shaft and having a diameter as specified in section 6.2.3.

6.1.3 Test apparatus shall include centering features that will ensure that ring is concentric with pullout insert shaft, and that applied load is axial to pullout shaft and uniform on bearing ring.

6.2 Equipment dimensions (fig. 2) shall be determined as follows:

6.2.1 Diameter of pullout insert head (d_2) shall be determined by specifier (note 2). Thickness of insert head and yield strength of metal shall be sufficient to avoid yielding of insert during test. Sides of the insert head shall be smooth.

NOTE 2.-Typical diameters are 1 and 1.2 inches (25 and 30 mm), but smaller and larger diameters have been used.

NOTE 3.-The pullout insert may be coated with a release agent to minimize bonding with concrete or shotcrete. Insert may be tapered to minimize side friction during testing, and may be notched to prevent rotation in the concrete or shotcrete if insert shafts are to be unthreaded from the embedded insert.

6.2.2 The length of the pullout insert shaft shall be such that the diameter of the insert head (d_2) and/or the bearing ring (d_3) may be varied to maintain an apex angle (α) of 65° to 70°, which is satisfactory in most cases and permits plotting of the inplace strength gain shortly after the concrete sets. Diameter of insert shaft (d_1) shall be no more than 0.6 times the head diameter (d_2). A pullout shaft may be threaded into the insert, or may be an integral part of insert.

6.2.3 Bearing ring shall have an inside diameter (d_3) of 2.0 to 2.4 times the insert head diameter (d_2), and shall have an outside diameter (d_4) of at least 1.25 times inside diameter (d_3). Thickness of bearing ring (t) shall be at least 0.4 times pullout insert head diameter (d_2).

6.2.4 The limits for the dimensions and configurations of pullout test inserts and apparatus are intended to accommodate various systems. Tolerances for dimensions of inserts shall be ±2 percent within a given system.

6.2.5 Loading apparatus shall have sufficient capacity to provide the loading rate prescribed in section 11.4, and to also exceed maximum load expected.

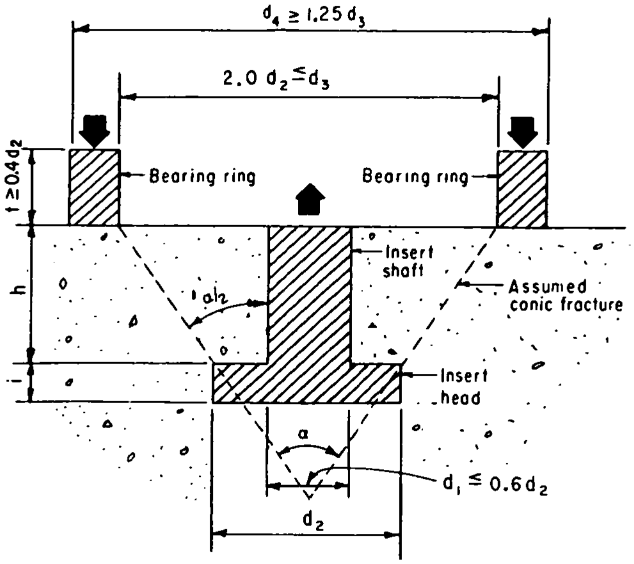


Figure 2. - Schematic of pullout test.

NOTE 4.-Hydraulic pumps that provide a smooth, uniform loading rate may give more uniform test results than pumps that apply load intermittently, such as repeated-stroke hand pumps.

6.2.6 Gauges shall have a minimum division not larger than 5 percent of minimum value in intended range of use. For most accurate results, gauges should have a maximum value indicator that retains the reading when fracture and stress release occur.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Sampling

8.1 Pullout test locations shall be separated so that the clear spacing between inserts is at least 10 times the pullout insert head diameter (d_2). There shall be at least four times the head diameter clear space between inserts and edges of the concrete or shotcrete. Inserts shall be placed so that reinforcement falls outside expected conic failure surface by more than one rebar diameter, or maximum size of aggregate, whichever is greater.

8.2 A minimum of three pullout tests shall comprise a test result.

NOTE 5.-The number of tests performed to represent an area or portion of a structure depends on type of construction; structure geometry; and the uniformity of exposure to temperature, moisture, and drying. Frequently, it will be desirable to provide more than three individual pullout inserts in a given placement.

9. Calibration and Standardization

9.1 The pullout apparatus shall be calibrated at least annually, and after all repairs or adjustments. Calibration shall be by one of the methods prescribed in USBR 1104 or with a compression testing machine conforming to requirements of USBR 4039 using the calibration procedures described in appendix X1.

10. Conditioning

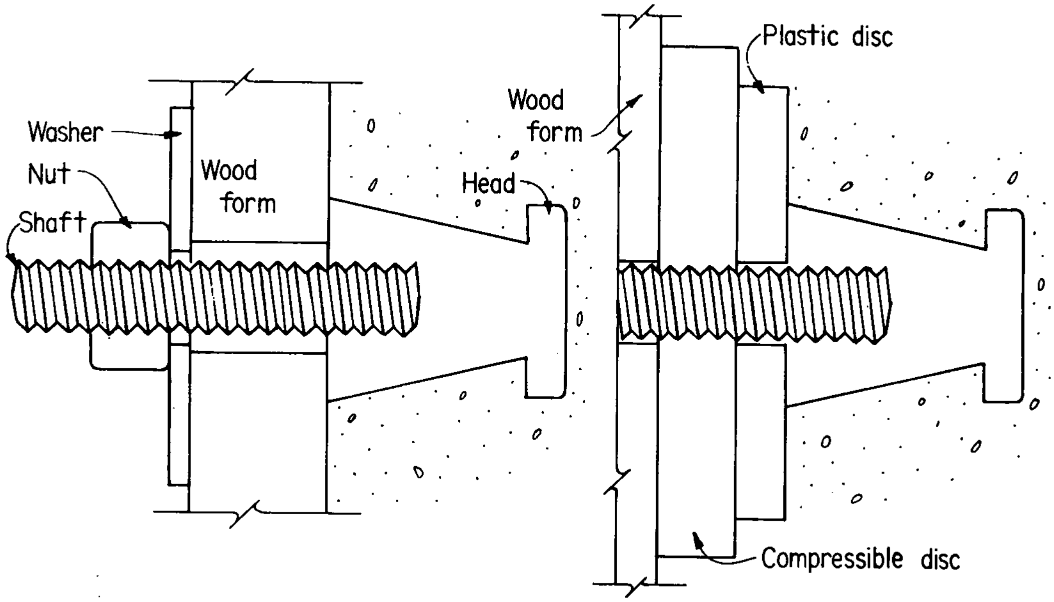
10.1 Because it is the intent of this procedure to evaluate strength of concrete or shotcrete inplace in a structure, no special conditioning should be given to the portion to be tested.

11. Procedure

11.1 Pullout inserts may be attached to forms prior to placement of concrete (fig. 3), embedded in horizontal unformed concrete or shotcrete surfaces, or embedded deep within the concrete or shotcrete.

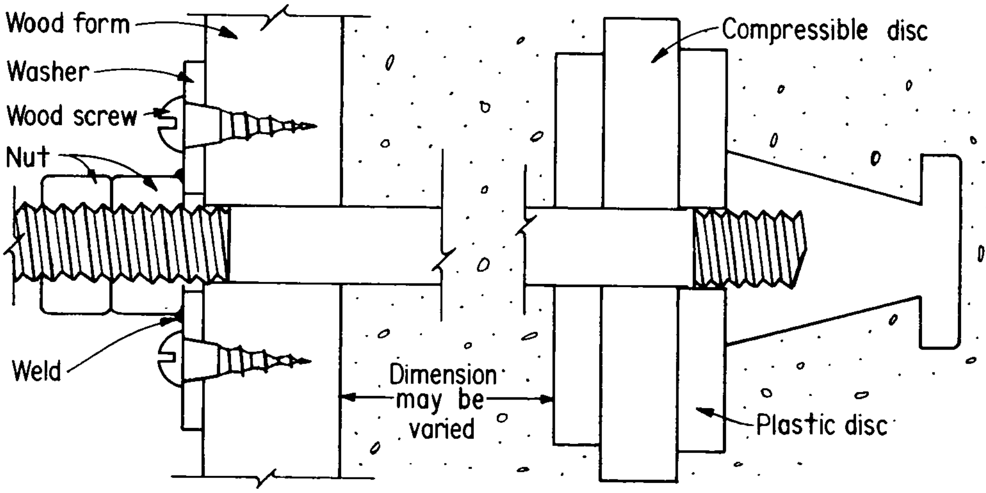
11.1.1 Attach pullout inserts to forms using bolts or other acceptable methods that firmly secure inserts in their proper location prior to concrete placement. All inserts for same test shall be embedded to same depth, and each shaft shall be perpendicular to formed surface.

11.1.2 Place surface pullout inserts directly into the fresh concrete or shotcrete such that uniform depth of embedment and a plane bearing surface perpendicular to insert shaft axis are ensured (fig. 4).



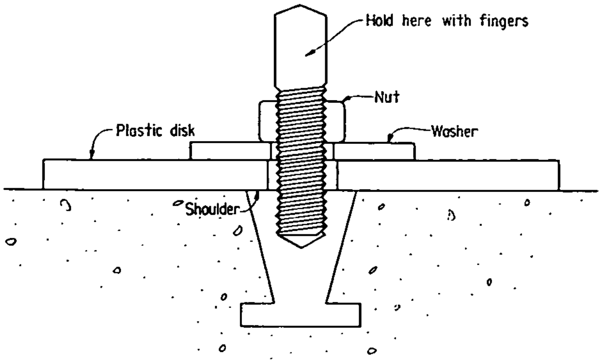
(a) Form must be removed prior to pullout test.

(b) Test pullout prior to form removal.



(c) Pullout insert held from outside the formwork and at desired distance from concrete surface.

Figure 3. – Methods of holding pullout inserts to formwork during concrete or shotcrete placement.



NOTE – Plastic disk ensures perpendicularity of shaft to surface. Insert is forced gently into fresh concrete or shotcrete with a twisting, puddling motion to obtain uniform embedment and a plane bearing surface with a minimum or air bubbles at surface that are visible through the transparent plastic disk.

Figure 4. - Method of placing insert into horizontal surface of fresh concrete or shotcrete.

NOTE 6.–The placing of inserts into unformed surfaces requires special awareness. Training and supervision of field personnel may be necessary to ensure proper installation. For placement of inserts deep within a concrete or shotcrete, follow manufacturer's instructions.

11.2 When concrete or shotcrete is to be tested, remove all hardware used for securing pullout inserts in position. Before mounting hydraulic ram for testing, ensure a smooth normal bearing surface by removing debris and surface abnormalities.

11.3 Use a bearing ring for all surface pullout test configurations. Place bearing ring around pullout insert shaft, connect shaft to hydraulic ram, and tighten pullout assembly snugly against bearing surface, ensuring that bearing ring is centered around shaft and flush against bearing surface.

11.4 If insert is to be tested to rupture of specimen, load at a uniform rate that will cause pullout rupture to occur in 120±30 seconds. Record maximum gauge reading to nearest half of the least division on dial. If insert is to be tested only to a specified level for acceptance, load at a uniform rate that will reach specified level in 120±30 seconds.

12. Calculations

12.1 To ensure maintaining a cone fracture with an apex angle between 65° and 70°, calculate the apex angle as follows:

$$\tan\left(\frac{\alpha}{2}\right) = \frac{d_3 - d_2}{2h} \qquad (1)$$

where:

α = apex angle of conic frustrum in degrees;
d_2 = diameter of pullout insert head, in inches (millimeters);
d_3 = inside diameter of bearing ring or large-base diameter of assumed conic frustrum, in inches (millimeters); and
h = height of conic frustrum from insert head to large-base surface, in inches (millimeters).

12.2 Convert test readings to force on the basis of the calibration data. When a stress calculation is required, calculate pullout strength by dividing pullout force by assumed area of frustrum (fig. 2) resulting from pullout fracture using the following equations:

$$f_p = \frac{P}{A} \qquad (2)$$

$$A = \frac{\pi}{4}(d_3 + d_2)\sqrt{[4h^2 + (d_3 - d_2)^2]} \qquad (3)$$

where:

f_p = pullout strength, in pound force per square inch (megapascals);
P = pullout force, in pound force (kilonewtons);
A = fracture surface area, in square inches (square millimeters); and
d_2, d_3, and h = as previously defined.

12.3 Figure 5 shows a typical calculation form.

12.4 A curve must be plotted, depicting cone pull-out strength against compressive strengths of whatever configuration or method of obtaining comparison samples that are desired, to establish a factor to convert from pullout strengths. No typical curve is included with this procedure because so many variables exist. To plot such a curve, a series of points would have to be established for whatever mix is chosen, desired age of mix, and a method of fabrication and curing.

13. Report

13.1 Figure 5 may also be used as a reporting form. The report shall include:

- Identification, from which specific location of pullout test can later be determined.
- Type of concrete or shotcrete surface tested; e.g., formed surface, unformed surface, or interior.
- Dimensions of the pullout insert and bearing ring (sketch or define dimensions).
- Maximum load.
- Abnormalities in ruptured specimen and in loading cycle.
- Curing methods used and moisture condition of concrete or shotcrete at time of test.
- Other information regarding unusual job conditions that may affect strength.

14. Precision and Bias

14.1 The precision for this procedure has not been determined.

14.2 *Bias.*–Existing stress may affect results.

15. References

[1] Clifton, J. R., Nondestructive Tests to Determine Concrete Strength - A Status Report," NBSIR 75-729, NTIS No. PB-246858, July 1975.

[2] Malhotra, V. M., "Evaluation of the Pullout Test to Determine Strength of In-Situ Concrete," RILEM *Materials and Structures*, vol. 8, No. 43, 1975.

[3] Richards, O., "Pullout Strength of Concrete," *Reproducibility and Accuracy of Mechanical Tests*, ASTM STP 626, pp. 32-40, 1977.

[4] Rutenbeck, T. E., "New Developments in In-Place Testing of Shotcrete," *Use of Shotcrete for Underground Structural Support*, American Concrete Institute Publication SP-45, 1974.

[5] Kierkegaard-Hansen, P., "Lok-Strength," Saertryk af Nordisk Betong 3, 1975.

APPENDIX

(Mandatory Information)

X1. CALIBRATION OF PULLOUT-HYDRAULIC LOADING SYSTEM

X1.1 Calibrate pullout-hydraulic loading system (pump, gauge, and hydraulic ram) with a testing machine meeting applicable requirements of USBR 4039.

X1.2 Place hydraulic ram between the two testing machine bearing blocks. Position ram and bearing blocks to ensure concentric and axial loading, and extend piston to level anticipated for actual pullout testing. Carefully position testing machine head against pullout ram.

NOTE X1.1–Protection of bearing blocks is required to prevent damage to testing machine. Cold-rolled steel plate at least 0.5 inch (13 mm) thick is recommended.

X1.3 Using hydraulic pump, apply loads progressively over range of anticipated use, and record hydraulic pressure gauge reading and testing machine load at each calibration load level. With available center-pull jacks, friction in system produces different calibration curves on an increasing series of loads as opposed to decreasing loads; therefore, only increasing loads should be used. In general, readings should be taken at about every 20 load levels distributed within range of loads anticipated in use.

X1.4 Using readings obtained during calibration loading, calculate a linear regression equation using the least-squares curve-fitting method. Pullout testing may occur within a narrow range of the capacity of pullout jack. If the test results fall within a narrow range, calculate regression equation based on calibration readings in that range, excluding those outside test range.

X1.5 Figures 1 and 2 in USBR 1430 show a typical calibration form and a calibration plot, respectively.

Spec. or Solic. No. NA	Structure SLABS	Tested by T. RUTENBECK Date 3-13&14-75
Project RESEARCH	Item PULL-OUT STRENGTH Location DENVER LAB	Couputed by T. RUTENBECK Date 3-13&14-75
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by E. SAMUELSON Date 3-13&14-75

PULLOUT STRENGTH OF HARDENED CONCRETE OR SHOTCRETE

Mix: ☐ Concrete ☒ Shotcrete (☒ Dry or ☐ Wet Process); MSA 1/2 inch ~~(mm)~~; Coarse Agg.: Nominal Size No. 4 to 3/8 inch 40 percentages; Fine Agg. 60 %; Cement: Type II ; 771 lbm/yd^3 ~~(kg/m^3)~~; Pozzolan: Class NA ; ____ lbm/yd^3(kg/m^3); Repl.____%
Admixtures: AEA NONE oz/yd^3(cc/m^3); WRA Type NONE, ____ oz/yd^3(cc/m^3); Accelerator: Brand GS-25, 1.5 %; Cementitious 11.6 oz/yd^3 ~~(cc)/m^3)~~
W/(C+P) 0.20 ; Air Content N.M.%; Slump N.M. inches(mm); Density N.M. lbm/yd^3(kg/m^3)

Placement Direction: VERTICALLY DOWNWARD ; Colsolidation: PNEUMATIC ; Type of Curing: FOG ROOM
Type of Surface Tested: AS SHOT ; Direction of Obtaining Sample: PARALLEL TO APPLICATION
Pump Ident.: ____ ; Ram Area 4.725 in^2 ~~(mm^2)~~; Ring Dia.: d_3 = 2.5 inches ~~(mm)~~; Washer Dia.: d_2 = 7/8 inch ~~(mm)~~

Sample No.	Date	Age			Bolt No.	Bolt Size, inches ~~(mm)~~	L_1 Eff. Bolt Length, inches ~~(mm)~~	L_2 Exposed Length, inches ~~(mm)~~	h (L_1-L_2), inches ~~(mm)~~	Pump Pressure, lbf/in^2 ~~(MPa)~~	Pump Pressure Times Ram Area, lbf ~~(kN)~~	α Apex Angle, degrees	A Cone Area, in^2 ~~(mm^2)~~	f_p Cone Pullout Strength, lbf/in^2 ~~(MPa)~~	Compressive Strength, lbf/in^2(MPa)		
		days	hrs.	min.											Cylinder 6 by 12 inches ~~(mm)~~	Core 4 by 4 inches ~~(mm)~~	Cube 3 inches ~~(mm)~~
1	3-14-75	1	—	—	1	3 by 3/8	2.90	1.62	1.28	650	3,071	65	8.04	382	1,770	1,788	2,206
2	3-14-75	1	—	—	2	3 by 3/8	2.90	1.82	1.08	490	BOLT PULLED UP IN TROWELING			NA	NA	2,078	2,325
3	3-14-75	1	—	—	3	3 by 3/8	2.90	1.62	1.28	650	3,071	65	8.04	382	1,780	1,841	2,136
													Average	382	1,780	1,900	2,220
4	4-23-75	1	—	—	1	3 by 3/8	2.90	1.78	1.20	625	2,953	68	7.68	385	1,790	1,800	2,272
5	4-23-75	1	—	—	2	3 by 3/8	2.90	1.68	1.22	625	2,953	67	7.77	380	1,767	1,733	2,074
6	4-23-75	1	—	—	3	3 by 3/8	2.90	1.63	1.27	730	3,449	65	7.99	432	2,010	1,992	1,683
													Average	399	1,860	1,840	2,010
													Average				

$$\tan\frac{\alpha}{2} = \frac{2.5-0.875}{2\,(1.28)} = 0.635;\ \frac{\alpha}{2}=32.4^\circ \qquad \alpha = 64.8^\circ;\ A = \frac{\pi}{4}(2.5+0.875)\left[(4)(1.28)^2+(2.5-0.875)^2\right]^{1/2} = 8.04\ in^2$$

Figure 5. - Typical data and calculation form for establishing correlation curves for compressive strength

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4901-92

PROCEDURE FOR

DRYING SHRINKAGE OF HARDENED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4901; the number immediately following the designation indicates year of original adoption or year of last revision. This procedure is somewhat similar to ASTM C 157 (Standard Test Method for Length Change of Hardened Cement Mortar and Concrete). The major item of variation is:

ASTM C 157–Includes length change of concrete and mortar due to causes other than externally applied forces and temperature changes.

USBR 4901–A procedure primarily for determining drying shrinkage of concrete using specimens of larger size than those described in ASTM C 157.

1. Scope

1.1 This designation covers the procedure for determination of length change of concrete due to a moisture loss from the concrete.

1.2 The term "length change," as used herein, is defined as "the decrease in a linear dimension of a test specimen caused by loss of moisture from specimen."

2. Applicable Documents

2.1 *USBR Procedures*:

4143 Slump of Concrete

4192 Making and Curing Concrete Test Specimens in Laboratory

4908 Length Change of Hardened Concrete Exposed to Alkali Sulfates

4910 Coefficient of Linear Thermal Expansion of Concrete

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]

C 157 Standard Test Method for Length Change of Hardened Cement Mortar and Concrete[1,3]

C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1,3]

3. Summary of Procedure

3.1 This procedure consists of casting concrete prisms and then subjecting them to an initial moist curing period followed by a drying atmosphere of controlled conditions. Length measurements are measured periodically during specimen drying period.

4. Significance and Use

4.1 Measurements of length change permit the assessment of the potential for linear and volumetric contraction of the concrete when subjected to a loss of moisture. This procedure is particularly useful for comparative evaluation of the drying shrinkage potential of different concrete mixtures.

5. Terminology

5.1 Terms used in this procedure are as defined in section 1.2 and in ASTM C 125.

6. Apparatus

6.1 *Molds.*–The molds (figs. 1 and 2) shall be constructed to produce 4- by 4- by 30-inch (100- by 100- by 760-mm) test prisms or cylinders. Concrete for the test specimens shall have a maximum size aggregate of 1-1/2 inches (37.5 mm), or be made from concrete wet-sieved to 1-1/2-inch maximum size. If concrete to be tested contains aggregate larger than 1-1/2 inches, the test specimen shall be a cylinder with a length-to-diameter ratio of 2 and a diameter that is a minimum of three times the maximum size of the aggregate.

6.1.1 Molds shall be made of steel or other hard metal that is not readily attacked by cement paste or concrete. Sides of molds shall be sufficiently rigid to prevent spreading or warping. The parts of the molds shall be tight fitting and firmly held together when assembled. Inside surfaces shall be smooth and free of pits.

6.1.2 Each end plate of the 4- by 4- by 30-inch mold shall be equipped to hold, properly in place during casting, one brass insert as shown on figure 2 of USBR 4908. Each cylinder mold shall have inserts for three gauge lines at equidistant points around perimeter of cylinder. To prevent restraint on insert before demolding of specimen, the device for holding insert in position shall be arranged such that,

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vol. 04.03.

[3] *Annual Book of ASTM Standards*, vol. 04.01.

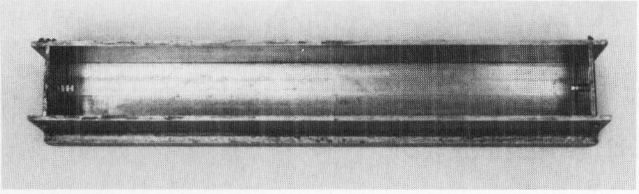


Figure 1. - Mold for casting 4- by 4- by 30-inch (102- by 102- by 762-mm) length change specimens. Inserts are mounted only at ends.

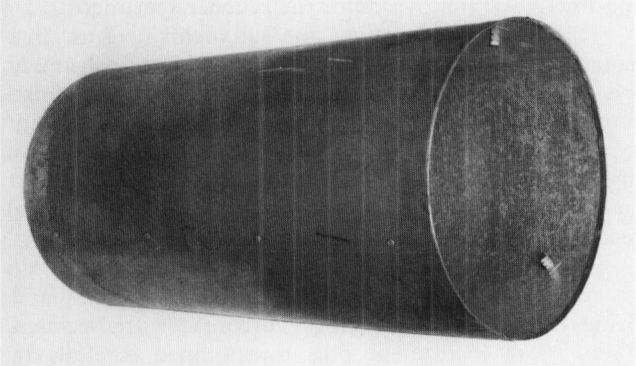


Figure 2. - Split sheet metal mold for casting 18- by 36-inch (457- by 914-mm) specimens.

if necessary, it can be partially or completely released after compaction of concrete in mold.

6.1.3 Gauge points to be threaded into inserts when specimens are unmolded shall be stainless steel, as shown on figure 2 of USBR 4908. The locking nut shall be brass.

6.2 *Internal Vibrators, Table Vibrators, and Tamping Rods.*-These items shall conform to the requirements of USBR 4192.

6.3 *Length Measurements*:

6.3.1 The 4- by 4- by 30-inch (100- by 100- by 760-mm) prisms shall be measured for length change using a flat-bed comparator (fig. 3). The comparator consists of a rigid, invar steel frame with a movable table that supports specimen at three points. Each end of the frame holds an upright invar steel post. One post is fitted with an adjustable head at the top, and the other post is fitted with a dial gauge. The head of the adjusting screw and stem of dial gauge contact the stainless steel gauge points in each end of specimen. A standard bar of invar steel with mounts to position it on comparator is used to obtain a constant dial setting.

6.3.2 Fulcrum plate strain gauges of the type shown on figure 4 shall be used to measure the length change on cylinders. These gauges are invar steel frames assembled to permit a short longitudinal travel using a flat plate spring arrangement. A dial gauge is mounted between the movable frames for length-change readings. Invar steel bars serve as standards for the dial gauge settings.

6.4 *Curing and Drying Rooms*:

6.4.1 The moist room used for curing the specimens must be maintained at a relative humidity above 90 percent, and at a temperature of 73.4±3.0 °F (23.0±1.7 °C). Tanks of lime-saturated water also maintained at 73.4±3.0 °F may be used as an alternate to a moist room.

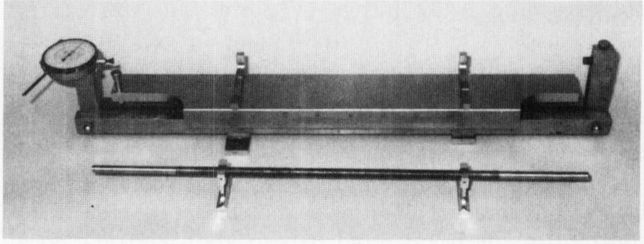


Figure 3. - Horizontal comparator and standard bar used for measuring length change of concrete and mortar test bars.

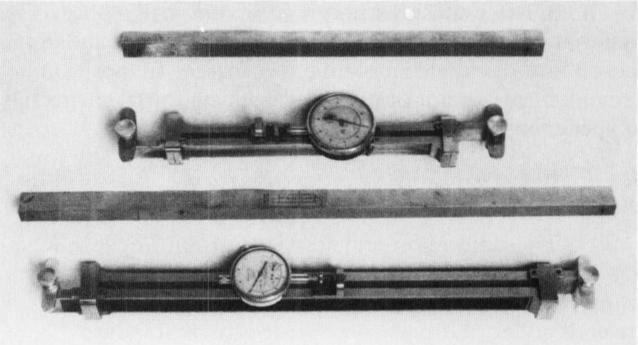


Figure 4. - Fulcrum plate strain gauges used for determining length changes of invar steel bars placed alongside the gauges serve as standards for gauge dial settings.

6.4.2 A drying room with suitable racks shall be provided for storing specimens in air. The racks shall be designed for free circulation of air around the specimens and shall be so situated, with respect to nearest wall or other obstruction, that air circulation is not restricted in intervening space. Air maintained at 73.4±2.0 °F (23.0±1.1 °C) and at a relative humidity of 50±4 percent shall be circulated through the room in a uniform manner.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsiblity of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Test Specimens

8.1 Mix concrete in a suitable laboratory mixer in accordance with the applicable provisions of USBR 4192. Determine consistency of concrete by the slump test in accordance with USBR 4143.

8.1.1 Concrete for the 4- by 4- by 30-inch (100- by 100- by 760-mm) test specimens shall contain aggregate not exceeding 1-1/2 inches (37.5 mm) in size. If test specimen is made from a mix having a larger maximum size, the concrete must be wet-sieved over a 1-1/2-inch (37.5-mm) sieve. In this case, the effect of wet-sieving on the mix proportions must be considered in interpreting the results.

8.1.2 Place concrete in the cylinder molds in three layers using internal vibrators to consolidate concrete. Place concrete in the beam mold in two approximately equal layers. Consolidate each layer using external vibration by placing mold on a table vibrator. As top layer is being placed in beam mold, work concrete thorougly around each insert with the fingers. The top layer shall slightly overfill the mold. After consolidation is complete, strike off excess material with a straightedge. After completion of molding, loosen the device for holding the inserts in position to prevent any restraint of the inserts during initial shrinkage of specimens.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 The comparator and fulcrum plate strain gauge shall be checked against a standard reference bar, as described in ASTM C 490. Table X1.2 in appendix X1 shows a typical calibrated dial reading correction factor for temperature variations. The dial gauge setting of the measuring device shall be checked by reference bar, as a minimum, at beginning and end of each set of readings and at intermediate intervals when a large number of specimens are being measured.

9.3 The adequacy to maintain the temperature and humidity control have to be assured by checking with a certified thermometer and humidity gauge.

10. Conditioning

10.1 *Initial Curing*:

10.1.1 Cure test specimens in molds at a relative humidity of 90 percent or above, and at a temperature of 73.4±3.0 °F (23.0±1.7 °C). Protect the specimens from dripping water.

10.1.2 Remove specimens from molds at the age of 3 days. Screw the stainless steel gauge points into the brass inserts previously embedded in specimens. The gauge length of the 4- by 4- by 30-inch (100- by 100- by 760-mm) prisms should be adjusted to a standard length using the adjustable gauge points and lock nuts. The gauge lengths of the cylinders are not adjustable, but an initial reading should be taken and recorded at this time with the strain gauge.

10.1.3 After initial measurements of length, cure the specimens in either a moist room or in lime-saturated water conforming to section 6.4.1 until specimens reach the age of 14 days, including period in molds, or to such other age of curing as may be specified.

10.2 *Subsequent Storage*.–At end of initial curing period, make a second length measurement. Store specimens in a drying room conforming to requirements of section 6.4.2.

11. Procedure

11.1 Make length measurements on each specimen after periods of air storage of 3, 7, 14, 21, 28, 42, and 60 days and every 30 days thereafter for 1 year for the 4- by 4- by 30-inch (100- by 100- by 760-mm) prism specimens and for 2 years for the cylinder specimens.

11.1.1 When making measurements, ensure that gauge points on specimen and feeler pins on instrument are clean. When making measurements with horizontal comparator, carefully place specimens on instrument supports. Place gauge point of specimen against neutral instrument pin. Release the gauge feeler pin to contact gauge point on opposite end of specimen. Record dial reading to nearest 0.0001 inch (0.0025 mm).

11.1.2 For measurements with fulcrum plate strain gauge, clasp gauge firmly with one end in either hand. Bring the fourth and index fingers in contact with specimen. Then, move instrument pins to specimen carefully by closing fingers until instrument pins are in contact with gauge points. The instrument pins shall be perpendicular to the specimen to ensure correct readings and to prevent breakage of feeler pins.

12. Calculations

12.1 Calculate the length change as follows:

$$\Delta L_t = \frac{d_o - d_t}{GL} \qquad (1)$$

where:

ΔL_t = shrinkage at time t in millionths,
d_o = original gauge reading in ten-thousandths of an inch (2.5×10^{-6} m),
d_t = gauge reading at time t in ten-thousandths of an inch (2.5×10^{-6} m), and
GL = gauge length in inches (millimeters).

12.2 Figures 5, 6, and 7 show suggested worksheets and typical data.

13. Report

13.1 The drying skrinkage of hardened concrete should be reported along with the coefficient of thermal expansion as part of the predicted volume change. Mix design studies including strength and elasticity, volume change, thermal properties, and temperature rise and heat of hydration are best covered by a separate report under a letter of transmittal. The report shall include:

- Identification of concrete specimens, number of specimens for each condition, and date molded.

- The source and identification of each material used.
- Type, maximum size, moisture condition, and gradation of aggregate.
- Size of specimens.
- Concrete mixture data, including consistency.
- Description of consolidation of concrete, including whether rodding or external or internal vibration was used.
- Conditions and periods of moist curing prior and subsequent to removal of molds if different from those specified in section 10.
- Description of storage condition, either by indicating whether air storage outlined in section 10 was followed or by giving details of any procedure not conforming to this condition.
- Length of drying period for each observation.
- Length change data reported as percent decrease in linear dimension to nearest 0.001 percent based on initial measurement made at start of drying period.
- Any other pertinent information.

14. Precision and Bias

14.1 The precision and bias statements for this procedure have not been established at this time.

Spec. or Solic. No. DC-7728	Structure DAM	Tested by D. ARNEY M. PEABODY — Date 2-1 TO 5-15-89
Project PSMBP (WYOMING)	Item RESEARCH — MIX STUDIES Location DENVER LAB	Computed by D. ARNEY — Date 5-15-89
Feature BUFFALO BILL DAM AND SPILLWAY MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by M. PEABODY — Date 5-15-89

DRYING SHRINKAGE OF HARDENED CONCRETE

Test No. 2 Date of Placement 2-1-89 Date Specimen Removed ~ Specimen: No. 1 & 2 Dimensions 4- BY 4- BY 30 - inches ~~(mm)~~

MSA 3 inches ~~(mm)~~ If Fabrication Desired, Scalped to 1½ inches ~~(mm)~~ Temp. of Mix 55 °F ~~(°C)~~ Thermal Coeff. 4.0 × 10⁻⁶

Conditioning ** Comparator No. 1 Invar Bar No. 1 Gauge No. 1 Gauge Length, GL = 28 inches ~~(mm)~~ Std. Bar Zero 1000

Date	Specimen Age, days	Conditioning (C) and/or Storing (S) Time, days		T Temp., [✓ °F] °C	ΔT [✓ 73.4 - T] 23.0 - T [✓ °F] °C	Standard Bar Base Reading	*	Standard Bar Correction to [✓ 73.4 °F] 23.0 °C	Dial Reading			Thermal Correction to Dial Reading[1]	Average Dial Reading Corrected to [✓ 73.4 °F] 23.0 °C	ΔL Total Length Change at [✓ 73.4 °F] 23.0 °C	ΔL_t Unit Length Change[2]	Length Change ΔL_t (100)	Differential Length Change
									Specimen No.								
		C	S						1	2	Avg.						
						[✓ Inches] or millimeters × 10⁻⁴									1 × 10⁻⁶	%	%
2-4-89	3	3	0	74.0	-0.6	1,000	0	1,000	1,000	1,000	1,000	-1	999	0			
2-6	5		2	72.0	+1.4				978	977	978	+2	980	19	67.9		
2-8	7		4	74.0	-0.6				961	959	960	-1	959	40	142.9		
2-9	8		5	73.4	0				951	959	955	0	955	44	157.1		
2-13	12		9	72.0	+1.4				929	925	927	+2	929	70	250.0		
2-16	15		12	73.3	-0.1				915	910	913	0	913	86	307.1		
2-21	20		17	74.9	-1.5				899	893	896	-2	894	105	375.0		
3-2	29		26	72.0	+1.4				876	877	877	+2	879	120	428.6		
3-10	37		34	74.0	-0.6				868	862	865	-1	864	135	482.1		
3-16	43		40	73.3	+0.1				862	853	858	0	858	141	503.6		
3-30	57		54	73.5	-0.1	↓	↓	↓	853	847	850	0	850	149	532.1		
5-15	103		100	75.0	-0.6	1,000	0	1,000	834	827	831	-1	830	169	603.6		

* Temperature correction factor, see table X1.2.

[1] Thermal correction = thermal coefficient (73.4 or 23.0 - T) times gauge length, where thermal coefficient is obtained from USBR 4910. $(0.000004)(-0.6)(28) = -0.0000672 = -1 \times 10^{-4}$

[2] Drying shrinkage or length change = $\Delta L_t = (d_o - d_t)/GL = (0.0999 - 0.0830)/28 = 0.0006036$ OR 603.6×10^{-6}

**3 DAYS IN MOLD AT 73.4 °F IN FOG ROOM AT 100% RELATIVE HUMIDITY
DRYING ENVIRONMENT AT 73.4 °F IN 50% ROOM AT 50% RELATIVE HUMIDITY

Figure 5. - Sample data form for determining length change of rectangular prisms of hardened concrete.

Spec. or Solic. No. DC-5915	Structure DAM	Tested by V. GUY L. MITCHELL · 2-15-63 To 6-7-65 Date
Project CURECANTI UNIT CRSP	Item RESEARCH – MIX STUDIES Location DENVER LAB	Computed by V. GUY · Date 6-7-65
Feature MORROW POINT DAM & POWERPLANT	Station ~ Offset ~ Depth ~ to ~	Checked by L. MITCHELL · Date 6-7-65

DRYING SHRINKAGE OF HARDENED CONCRETE

Test No. MIX 47 Date of Placement 2-15-63 Date Specimen Removed ~ Specimen: No. 342 Dimensions 18"Dia×36 inches ~~(mm)~~

MSA 4½ inches ~~(mm)~~ If Fabrication Desired, Scalped to NA inches (mm) Temp. of Mix 55 °F ~~(°C)~~ Thermal Coeff. 3.9 × 10⁻⁶

Conditioning ** Comparator No. 1 Invar Bar No. 1 Gauge No. 7 Gauge Length, GL = 10 inches ~~(mm)~~ Std. Bar Zero 1534

Date	Specimen Age, days	Conditioning (C) and/or Storing (S) Time, days		T Temp.	ΔT [✓ 73.4 – T] 23.0 – T	Std. Bar Base Reading	Std. Bar Correction to [✓ 73.4 °F] 23.0 °C		Gauge Line Dial Readings									Σ of Dial Readings	Thermal Correction[1]	Σ of Dial Readings Corr. to [✓ 73.4 °F] 23.0 °C	ΔL Total Length Change at [✓ 73.4 °F] 23.0 °C	ΔL_t Drying Shrinkage[2], [✓ inches] or mm
		C	S	[✓ °F] °C	[✓ °F] °C	*			1	2	3	4	5	6	7	8	9					
									[✓ Inches] or millimeters × 10⁻⁴													× 10⁻⁶
2-18-63	3	3							1357	1372	1495	1432	1369	1295	1448	1443	1501					
3-1	14	14		72.6	+0.8	1,534	0	1,534	1358	1374	1499	1432	1372	1295	1453	1446	1506	12735	0	0		
3-4	17		3	73.2	+0.2				1359	1374	1499	1428	1375	1293	1455	1445	1505	12733	+1	12734	1	1
3-8	21		7	74.0	-0.4				1358	1373	1499	1425	1376	1291	1457	1445	1505	12729	-1	12728	7	8
3-15	28		14	72.9	+0.5				1359	1372	1499	1422	1378	1290	1457	1444	1505	12726	+2	12728	7	8
3-22	35		21	72.9	+0.5				1360	1371	1498	1421	1378	1289	1457	1444	1505	12723	+2	12725	10	11
3-29	42		28	74.2	-0.6				1360	1370	1498	1420	1377	1288	1456	1444	1505	12718	-2	12716	19	21
4-12	56		42	74.2	-0.6				1360	1367	1497	1416	1377	1287	1455	1444	1502	12705	-2	12703	32	36
4-30	74		60	73.3	+0.1				1359	1365	1496	1412	1376	1284	1455	1442	1501	12690	0	12690	45	50
5-30	104		90	72.8	+0.6				1357	1361	1492	1410	1375	1282	1451	1439	1498	12665	+2	12667	68	76
6-28	133		119	73.7	-0.3				1357	1360	1490	1408	1374	1280	1455	1438	1496	12658	-1	12657	78	87
8-28	194		180	72.6	+0.8				1353	1355	1488	1404	1371	1276	1449	1434	1491	12621	+3	12624	111	123
11-26	284		270	73.2	+0.2				1352	1352	1484	1401	1367	1272	1443	1429	1487	12587	+1	12588	147	163
3-2-64	381		367	72.8	+0.6				1351	1350	1482	1399	1366	1271	1441	1427	1486	12573	+2	12575	160	178
6-4	475		461	73.7	-0.3				1352	1346	1479	1398	1364	1270	1439	1425	1482	12555	-1	12554	181	201
8-19	551		537	73.4	0				1346	1344	1477	1395	1364	1268	1437	1424	1483	12538	0	12538	197	218
11-3	627		613	72.0	+1.4				1346	1344	1477	1396	1363	1268	1437	1422	1481	12534	+5	12539	196	218
2-4-65	720		706	73.1	+0.3	↓	↓	↓	1346	1344	1476	1395	1362	1267	1437	1422	1481	12530	+1	12531	204	227
6-7	843		829	73.0	+0.4	1,534	0	1,534	1345	1343	1476	1395	1362	1266	1436	1421	1480	12524	+1	12525	210	233
																					SEE NOTE	

* Temperature correction factor, see table X1.2.

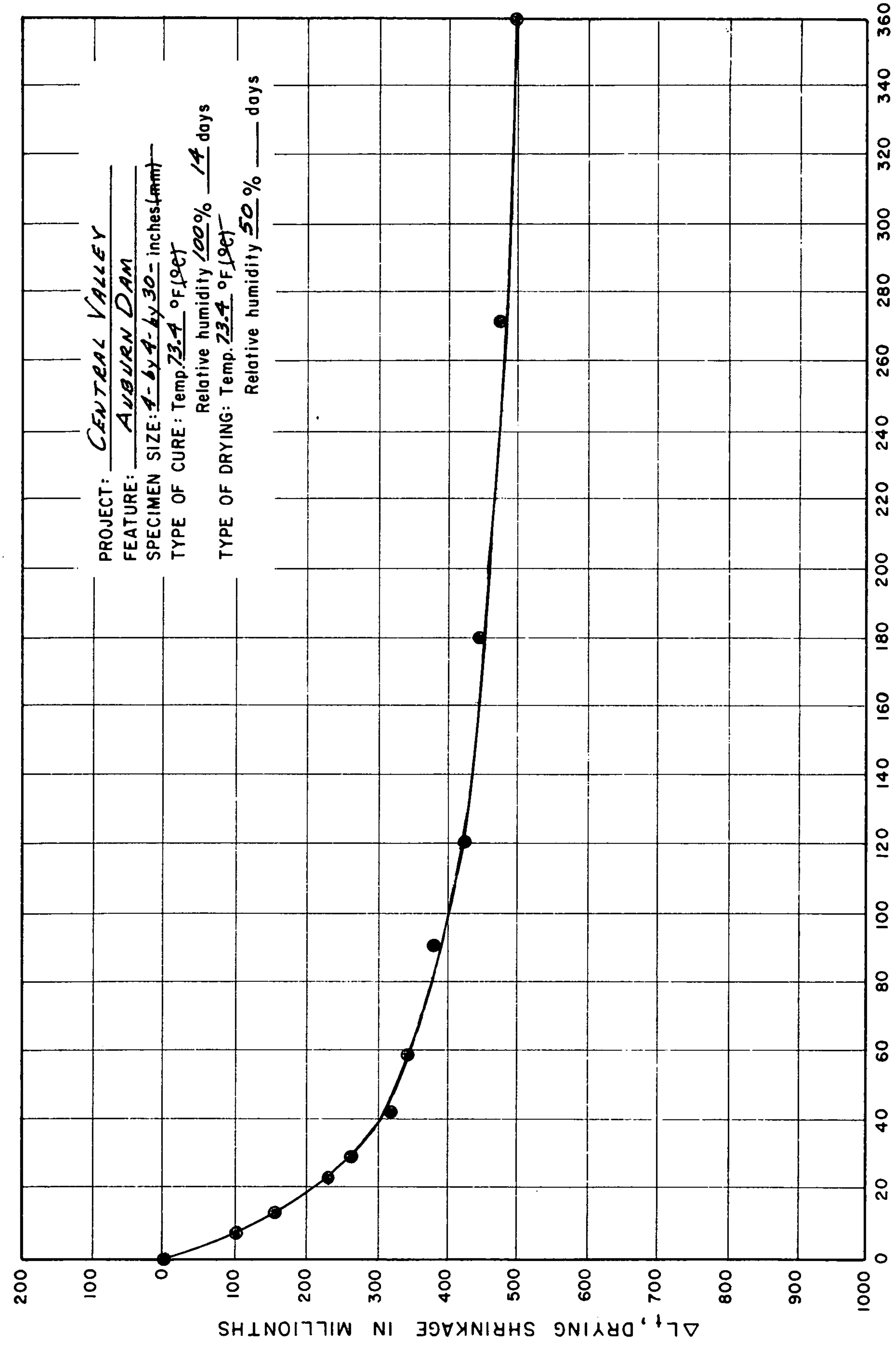
[1] Thermal correction = thermal coefficient (73.4 or 23.0 – T) times summation of gauge lengths, where thermal coefficient is obtained from USBR 4910. (0.0000039)(+0.4)(90) = 0.0001404 OR 1×10^{-4}

[2] Drying shrinkage or length change = $\Delta L_t = (d_o - d_t)/GL$ = (1.2735-1.2525)/90 = 0.0210/90 = 0.0002333 OR 233×10^{-6}

Note: If length change in percent is desired, use ΔL_t (100). This is only needed to determine if length change is less than 0.001 percent. $(227 \times 10^{-6})(100) - (218 \times 10^{-6})(100) = 0.0009$ %

** 3 Days in mold and 11 additional days at 73.4°F in fogroom at 100% Relative Humidity. Drying environment at 73.4°F in 50% room at 50% Relative Humidity

Figure 6. - Sample data form for length change of cylindrical or prism specimens measured with fulcrum plate strain gauges.



PROJECT: Central Valley
FEATURE: Auburn Dam
SPECIMEN SIZE: 4- by 4- by 30- inches ~~(mm)~~
TYPE OF CURE: Temp. 73.4 °F ~~(°C)~~
Relative humidity 100 % 14 days
TYPE OF DRYING: Temp. 73.4 °F ~~(°C)~~
Relative humidity 50 % ____ days

Figure 7. - Sample data plot of length change tests.

APPENDIX

X1. TEMPERATURE CORRECTIONS FOR VARIOUS GAUGE LENGTHS OF REFERENCE BARS
(Nonmandatory Information)

X1.1 The Bureau of Reclamation primarily uses 10-, 20-, and 28-inch reference bars made of annealed invar steel, that most textbooks show as having a coefficient of thermal expansion of 0.6×10^{-6} inch per inch per °F. Reference ASTM C 490 states that reference bars "shall be of a steel alloy having a coefficient of thermal expansion no greater than 2×10^{-6} inch per inch per °C," which is equivalent to 1.1×10^{-6} inch per inch per °F.

X1.2 Bureau files reveal that invar steel furnished for reference gauges and fabricated in the Denver Research Laboratory was checked for the thermal coefficient of expansion in July 1948, along with a 30-inch flat-bed comparator and its reference bars. The coefficient was found to be 0.96×10^{-6} inch per inch per °F at a base temperature of 70 °F (21.1 °C). The Bureau's *Materials Laboratory Procedures Manual*, dated January 2, 1951, shows temperature corrections for a 30-inch comparator to be applied to invar bars No. 1 and No. 2 based on a base temperature of 73.4 °F (23.0 °C).

X1.3 Based on the above data and that most Bureau gauges used with comparators are designed to be read to 10^{-4} inches, tables X1.1 and X1.2 were generated to reflect corrections to gauge readings through different temperature ranges, based on a base temperature of 73.4 °F for a zero reading, for 10-, 20-, and 28-inch reference bars.

Table X1.1.–Reference bar data[1].

Gauge Length		Total Shrinkage or Expansion		Temperature Range with Zero Corrections	
inches	mm	inch/°F $\times 10^{-6}$	mm/°C $\times 10^{-6}$	°F	°C
10	254	9.6	17.2	68.2 through 78.6	20.1 through 25.9
20	508	19.2	34.4	70.8 through 76.0	21.6 through 24.4
28	711	26.9	48.1	71.6 through 75.2	22.0 through 24.0

[1] Values shown in this table are based on a thermal coefficient of expansion for invar steel equal to 0.96×10^{-6} inch per inch per °F and gauges accurate to 10^{-4} inch, based on 73.4 °F (23.0 °C) as a zero reading. Table values are not valid for reference bar lengths other than those shown or for dial gauges with an accuracy other than 10^{-4} inch.

Table X1.2.–Temperature correction factors for various invar reference bars by gauge length.[1]

10-inch or 254-mm Gauge Length			20-inch or 508-mm Gauge Length			28-inch or 711-mm Gauge Length		
Temperature Range		Correction, inch × 10^{-4}	Temperature Range		Correction, inch × 10^{-4}	Temperature Range		Correction, inch × 10^{-4}
°F	°C		°F	°C		°F	°C	
37.0–47.3	2.7–8.4	-3	34.4–39.5	1.2–4.1	-7	34.4–38.0	1.2–3.2	-10
47.4–57.7	8.5–14.2	-2	39.6–44.7	4.2–7.0	-6	38.1–41.8	3.3–5.3	-9
57.8–68.1	14.3–20.0	-1	44.8–49.9	7.1–9.9	-5	41.9–45.5	5.4–7.4	-8
68.2–78.6	20.1–25.9	0	50.0–55.1	10.0–12.8	-4	45.6–49.2	7.5–9.4	-7
78.7–89.0	26.0–31.7	+1	55.2–60.3	12.9–15.7	-3	49.3–52.9	9.5–11.5	-6
89.1–99.4	31.8–37.5	+2	60.4–65.5	15.8–18.6	-2	53.0–56.6	11.6–13.6	-5
99.5–109.8	37.6–43.3	+3	65.6–70.7	18.7–21.5	-1	56.7–60.3	13.7–15.7	-4
109.9–120.2	43.4–49.1	+4	70.8–76.0	21.6–24.4	0	60.4–64.1	15.8–17.8	-3
120.3–130.6	49.2–54.9	+5	76.1–81.2	24.5–27.3	+1	64.2–67.8	17.9–19.8	-2
130.7–141.1	55.0–60.7	+6	81.3–86.4	27.4–30.2	+2	67.9–71.5	19.9–21.9	-1
141.2–151.5	60.8–66.6	+7	86.5–91.6	30.3–33.1	+3	71.6–75.2	22.0–24.0	0
151.6–161.9	66.7–72.4	+8	91.7–96.8	33.2–36.0	+4	75.3–78.9	24.1–26.1	+1
162.0–172.3	72.5–78.3	+9	96.9–102.0	36.1–38.9	+5	79.0–82.6	26.2–28.1	+2
Approx. spread: 10.3 °F, 5.7 °C			102.1–107.2	39.0–41.8	+6	82.7–86.4	28.2–30.2	+3
			107.3–112.4	41.9–44.8	+7	86.5–90.1	30.3–32.3	+4
			112.5–117.6	44.9–47.7	+8	90.2–93.8	32.4–34.4	+5
			117.7–122.8	47.8–50.6	+9	93.9–97.5	34.5–36.5	+6
			122.9–128.0	50.7–53.5	+10	97.6–101.2	36.6–38.5	+7
			128.1–133.2	53.6–56.4	+11	101.3–104.9	38.6–40.6	+8
			133.3–138.5	56.5–59.3	+12	105.0–108.7	40.7–42.7	+9
			138.6–143.7	59.4–62.2	+13	108.8–112.4	42.8–44.8	+10
			143.8–148.9	62.3–65.1	+14	112.5–116.1	44.9–46.9	+11
			149.0–154.1	65.2–68.0	+15	116.2–119.8	47.0–48.9	+12
			154.2–159.3	68.1–70.9	+16	119.9–123.5	49.0–51.0	+13
			159.4–164.5	71.0–73.8	+17	123.6–127.3	51.1–53.1	+14
			164.6–169.7	73.9–76.7	+18	127.4–131.0	53.2–55.2	+15
			169.8–174.9	76.8–79.6	+19	131.1–134.7	55.3–57.3	+16
			Approx. spread: 5.1 °F, 2.8 °C			134.8–138.4	57.4–59.3	+17
						138.5–142.1	59.4–61.4	+18
						142.2–145.8	61.5–63.5	+19
						145.9–149.6	63.6–65.6	+20
						149.7–153.3	65.7–67.6	+21
						153.4–157.0	67.7–69.7	+22
						157.1–160.7	69.8–71.8	+23
						160.8–164.4	71.9–73.9	+24
						164.5–168.1	74.0–76.0	+25
						168.2–171.9	76.1–78.0	+26
						172.0–175.6	78.1–80.1	+27
						Approx. spread: 3.6 °F, 2.0 °C		

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[1] Values shown in this table are based on a thermal coefficient of expansion for invar steel equal to 0.96×10^{-6} inch per inch per °F and gauges accurate to 10^{-4} inch, based on 73.4 °F (23.0 °C) as a zero reading. Table values are not valid for reference bar lengths other than those shown or for dial gauges with an accuracy other than 10^{-4} inch.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4902-92

PROCEDURE FOR

INDEX OF AGGREGATE PARTICLE SHAPE AND TEXTURE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4902; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM designation: D 3398-81.

1. Scope

1.1 This designation covers the procedure for determination of the particle index of aggregate as an overall measure of particle shape and texture characteristics.

NOTE 1.-This procedure is suggested for testing aggregates with a maximum particle size of 3/4 inch (19.0 mm). In testing aggregates larger than this size, a larger mold having a similar diameter-to-height ratio may be used, but the rodding energy per layer must be increased proportional to the increased horizontal cross-sectional area of the mold [1][1].

2. Applicable Documents

2.1 *USBR Procedures*:
1012 Calibrating Balances or Scales
4075 Sampling Aggregates
4127 Specific Gravity and Absorption of Coarse Aggregate
4128 Specific Gravity and Absorption of Fine Aggregate
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[2,3]
D 1883 Standard Test Method for Bearing Ratio of Laboratory-Compacted Soils[4]
D 3398 Standard Test Method for Index of Aggregate Particle Shape and Texture[3]
D 3665 Standard Practice for Random Sampling of Paving Materials[3]

3. Summary of Procedure

3.1 A sample of aggregate is separated into stipulated sieve fractions and each fraction is compacted in a calibrated container under two different degrees of tamping. From aggregate mass and its known specific gravity, it is possible to calculate the percent of voids corresponding to each degree of compaction. The particle index is then calculated as a function of the two percents of voids[2,3,4].

4. Significance and Use

4.1 This procedure provides an index value for the relative particle shape and texture characteristics of aggregate. This value is a quantitative measure of the aggregate shape and texture characteristics that may affect the performance of road and paving mixtures. This procedure has been successfully used to indicate the effects of these characteristics on the compaction and strength characteristics of soil-aggregate and asphaltic concrete mixtures.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125.

6. Apparatus

6.1 *Cylindrical Mold.*-The cylindrical mold shall have an inside diameter of 6.000±0.005 inches (152.40±0.13 mm), and shall have an inside height of 7.000±0.005 inches (177.80±0.13 mm), as shown on figure 1 (note 2). The mold shall be made from metal of a thickness of at least 0.24 inch (6.1 mm), and shall be of sufficient rigidity to retain its form during rough usage.

NOTE 2.-The mold specified in ASTM D 1883 is the same size.

NOTE 3.-For testing of the fine sieve fractions of aggregate smaller than the No. 4 (4.75-mm) sieve, it may be appropriate in some circumstances to use a smaller cylindrical container having a similar diameter-to-height ratio with a decreased rodding effort per layer required, and proportional to the decreased horizontal cross-sectional area of mold.

6.2 *Tamping Rod.*-A round, straight, steel rod that is 5/8 inch (16 mm) in diameter and about 24 inches

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[1] Numbers in brackets refer to entries in References, section 15.
[2] *Annual Book of ASTM Standards*, vol. 04.02.
[3] *Annual Book of ASTM Standards*, vol. 04.03.
[4] *Annual Book of ASTM Standards*, vol. 04.08.

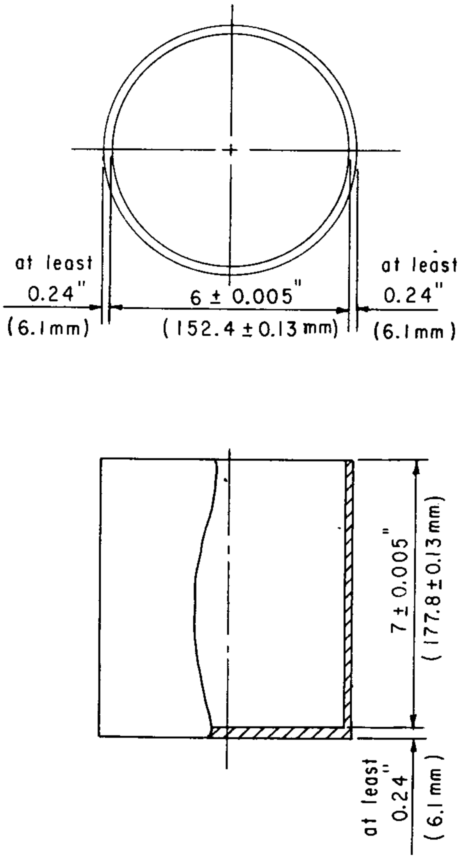

Figure 1. - Cylindrical mold.

(610 mm) long, with tamping end rounded to a 5/8-inch-diameter hemispherical tip. Mass of rod shall be 2.05±0.02 lbm (930±9 g).

6.3 *Scale.*-A scale of at least 33-lbm (15-kg) capacity, sensitive to 0.004 lbm (2 g) or less, and accurate to 0.009 lbm (4 g) or less.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Sampling, Test Specimens, and Test Units

8.1 Sample aggregate to be tested in accordance with ASTM D 3665 and USBR 4075, and reduce to the appropriate size test sample in accordance with USBR 4702.

8.2 Obtain a sample of such size that it will yield at least 13 lbm (5.9 kg) of each size of aggregate, as described in section 10.1, which is available in amounts of 10 percent or more in grading of aggregate. Only test size groups that are present in sample in quantities of at least 10 percent of total sample unless otherwise specifically requested.

NOTE 4.-For fine aggregate sizes, if a smaller mold is used as mentioned in note 3, less fine material will be needed and sample size can be adjusted accordingly.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference to another.

9.2 Determine volume of mold as described in 9.2.1, 9.2.2, and 9.2.3 at least two times, and use average volume for calculation of percentage of voids in 12.1.

9.2.1 Fill measure with water at room temperature and cover with a piece of plate glass in such a way as to eliminate bubbles and excess water.

9.2.2 Determine net mass of water in measure to an accuracy of 0.009 lbm (4.1 g) or less.

9.2.3 Measure temperature of water and determine volume of measure by multiplying net mass of water by corresponding density of water at given temperature listed in table 2 of USBR 4029.

9.2.4 Figure 2 shows a sample data form with calculations.

9.3 Scales shall be calibrated in accordance with USBR 1012.

10. Conditioning

10.1 Wash sample of aggregate by decantation of wash water through a No. 200 (75-μm) sieve or through a fine aggregate sieve that is at least one size smaller than smallest sieve size fraction to be tested. Continue the washing and decanting operation until wash water is clear, then flush residue on sieve back into aggregate sample. Dry sample to a constant mass at 230±9 °F (110±5 °C), and sieve material in accordance with USBR 4136 into the following sieve fractions:

Passing	Retained
3/4 inch (19.0 mm)	1/2 inch (12.5 mm)
1/2 inch (12.5 mm)	3/8 inch (9.5 mm)
3/8 inch (9.5 mm)	No. 4 (4.75 mm)
No. 4 (4.75 mm)	No. 8 (2.36 mm)
No. 8 (2.36 mm)	No. 16 (1.18 mm)
No. 16 (1.18 mm)	No. 30 (600 μm)
No. 30 (600 μm)	No. 50 (300 μm)
No. 50 (300 μm)	No. 100 (150 μm)
No. 100 (150 μm)	No. 200 (75 μm)

It is not necessary to include sieves in the sieve analysis below the smallest size which is available in an amount of more than 10 percent.

10.2 After the required amount of material has been sieved for each size fraction to be tested, determine bulk-dry specific gravity of each size group in accordance with USBR 4127 and 4128, whichever is applicable, except that for the saturated-surface-dry condition for fine aggregate in USBR 4128, hard-finished paper towels should be used to dry particles until no more moisture is evident on fresh towels.

NOTE 5.-The standard mold procedure for determination of the saturated-surface-dry condition of fine aggregate in USBR 4128 does not work well with these uniform size fractions. For example, rounded aggregates with small particle indexes will not retain the cone mold shape at any moisture content.

11. Procedure

11.1 Using oven-dried samples for each size fraction, run determinations of percentage of voids at each of the two levels of compaction in accordance with procedure given in this section. Use a new sample of material selected from the oven-dried material for each test. First, run two tests for each size at the compaction of 10 drops of tamping rod per layer. Then, run test two more times using 50 drops of rod per layer as compactive effort.

11.1.1 Place cylindrical mold on a uniform, solid foundation. Fill mold in three layers. Gently place aggregate into mold by feeding from a hand scoop until mold is about one-third full. The distance from point of discharge from hand scoop to surface of each layer should be about 6 inches (150 mm). Level surface by hand and compact layer using 10 drops of tamping rod evenly distributed over surface. Apply each drop by holding rod vertically with its rounded end about 2 inches (50 mm) above surface of aggregate and releasing so that rod falls freely. Place a second layer in mold using same procedure, filling mold about two-thirds full. As before, level surface and apply 10 drops of rod. Fill remaining space in mold with a third layer and again level surface and apply same compactive effort, 10 drops of rod. After final layer has been compacted, add individual peices of aggregate to make surface of aggregate mass even with rim of mold, with no projections above rim. Determine net mass of aggregate in mold to an accuracy of at least 0.009 lbm (4.1 g).

NOTE 6.-In compacting the aggregate, height of drop of tamping rod may be controlled by using a rule to check height, or by adding a loose-fitting sleeve over rod with a slot-and-pin arrangement that will permit rod to move about 2 inches (50 mm) vertically within sleeve when placed on surface of aggregate.

11.1.2 Repeat filling of mold using the same sample and compaction, and make a second determination of net mass of aggregate in mold as described in 11.1.1. Use the average mass of the two runs to calculate the percentage of voids at 10 drops for each size.

NOTE 7.-The net mass obtained in the replicate determinations should agree within about 0.5 percent.

11.1.3 For the higher degree of compaction test, follow the steps outlined in 11.1.1 and 11.1.2, except use 50 drops of tamping rod in compacting each layer. Again average the net mass from two runs for use in computing percentage of voids at 50 drops for each size fraction.

12. Calculations

12.1 Calculate percentage of voids in each size fraction of aggregate for both 10 and 50 drops per layer:

$$V_{10} = \frac{\left(sD_w - \frac{M_{10}}{v_m}\right)}{sD_w}(100) \qquad (1)$$

$$V_{50} = \frac{\left(sD_w - \frac{M_{50}}{v_m}\right)}{sD_w}(100) \qquad (2)$$

where:

V_{10} = percentage of voids in aggregate compacted at 10 drops per layer,
V_{50} = percentage of voids in aggregate compacted at 50 drops per layer,
M_{10} = average net mass of aggregate in mold compacted at 10 drops per layer, in pound mass (kilograms),
M_{50} = average net mass of aggregate in mold compacted at 50 drops per layer, in pound mass (kilograms),
s = bulk-dry specific gravity of aggregate size fraction,
v_m = volume of cylindrical mold, in cubic feet (cubic meters), and
D_w = density of water (62.4 lbm/ft^3 at 39 °F or 1000 kg/m^3 at 4 °C or corresponding density at measured temperature).

12.1.1 Figure 3 shows a typical calculation form.

12.2 Determine the particle index I_a for each size fraction tested by using nomograph shown on figure 4 or as follows:

$$I_a = 1.25\ V_{10} - 0.25\ V_{50} - 32.0 \qquad (3)$$

12.3 Calculate the weighted particle index of an aggregate containing several sizes by averaging the particle index data for each size fraction weighted on basis of percentage of fraction in original grading of sample as received or, preferably, on basis of average grading of material to be used in work. Figure 4 shows a typical example method for determining the weighted particle index. For sizes represented by less than 10 percent in the grading, for which no particle index data were obtained, use the average of the particle index of the next coarser and next finer sizes for which data are available, or the particle index for the next coarser or finer size if a value is available only in one direction.

13. Report

13.1 Figure 3 along with a cover letter may be used as the reporting form, which shall include:

- Identification of aggregate
- Weighted particle index

14. Precision and Bias

14.1 This procedure is primarily used in research work, and the precision has not currently been determined.

14.2 There is no known bias.

Spec. or Solic. No. NOT APPLICABLE	Structure —	Tested by N. JOHNSON Date 4-14-89
Project —	Item VERIFICATION OF TEST PROCEDURE Location CONCRETE LAB	Computed by N. JOHNSON Date 4-14-89
Feature —	Station ~ Offset ~ Depth ~ to ~	Checked by E. SAMUELSON Date 4-15-89

INDEX OF AGGREGATE PARTICLE SHAPE AND TEXTURE

Mold ID No.	D Inside Diameter, [✓ inches] mm	H Inside Height, [✓ inches] mm	M_m Mold Tare Mass [✓ lbm] kg	P_g Glass Plate Tare Mass, [✓ lbm] kg	T Water Temp., [✓ °F] °C	D_w Absolute Density of Water at Meas. Temp., [✓ lbm/ft³] kg/m³	Mass of Mold + Plate + Water M_{w1} [✓ lbm] kg	M_{w2} [✓ lbm] kg	M_{wa} $\frac{M_{w1} + M_{w2}}{2}$ [✓ lbm] kg	W Net Mass of Water $M_{wa} - (M_m + P_g)$ [✓ lbm] kg	V_w Volume of Water $\frac{W}{D_w}$ [✓ ft³] m³	V_m Volume of Mold $(= V_w)$ [✓ ft³] m³
2	5.999	7.002	8.9151	2.5381	65.3	62.334	18.6120	18.6119	18.61195	7.15875	0.1148	0.1148

Remarks:

Figure 2. – Sample data form for mold calibration.

Spec. or Solic. No. NOT APPLICABLE	Structure ~	Tested by N. JOHNSON Date 4-14-89
Project ~	Item VERIFICATION OF TEST PROCEDURE Location DENVER CONCRETE LAB	Computed by N. JOHNSON Date 4-14-89
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by E. SAMUELSON Date 4-15-89

INDEX OF AGGREGATE PARTICLE SHAPE AND TEXTURE

Sieve Size Fraction	Mass Retained, lbm	Individual Mass Retained, %	Compaction Level						M_m Mold Tare Mass, lbm	M_{10} $M_{ta} - M_m$ Avg. Net Mass at 10 Drops, lbm	M_{50} $M_{tb} - M_m$ Avg. Net Mass at 50 Drops, lbm	s Bulk Oven-Dry Specific Gravity	V_{10} Voids in Agg. Comp. at 10 Drops per Layer, %	V_{50} Voids in Agg. Comp. at 50 Drops per Layer, %	I_a Particle Index For Each Size Tested	I_{aw} Weighted I_a, Avg. Agg. Grad. Times I_a Divided by 100
			10 Rod Drops per Layer			50 Rod Drops per Layer										
			1 M_{t1} lbm	2 M_{t2} lbm	Avg. M_{ta} $\frac{1+2}{2}$ lbm	3 M_{t3} lbm	4 M_{t4} lbm	Avg. M_{tb} $\frac{3+4}{2}$ lbm								
3/4 to 1/2 inch	0.08	3													[1]17.1	0.5
1/2 to 3/8 inch	1.16	42	18.50	18.51	18.505	19.88	19.87	19.875	8.915	9.59	10.96	2.54	47.2	39.7	[2]17.1	7.2
3/8 inch to No. 4	0.99	36	18.67	18.66	18.665	19.67	19.68	19.675	8.915	9.75	10.76	2.54	46.4	40.8	[2]15.8	5.7
No. 4 to No. 8	0.20	7													[3]15.2	1.1
No. 8 to No. 16	0.28	10	18.82	18.81	18.815	19.53	19.52	19.525	8.915	9.90	10.61	2.54	45.5	41.6	[2]14.5	1.5
No. 16 to No. 30	0.05	2													[4]14.5	0.3
No. 30 to No. 50																
No. 50 to No. 100																
No. 100 to No. 200																
Pan	0.00	0														
Totals	2.76	100														16.3

Remarks:

[1] Use particle index for next size because less than 10 percent.

[2] Particle index measured for these sizes.

[3] Use average particle index for No. 8 to No. 16 and 3/8 inch to No. 4 sieves because quantity is less than 10 percent.

[4] Use previous particle size index because there is not a finer size listed with which to average.

Example:

$$V_{10} = \frac{(2.54)(62.334) - \left(\frac{9.75}{0.1148}\right)}{(2.54)(62.334)}(100) = 46.4$$

$$I_a = (1.25)(46.4) - (0.25)(40.8) - 32.0 = 15.8$$

Figure 3a. – Determination of particle index of sieve size fractions (inch-pound units).

Spec. or Solic. No. NOT APPLICABLE	Structure ~	Tested by N. JOHNSON Date 4-14-89
Project ~	Item VERIFICATION OF TEST PROCEDURE Location DENVER CONCRETE LAB	Computed by N. JOHNSON Date 4-14-89
Feature ~	Station ~ Offset ~ Depth ~ to ~	Checked by E. SAMUELSON Date 4-15-89

INDEX OF AGGREGATE PARTICLE SHAPE AND TEXTURE

Sieve Size Fraction	Mass Retained, kg	Individual Mass Retained, %	Compaction Level: 10 Rod Drops per Layer: 1 M_{t1} kg	2 M_{t2} kg	Avg. M_{ta} $\frac{1+2}{2}$ kg	50 Rod Drops per Layer: 3 M_{t3} kg	4 M_{t4} kg	Avg. M_{tb} $\frac{3+4}{2}$ kg	M_m Mold Tare Mass, kg	M_{10} $M_{ta} - M_m$ Avg. Net Mass at 10 Drops, kg	M_{50} $M_{tb} - M_m$ Avg. Net Mass at 50 Drops, kg	s Bulk Oven-Dry Specific Gravity	V_{10} Voids in Agg. Comp. at 10 Drops per Layer, %	V_{50} Voids in Agg. Comp. at 50 Drops per Layer, %	I_a Particle Index For Each Size Tested	I_{aw} Weighted I_a, Avg. Agg. Grad. Times I_a Divided by 100
19.0 to 12.5 mm	0.04	3													[1]17.1	0.5
12.5 to 9.5 mm	0.53	42	8.39	8.40	8.395	9.02	9.01	9.015	4.04	4.35	4.97	2.54	47.2	39.7	[2]17.1	7.2
9.5 to 4.75 mm	0.45	56	8.47	8.46	8.465	8.92	8.93	8.925	4.04	4.42	4.88	2.54	46.4	40.8	[2]15.8	5.7
4.75 to 2.36 mm	0.09	7													[3]15.2	1.1
2.36 to 1.18 mm	0.13	10	8.54	8.53	8.535	8.86	8.85	8.855	4.04	4.49	4.81	2.54	45.5	41.6	[2]14.5	1.5
1.18 mm to 600 µm	0.02	2													[4]14.5	0.3
600 to 300 µm																
300 to 150 µm																
150 to 75 µm																
Pan	0.00	0														
Totals	1.25	100														16.3

Remarks:

[1] Use particle index for next size because less than 10 percent.
[2] Particle index measured for these sizes.
[3] Use average particle index for 2.36 to 1.18-mm and 9.5 to 4.75-mm sieves because quantity is less than 10 percent.
[4] Use previous particle size index because there is not a finer size listed with which to average.

Example:

$$V_{10} = \frac{(2.54)(998.5) - \left(\frac{4.42}{0.00325}\right)}{(2.54)(998.5)}(100) = 46.4$$

$$I_a = (1.25)(46.4) - (0.25)(40.8) - 32.0 = 15.8$$

Figure 3b. - Determination of particle index of sieve size fractions (SI-metric units).

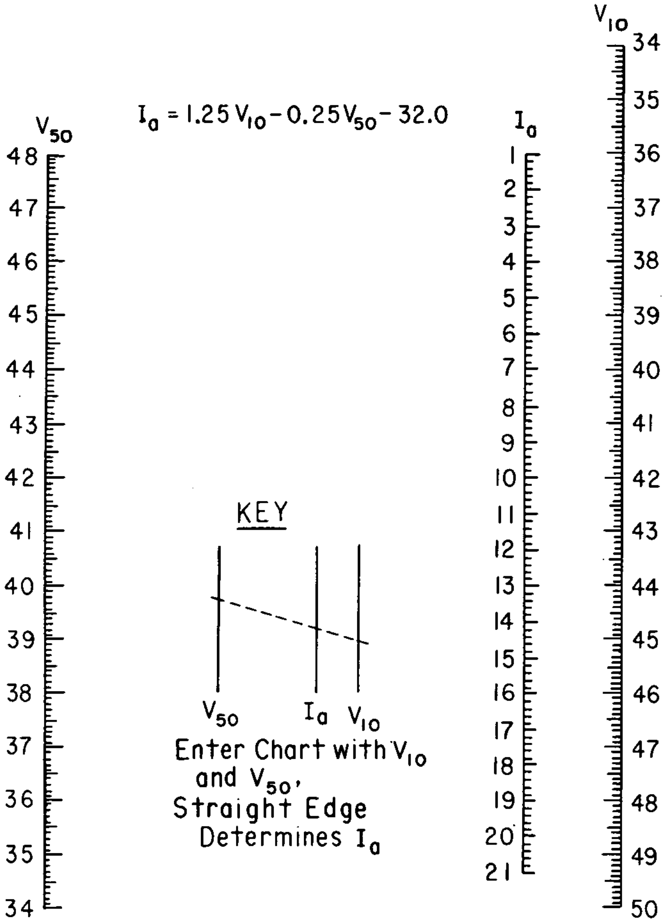

Figure 4. - Nomograph for determining particle index I_a.

15. References

[1] Hosking, J. R., "An Investigation into Some Factors Affecting the Results of Bulk Density Tests for Aggregates," *Cement, Lime, and Gravel* (Gr. Br.), p. 319, November 1961. (Reports data showing that for comparable compaction in different size containers, the number of blows per unit surface area should be constant.)

[2] Huang, E. Y., "A Test for Evaluating the Geometric Characteristics of Coarse Aggregate Particles," *ASTM Proceedings*, vol. 62, pp. 1223-1242, 1962.

[3] Huang, E. Y., A. Auer, and R. P. Triffo, "Effect of Geometric Characteristics of Coarse Aggregates on Strength of Soil-Aggregate Mixtures," *ASTM Proceedings*, vol. 64, pp. 922-933, 1964.

[4] McLeod, Normal W., and J. A. McLean, "A Laboratory Investigation of the Compaction of Dense Graded Asphalt Concrete," paper presented at 19th Annual Conference of Canadian Technical Asphalt Association, Regina Saskatchewan, Canada, 1974.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4903-92

PROCEDURE FOR

FLAT AND ELONGATED PARTICLES IN COARSE AND FINE AGGREGATES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4903; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is patterned after Test Methods CRD-C, 119-53, "Method of Test for Flat and Elongated Particles in Coarse Aggregate;" and CRD-C, 120-55, "Method of Test for Flat and Elongated Particles in Fine Aggregate," both from the *Handbook for Concrete and Cement* [1][1].

1. Scope

1.1 This designation covers the procedure for determining the proportion of flat and/or elongated particles in coarse and fine aggregates proposed for use in concrete. The workability of fresh concrete is markedly decreased as the percentage of flat and/or elongated particles in coarse aggregate increases, which can be detrimental to obtaining the required flexural or high-compressive strengths in the hardened concrete. The workability of fresh concrete is also decreased when significant proportions of the flat and/or elongated particles are present in fine aggregate, which can result in increased cement and water requirements.

1.2 This procedure is to be applied to the coarse aggregate size gradation ranges of 6 to 3 inches (150 to 75 mm), 3 to 1-1/2 inches (75 to 37.5 mm), 1-1/2 to 3/4 inch (37.5 to 19.0 mm), 3/4 to 3/8 inch (19.0 to 9.5 mm) and, when a visual inspection indicates high proportions of flat and/or elongated particles, to the 3/8-inch to No. 4 (9.5 to 4.75 mm) size; and to the fine aggregate sieve size fractions of No. 4 to No. 8 (4.75 to 2.36 mm) and No. 8 through No. 100 (2.36 mm through 150 μm). Four methods are described in this procedure, three for coarse aggregate and one for fine aggregate, as follows:

(1) Measured coarse particles (both counted particles or particle mass determined), weighted averages not required;

(2) Measured coarse particles (both counted particles or particle mass determined), weighted averages required;

(3) Visual inspection of coarse particles; and

(4) Microscopic and/or visual inspection of fine particles.

2. Applicable Documents

2.1 *USBR Procedures*:

1000 Standards for Linear Measurement Devices
1012 Calibrating Balances or Scales
1020 Calibrating Ovens
1025 Checking Sieves
4075 Sampling Aggregates
4136 Sieve Analysis of Fine and Coarse Aggregates
4295 Petrographic Examination of Aggregate for Concrete
4702 Reducing Field Samples of Aggregate to Testing Size
5005 Determining Unified Soil Classification (Visual Method)

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Summary of Procedure

3.1 Samples of coarse and fine aggregate to be examined should be dry sieved in accordance with USBR 4136, and then further reduced to at least 300 particles in each gradation range, except for selected sieve size fractions finer than No. 30 (600 μm) where only 200 particles are needed. The particles in each of the selected and reduced gradation ranges are then subdivided into flat, elongated, flat and elongated, and not flat and/or elongated, dependent upon method selected (note 1). The subdivided groups are then counted, mass determined (as required), and calculations made to determine specific proportions of each subdivided group of particles in the examined aggregate sample.

NOTE 1.-The flat, elongated, and the flat and elongated groups could be combined into one category and be determined by count or by mass determination; or may be determined by the summation of each individual group.

4. Significance and Use

4.1 As noted in section 1, large proportions of flat and/or elongated particles in coarse or fine aggregate can

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[1] Numbers in brackets refer to entries in References, section 17.

[2] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

deleteriously affect the workability of a fresh concrete mixture, which may require increases in cementitious materials and, subsequently, cost increases. This procedure is used to aid in determining the concrete making properties of aggregate and to determine compliance of the particle shape characteristics, flat and/or elongated, with specification requirements. This procedure may also provide data necessary for control of the mechanical production of coarse and fine aggregate for concrete.

5. Terminology

5.1 *Flat Piece.*-A particle of aggregate for which ratio of width to thickness of its circumscribing rectangular prism is three or greater.

5.2 *Elongated Piece.*-A particle of aggregate for which ratio of length to width of its circumscribing rectangular prism is three or greater.

5.3 *Flat and Elongated Piece.*-A particle of aggregate that meets criteria for both flat and elongated particles.

NOTE 2.-The length, width, and thickness are, respectively, the greatest, intermediate, and least dimensions of any particle along mutually perpendicular directions of the particle's circumscribing prism. These definitions use the ratio criterion of three, are specific to this test procedure, and are based on the definitions given in ASTM C 125 and the illustration shown on figure 4 of USBR 5005.

6. Apparatus

6.1 The apparatus used in this test procedure shall consist of any suitable equipment by which aggregate particles may be tested for compliance with definitions in section 5, when required. The apparatus shall permit the use of all methods described in this procedure for coarse aggregate; it is not intended to imply that other equipment cannot be substituted to serve similar functions.

6.1.1 *Proportional Caliper Device.*[4]-This device, which is shown on figure 1, consists of a base with two fixed posts and a swinging arm between them. The axis (thumbscrew) on which the arm swings is positioned so that the openings between the ends of the arm and the fixed posts maintain a constant ratio. The device shown on figure 1 has three axis positions which allow ratios of 1:2, 1:3, and 1:5 to be obtained.

6.1.2 *Outside Caliper.*-This general purpose caliper, shown on figure 2, has a type II spring, rectangular leg, adjusting screw, and is class 1, style A.

6.1.3 *Rule.*-The rule consists of any strip of material marked off in units for measuring, and may be graduated in fractions of inches, tenths of feet, and/or metric measures. A 6-inch, 0.5-foot, or 15-cm rule is generally considered adequate.

6.1.4 *Balance or Scales.*-The balance or scales used shall be sensitive to 0.5 percent of mass of sample to be measured (note 3).

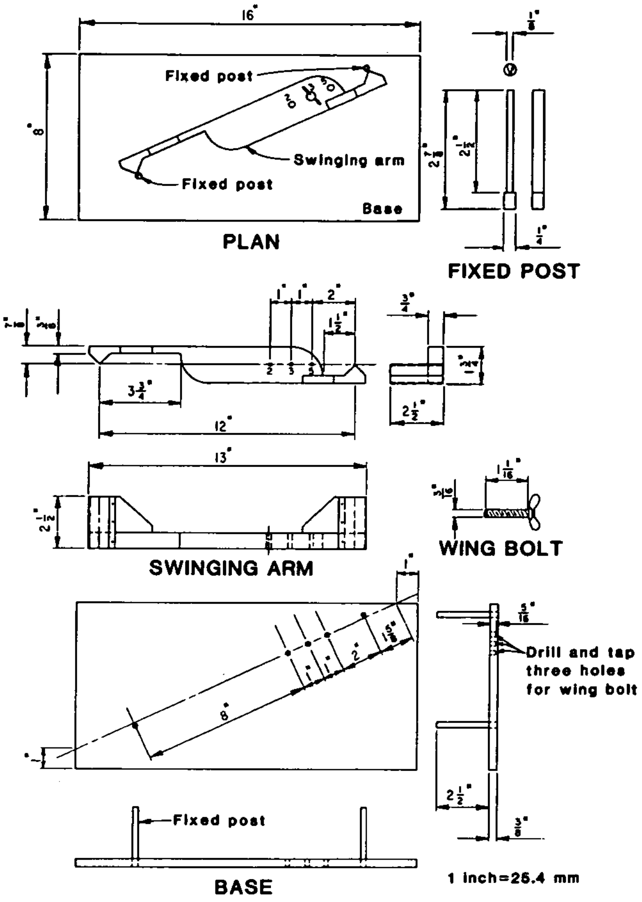

Figure 1. - Proportional caliper device.

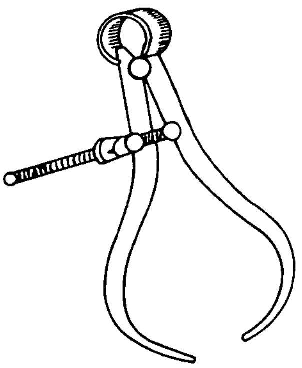

Figure 2. - General purpose caliper for checking flat and elongated particles.

6.1.5 *Oven.*-An oven of appropriate size capable of maintaining a uniform temperature of 230 ±9 °F (110 ±5 °C).

6.1.6 *Sieves.*-The sieves shall have square openings and shall conform to ASTM E11. For the coarse aggregate, 6- to 3-inch (150- to 75-mm), 3- to 1-1/2-inch (75- to 37.5-mm), 1-1/2- to 3/4-inch (37.5- to 19.0-mm), 3/4- to 3/8-inch (19.0- to 9.5-mm), and 3/8-inch to No. 4 (9.5- to 4.75-mm) sieves are required (note 4). For the fine

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[4] Developed by the Concrete Research Division, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

aggregate, No. 4 to 200 (4.75-mm to 75-µm), No. 4, 8, 16, 30, 50, 100, and 200 (4.75-, 2.36-, and 1.18-mm and 600-, 300-, 150- and 75-µm) sieves are required.

6.1.7 *Microscope.*–The microscope shall be stereoscopic, equipped with 10X oculars and 0.66X and 2.0X objectives to give magnifications of 6.6 and 20 diameters (note 5).

6.1.8 *Other Equipment.*–Also required are smooth, straight-pointed forceps; needleholder and points; and a focusing or spot illuminator of variable intensity (note 6).

NOTE 3.–A balance or scale will not be required when percentages of particles are based on count rather than mass.

NOTE 4.–Primarily, Bureau concrete mixes use the size fraction 3/4 inch to No. 4, and do not use the 3/4 to 3/8 inch or the 3/8 inch to No. 4 size fractions. However, concrete in canal linings is an exception. Select the sieve size fraction that is pertinent to the specific type of construction.

NOTE 5.–Any magnification in the range of 5 to 30 diameters or greater may be used in place of the 6.6 and 20 diameters specified. If desired, a micrometer disk with a scale division of 0.1 mm fitted into one of the oculars may be used as a measuring device for determining dimensions of fine aggregate particles.

NOTE 6.–Any illuminating device that is satisfactory to the operator and provides adequate glare-free illumination may be used.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Sampling

8.1 Samples of coarse and fine aggregate shall be obtained in accordance with USBR 4075 and shall be dry sieved in accordance with USBR 4136 to provide samples of each nominal size range to be examined.

8.1.1 Figure 3 shows a typical size distribution of suitably graded aggregate for concrete. Most concrete aggregates, depending on the nominal MSA (maximum size aggregate), will approximate the grading curve shown on figure 3. For whatever nominal MSA is desired, a scalp of the material retained on that nominal size (in percent), subtracted from the percentages retained (as shown on the table and curve on figure 3), multiplied by a factor of 100, and divided by the percent passing results in the percent retained for the minus 3-inch (–75-mm) MSA sample. If the table on figure 3 was in terms of cumulative percent passing instead of cumulative percent retained, that percentage multiplied by the same factor would give the typical size distribution for a suitably graded aggregate for concrete in terms of percent passing for whatever nominal MSA is desired. For example, using figure 3, the cumulative percent retained or passing the various sieves on the coarse aggregate fraction of a 6-inch (150-mm) sieve reduced to a 3-inch (75-mm) sieve would be as shown in table 1.

SIEVE SIZE	PERCENT RETAINED		COMBINED PERCENT RETAINED	
	INDIVIDUAL	CUMULATIVE	INDIVIDUAL	CUMULATIVE
6 Inches	0	0	0	0
3 Inches	28	28	21	21
1-1/2 Inches	26	54	20	41
3/4 Inch	22	76	16	57
3/8 Inch	16	92	12	69
No. 4	8	100	6	75
No. 4	0	0	0	
No. 8	12	12	3	78
No. 16	20	32	5	83
No. 30	24	56	6	89
No. 50	24	80	6	95
No. 100	16	96	4	99
Pan	4	100	1	100
FINENESS MODULUS=2.76				
PERCENT SAND (clean separation)=25 Percent				
(Sieve sizes are based on square openings)				

NOTE: 1 inch = 25.4 mm

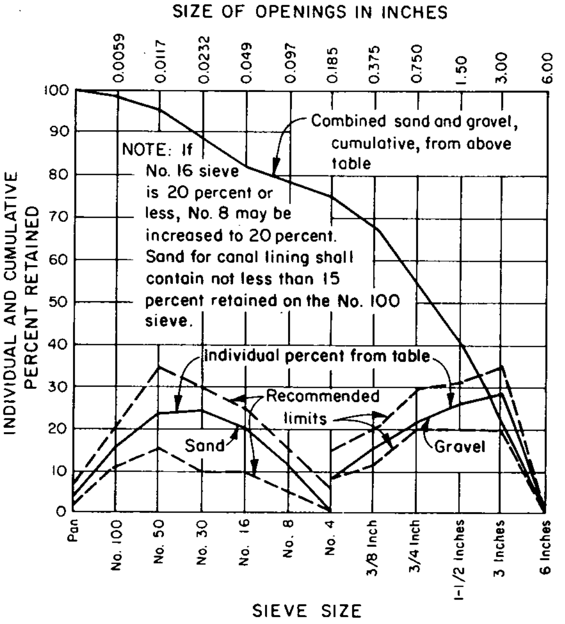


Figure 3. – Typical sieve size distribution of a suitably graded natural aggregate.

8.1.2 Samples taken to provide the sufficient mass required for the coarser sieves in table 2 will probably overload some of the finer sieves also shown in the table. An overload will require from one to several splits, as described in USBR 4702, of the minus fraction of the material smaller than the next larger sieve to the seive that caused the split. For example, figure 3 shows a typical size distribution of a suitably graded 6-inch (150-mm) MSA natural aggregate. If a 1-1/2-inch (37.5-mm) MSA similarly graded aggregate was desired for a flat and/or elongated particle count, this grading would yield a cumulative percent

Table 1. – Cumulative percent retained or passing various sieves on coarse aggregate fraction of a 6-inch sieve reduced to a 3-inch sieve.

Nominal Sieve Size	CPR	CPP	Retained CPR -21	Retained Times F = 1.266	Passing, Times F = 1.266*
6 inches (150 mm)	0	100	–	–	–
3 inches (75 mm)	21	79	0	0	100
1-1/2 inches (37.5 mm)	41	59	20	25	75
3/4 inch (19.0 mm)	57	43	36	46	54
3/8 inch (9.5 mm)	69	31	48	61	39
No. 4 (4.75 mm)	75	25	54	68	32
No. 8 (2.36 mm)	78	22	57	72	28
No. 16 (1.18 mm)	83	17	62	78	22
No. 30 (600 μm)	89	11	68	86	14
No. 50 (300 μm)	95	5	74	94	6
No. 100 (150 μm)	99	1	78	99	1
No. 200 (75 μm)	99.5	0.5	78.5	99.4	0.6
Pan	100	0	79	100	0

CPR = cumulative percent retained.
CPP = cumulative percent passing.
* F = 100/percent passing = 100/79 = 1.266. For whichever sieve a scalp is desired for, the percentage retained is the negative value and F = 100 divided by corresponding percent passing.

Table 2. – Minimum representative sample size required by test designations USBR 4075, 4136, and 4903.

Nominal size range fraction	4075 Field sample, four times min. required sieve analysis Mass lbm	4075 Mass kg	4136 Sieve analysis Mass lbm	4136 Mass kg	4903 For 300 particles Avg. mass lbm	4903 For 300 particles Avg. mass kg	4903 For 200 particles Avg. mass lbm	4903 For 200 particles Avg. mass kg	Max. for accuracy and no overload[1] Mass lbm	Max. Mass kg
6 to 3 inches (150 to 75 mm)	4,700	2140	1,175	535	1,375	625			129	58
3 to 1-1/2 inches (75 to 37.5 mm)	600	280	150	70	165	75			54	25
1-1/2 to 3/4 inch (37.5 to 19.0 mm)	80	40	20	10	21	10			29	13
3/4 to 3/8 inch (19.0 to 9.5 mm)	10	4.5	2.5	1.1	2.6	1.2			14.5	6.5
3/4 inch to No. 4 (19.0 to 4.75 mm)	10	4.5	2.5	1.1	1.6	0.7			7.2	3.3
3/8 inch to No. 4 (9.5 to 4.75 mm)	2	1.0	0.5	0.25	0.3	0.15			7.2	3.3
No. 4 to No. 8 (4.75 to 2.36 mm)	0.8	0.4	0.2	0.1	0.04	0.02			0.7	0.3
	lbm	g	lbm	g	lbm	g	lbm	g	lbm	g
No. 8 to No. 16 (2.36 to 1.18 mm)	0.8	400	0.2	100	0.005	2.3	–	–	0.31	141
No. 16 to No. 30 (1.18 mm to 600 μm)					–	0.3	–	–	0.15	68
No. 30 to No. 50 (600 to 300 μm)							–	0.026	0.08	36
No. 50 to No. 100 (300 to 150 μm)							–	0.003	0.04	18
No. 100 to No. 200 (150 to 75 μm)							–	0.0004	0.02	9

[1] The maximum mass allowed on each sieve to provide accuracy and not overload the sieves was based on the assumption that the Gilson shaker with an effective sieve area of 14.75 by 22.75 inches = 335.56 in^2 (0.2165 m^2) would be used through the No. 4 sieve, and the 8-inch (200-mm) sieve would be used through the No. 200 sieve with an effective sieve area of 50.26 in^2 (0.0324 m^2). The maximum mass was assumed to be the volume of the particle just passing the largest sieve size in the fraction times an assumed specific gravity of 2.75.

retained on the sieves as shown in table 3. From table 2, 21 lbm (10 kg) is required for a minimum mass for 300 particles and only 20 lbm (9 kg) is required for a sieve analysis sample. Consequently, the mass required for a 300-particle count would control; however, the gradation shown in table 3 shows that only 27 percent of the total material was retained on the 3/4-inch (19.0-mm) sieve. By proportioning, 27/21 as 100/*x*, and *x* = 78 lbm (35.3 kg) to satisfy the criteria for sieve analysis determination. Four times this amount, (4) (78) = 312 lbm (141.5 kg), determines the size of the field sample required to initiate the test. The 312-lbm sample should be split three times, as directed in USBR 4702, until sample is about 78 lbm. A sieve analysis should then be run on this sample. Assume that the resulting gradation agrees with that shown in table 3, then 21 lbm plus is available for the flat and/or elongated particle count and does not overload the 3/4-inch sieve (29 lbm, table 2). The analysis may now proceed with one operation of the Gilson shaker. This completes preparation of the 1-1/2- to 3/4-inch (37.5- to 19.5-mm) sieve size for the flat and/or elongated determination.

Preparation of the 3/4- to 3/8-inch (19.5- to 9.5-mm) sieve fraction should now be undertaken. From table 3, 20 percent of the total sieve analysis sample is retained between the 3/4- and 3/8-inch sieves. Using this percentage with the 78-lbm sample results in (0.20) (78) = 15.6 lbm (7.1 kg). From table 2,only 2.6 lbm (1.2 kg) is required for the 300-particle count; however, a mass in excess of 14.5 lbm (6.5 kg) will overload the 3/8-inch sieve. Therefore, a split down in accordance with USBR 4702 will be required for all material passing the 3/4-inch sieve and to satisfy the overload criteria. The 78-lbm sample minus 27 percent of the 1-1/2- to 3/4-inch scalped material results in 78 - (0.27) (78) = 56.94 lbm (25.8 kg). To approximate a closer mass of minus 3/4 inch to the 2.6 lbm required to furnish the 300-particle count, it would be advisable to split the 56.94 lbm four times to obtain a mass of about 3.6 lbm (1.6 kg) and process the resulting 3/4-inch material through the rest of the sieves. To correct this new grading back to the original 1-1/2-inch grading, see table 4.

Table 3. - Cumulative percent retained on various sieves for the coarse aggregate fraction of a 1-1/2-inch sieve reduced to a 3/4-inch sieve.

Nominal Sieve Size	CPR	Nominal Sieve Size	CPR
1-1/2 inches (37.5 mm)	0	No. 30 (600 μm)	81
3/4 inch (19.0 mm)	27	No. 50 (300 μm)	92
3/8 inch (9.5 mm)	47	No. 100 (150 μm)	98
No. 4 (4.75 mm)	58	No. 200 (75 μm)	99.2
No. 8 (2.36 mm)	63	Pan	100
No. 16 (1.18 mm)	71		

CPR = cumulative percent retained.

8.2 *Number of Particles*:

8.2.1 The number of particles in each nominal size range fraction to be examined are minimal and are based on experience and statistical considerations, see table 5. At least 300 particles of each nominal size range fraction shall be examined, except for sieve size fractions finer than No. 30 (600 μm) where a minimum of 200 particles shall be examined.

8.2.2 If sample of a nominal size range contains many more particles than need to be examined, the range may be reduced to the proper number of particles in accordance with methods of USBR 4702 (Method A preferred) or as described in section 8 of USBR 4295.

NOTE 7.–If there is less than 10 percent of sample retained in any one nominal size range of coarse aggregate fractions, the flat and elongated particles are not physically determined.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed in the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

9.2 Calipers and rule shall be calibrated in accordance with USBR 1000.

9.3 Balances or scales shall be calibrated in accordance with USBR 1012 to comply with section 6.1.4.

Table 4. - Corrected grading to reflect original 1-1/2-inch grading.

	Total Sample		Split-Down Sample -3/4 inch (-19.0 mm)		CPR of Split-Down-Sample Times CPP of Total Sample	Corrected Gradings to Reflect Original Sample	
	CPR	CPP	CPR	CPP		CPR Add CPR of Total Sample	CPP CPP of Split-Down Sample Times CPP of Total Sample
1-1/2 inches (37.5 mm)	0	100	-	-	-	-	-
3/4 inch (19.0 mm)	27	73	0	100	0	-	-
3/8 inch (9.5 mm)			28	72	20	47	53
No. 4 (4.75 mm)			42	58	31	58	42
No. 8 (2.36 mm)			49	51	36	63	37
No. 16 (1.18 mm)			60	40	44	71	29
No. 30 (600 μm)			74	26	54	81	19
No. 50 (300 μm)			88	12	64	91	9
No. 100 (150 μm)			98	2	72	99	1
No. 200 (75 μm)			98.8	1.2	72.1	99.1	0.9
Pan			100	0	73	100	0

CPR = cumulative percent retained.
CPP = cumulative percent passing.
Note: For whichever sieve size a split-down is required, the percentages retained or passing the original sample for that particular sieve size are applicable.

Table 5. - Minimum to maximum representative sample size to yield number of particle sizes under section 8.2.

Nominal size range fraction	Mass of 300 particles						Mass of 200 particles					
	Max.		Min.		Probable		Max.		Min.		Probable	
	lbm	kg	lbm	kg	lbm	kg	lbm	kg	lbm	kg	lbm	kg
6 to 3 inches (150 to 75 mm)	3,214	1458	402	182	1,374	623						
3 to 1-1/2 inches (75 to 37.5 mm)	402	182	50	23	167	76						
1-1/2 to 3/4 inch (37.5 to 19.0 mm)	50	23	6.5	3.0	21	9.5						
3/4 to 3/8 inch (19.0 to 9.5 mm)	6.5	3.0	0.8	0.4	2.6	1.2						
3/4 inch to No. 4 (19.0 to 4.75 mm)	6.5	3.0	0.8	0.4	1.6	0.7						
	lbm	g	lbm	g	lbm	g	lbm	g	lbm	g	lbm	g
3/8 inch to No. 4 (9.5 to 4.75 mm)	0.8	363	0.1	45	0.3	136						
No. 4 to No. 8 (4.75 to 2.36 mm)	-	46	-	5.7	-	19.4						
No. 8 to No. 16 (2.36 to 1.18 mm)	-	5.7	-	0.7	-	2.4						
No. 16 to No. 30 (1.18 mm to 600 μm)	-	0.7	-	0.1	-	0.3						
No. 30 to No. 50 (600 to 300 μm)	-	-	-	-	-	-	-	0.06	-	0.008	-	0.026
No. 50 to No. 100 (300 to 150 μm)	-	-	-	-	-	-	-	0.008	-	0.001	-	0.003
No. 100 to No. 200 (150 to 75 μm)	-	-	-	-	-	-	-	0.001	-	0.0001	-	0.0004

Note: The concentration of particles to the maximum or minimum side of the sieve fraction, and the degree of sphericity dictate a wide variation in the amount of sample required. For values in the probable size of samples, an intermediate size fraction was assumed with perfect sphericity, and a specific gravity of 2.75 was assumed for mass determination.

9.4 Ovens shall be calibrated in accordance with USBR 1020 to comply with section 6.1.5.

9.5 Sieves shall be calibrated in accordance with USBR 1025 to comply with section 6.1.6.

10. Conditioning

10.1 Preconditioning and preparation of sample are required as described in section 8.

11. Measured Coarse Particles Method-Weighted Averages Not Required

11.1 *Procedure.*-Each particle from the coarse aggregate nominal size ranges, as selected in section 8, is examined using the proportional caliper device or appropriate apparatus. The particles are then separated into four groups: (1) flat, (2) elongated, (3) both flat and elongated, and (4) not flat or elongated.

11.1.1 *Elongation.*-When using the proportional caliper device and testing for elongation, set larger opening of device equal to length of particle by placing particle between fixed post and point of swinging arm. If width of particle can be placed within smaller opening of swinging arm and its fixed point, the particle is elongated (fig. 4).

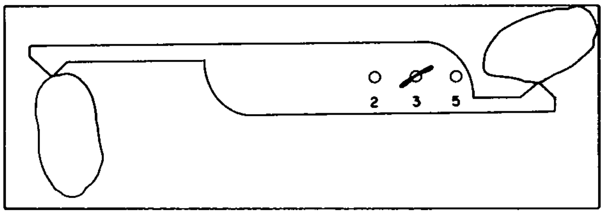
11.1.2 *Flatness.*-When using proportional caliper device and testing for flatness, set larger opening of device equal to width of particle by placing particle between fixed post and point of swinging arm. If thickness of particle can be placed within smaller opening of swinging arm and its fixed point, the particle is flat (fig. 4).

11.1.3 *Elongation and/or Flatness.*-Meets the criteria established under both sections 11.1.1 and 11.1.2.

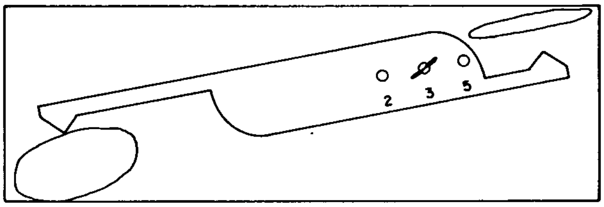
11.1.4 *Not Flat or Elongated.*-Does not meet the criteria established under either 11.1.1 or 11.1.2.

11.2 *Calculations.*-After the examined particles have been classified as described in section 11.1, they are counted and expressed as the percentage of flat, elongated, flat and elongated, and not flat or elongated present in each sieve size fraction examined, and recorded to nearest whole percent (fig. 5). The flat and/or elongated particles are expressed as a percentage by particle count according to:

$$\begin{aligned} P &= \frac{F}{n}\,(100), \text{ or} \\ &= \frac{E}{n}\,(100), \text{ or} \\ &= \frac{F\,\&\,E}{n}\,(100) \qquad (1) \end{aligned}$$



A. TEST FOR ELONGATION



B. TEST FOR FLATNESS

Figure 4. - Illustrations on using the proportional caliper device.

where:

P = percent of flat and/or elongated particles by particle count,
F = number of flat particles,
E = number of elongated particles,
$F \& E$ = number of particles that are both flat and elongated, and
n = number of particles examined.

11.2.1 Figure 5 shows an example of the calculations required when using this method.

12. Measured Coarse Particles Method-Weighted Averages Required

12.1 *Procedure.*-Each particle from the coarse aggregate nominal size ranges, as selected in section 8, is examined using the proportional caliper device or appropriate apparatus. The particles are then separated into four groups: (1) flat, (2) elongated, (3) both flat and elongated, and (4) not flat or elongated, and the mass determined for each group.

12.1.1 The specific procedure for use with the proportional caliper device is the same as described in sections 11.1.1 and 11.1.2.

12.2 *Calculations.*-After the examined particles have been classified, they are counted and expressed as the percentage of flat, elongated, flat and elongated, and not flat or elongated present in each nominal size range examined, and recorded to nearest 0.1 percent (fig. 6). The particles in each group shall have the weighted average mass determined and recorded as a percentage of total mass of each gradation range examined to the nearest whole percent. The flat and elongated particles are expressed as a percentage by particle count according to equation (1) in section 11.2. These same particles are expressed as a percentage of mass according to:

$$P_m = \frac{F_m}{n_m}(100), \text{ or}$$

$$= \frac{E_m}{n_m}(100), \text{ or}$$

$$= \frac{F_m \& E_m}{n_m}(100) \qquad (2)$$

where:

P_m = percent of flat and/or elongated particles by mass;
F_m = mass of flat particles, in pound mass (kilograms);
E_m = mass of elongated particles, in pound mass (kilograms);
$F_m \& E_m$ = mass of particles that are both flat and elongated; and
n_m = mass of particles measured (300 particles minimum), in pound mass (kilograms).

12.2.1 When weighted averages are calculated, based on actual or assumed proportions of the several sieve sizes in a nominal size range, the ranges not tested shall be assumed to have same percentages of flat and elongated particles as the average of next smaller and next larger ranges or, if one range is not represented, it shall be considered to have same percentage as next larger or next smaller range, whichever is present. Ranges used for calculating weighted averages shall be based on smallest coarse range examined, which is usually the 3/8-inch to No. 4 (9.5- to 4.75-mm) range.

12.2.2 Figure 6 shows an example of the calculations required when using this method.

13. Visual Inspection of Coarse Particles Method

13.1 *Procedure.*-Each particle from the coarse aggregate nominal size ranges, as selected in section 8, is visually examined. The particles are then separated into two groups: (1) flat and/or elongated, and (2) not flat or elongated.

13.1.1 The specific procedure shall be a visual estimation of the width-to-thickness and length-to-width ratios. The investigator is assumed to have the experience and expertise necessary to recognize and separate the flat and elongated particles in accordance with the 3:1 ratio described in section 5.

13.2 *Calculations.*-After the examined particles have been classified as described in section 13.1, they are counted and expressed as the percentage of flat and/or elongated present in each nominal size range examined, and recorded to nearest whole percent (fig. 5). If required, determine mass of separated groups, expressed as described in section 12.2, and record to nearest 0.1 percent as shown on figure 6. If weighted averages are required, use the calculations described in section 12.2.1, and expressed as shown on figure 6.

14. Microscopic and Visual Inspection of Fine Particles Method

14.1 *Procedure.*-Each particle from the fine aggregate sieve size ranges, as selected in section 8, is visually examined and with the aid of a microscope. The particles are then separated into two groups: (1) flat and/or elongated, and (2) not flat or elongated. The largest sieve size fraction, No. 4 to No. 8 (4.75 to 2.36 mm), may be examined with no or low magnification with equal ease and accuracy. Any suitable magnification in the range of 5X to 30X may be used for the finer sizes.

14.1.1 The specific procedure shall be a visual or microscopic inspection and estimation of the length-to-width and width-to-thickness ratios in accordance with section 5.

14.2 *Calculations.*–After the examined particles have been classified as described in section 14.1, they are counted and expressed as the percentage of flat and elongated present in each sieve size fraction examined, and recorded to nearest whole percent. The total flat and/or elongated particle count is reported as the average of the sieve size examined to the nearest whole percent (fig. 7). If required, separated groups may also be expressed using weighted averages, and recorded to nearest 0.1 percent as shown on figure 7. The weighted average shall be based on a recalculated grading which includes only those sieve size fractions.

NOTE 8.–For example, the weighted average percentage of flat and/or elongated particles, based on a recalculated grading of the No. 8 (2.36-mm) sieve size fraction, is obtained by multiplying recalculated individual percent retained times percentage of flat and/or elongated particles in the examined sieve size fraction. For the example on figure 7, 5 percent times 12.5 percent yields 0.6 percent. It should be noted that the percent of flat and/or elongated particles is recorded to nearest 0.1 percent. However, the total (cumulative) flat and elongated, as a weighted average percent of recalculated gradings, is reported to nearest whole percent.

14.2.1 Figure 7 shows an example of the calculations required when using this method.

15. Report

15.1 Refer to figure 4 of USBR 4075 for a typical reporting form. The report shall include:

- Adequate identification of aggregate tested.
- Percentages to nearest whole percent of the flat, elongated, flat and elongated, and not flat or elongated, as required and dependent upon method used, in each nominal size range or sieve size fraction examined and calculated by number, mass, and weighted averages as required.
- Number of particles tested in each nominal size range or sieve size fraction examined.

15.2 When values for percent of flat, elongated, flat and elongated, and not flat or elongated particles, dependent upon method used, have been calculated both by particle count and by mass and only a single value is required for determination of compliance with specification limit or in case of dispute, the percent by mass value shall be used.

15.3 When results are to be reported as part of USBR 4295, the visual inspection methods may be used.

16. Precision and Bias

16.1 The precision and bias for this procedure have not been established.

17. References

[1] *Handbook for Concrete and Cement*, Corps of Engineers, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Spec. or Solic. No. DC-7298	Structure CONCRETE CANAL LINING	Tested by J. JACOB	Date 4-7-80
Project CENTRAL ARIZONA	Item COARSE AGGREGATE Location STOCKPILE	Computed by J. JACOB	Date 4-7-80
Feature GRANITE REEF AQUEDUCT-REACH 2	Station ~ Offset ~ Depth ~ to ~	Checked by D. KILGORE	Date 4-8-80

FLAT AND ELONGATED PARTICLES IN COARSE AND FINE AGGREGATES

Nominal Sieve Size	Grading, Individual Mass Retained			Particle Count	Flat Particles		Elongated Particles		Flat and Elongated Particles		Neither Flat nor Elongated Particles		Total Flat and/or Elongated Particles,
	lbm	kg	%		No.	%	No.	%	No.	%	No.	%	%
PLUS 1½ INCHES	0		0	0	—	—	—	—	—	—	—	—	—
+37.5 mm		0	0										
1½ TO ¾ INCH	21.1		48	333	50	15	7	2	4	1	272	82	18
37.5 TO 19.0 mm		9.6	48										
¾ TO ⅜ INCH	15.4		35	372	74	20	10	3	4	1	284	76	24
19.0 TO 9.5 mm		7.0	35										
⅜ INCH TO No. 4	7.5		17	373	93	25	15	4	7	2	258	69	31
9.5 TO 4.75 mm		3.4	17										
MINUS No. 4	0		0	0	—	—	—	—	—	—	—	—	—
-4.75 mm		0	0										
Totals	44	20	100										73
Average													24

Figure 5. – Sample calculation form using the measured coarse particles method—weighted averages not required.

Spec. or Solic. No. DC-7298	Structure CONCRETE CANAL LINING	Tested by J. JACOB Date 4-7-80
Project CENTRAL ARIZONA	Item COARSE AGGREGATE Location STOCKPILE	Computed by J. JACOB Date 4-7-80
Feature GRANITE REEF AQUEDUCT REACH 2	Station ~ Offset ~ Depth ~ to ~	Checked by D. KILGORE Date 4-8-80

FLAT AND ELONGATED PARTICLES IN COARSE AND FINE AGGREGATES

Nominal Sieve Size	Grading, Individual Percent Retained			Particle Mass		BY MASS								BY NUMBER							
	Sample As Received		Calcualted on Portion Retained			Flat Particles		Elongated Particles		Flat and Elongated Particles		Neither Flat nor Elongated Particles		Flat Particles		Elongated Particles		Flat and Elongated Particles		Neither Flat nor Elongated Particles	
	[✓ lbm] kg	%	⅜"	[✓ lbm] kg	No.	[✓ lbm] kg	%	[✓ lbm] kg	%	[✓ lbm] kg	%	[✓ lbm] kg	%	No.	%	No.	%	No.	%	No.	%
PLUS 1½"	1.3	3	3.8*				(15.4)		(2.6)		(1.3)		(80.7)		(15.1)		(2.2)		(1.3)		(81.4)
1½ TO ¾"	19.8	45	56.2	15.6	312	2.4	15.4	0.4	2.6	0.2	1.3	12.6	80.7	47	15.1	7	2.2	4	1.3	254	81.4
¾ TO ⅜"	14.1	32	40.0	2.6	299	0.5	19.2	0.07	2.7	0.03	1.2	2.0	76.9	59	19.7	8	2.7	3	1.0	228	76.3
⅜" TO NO.4	7.9	18	0.0																		
MINUS NO.4	0.9	2	0.0																		
Totals	44	100	100.0																		

Nominal Sieve Size	Flat Particles		Elongated Particles		Flat and Elongated Particles		Neither Flat nor Elongated Particles		Total Flat and/or Elongated Particles, percent			
									By Sizes		Weighted Average	
	By Mass	By No.	By Mass	By No.	By Mass	By No.	By Mass	By No.	By Mass	By No.	By Mass	By No.
PLUS 1½"	1	1	0	0	0	0	3	3	—	—	1	1
1½ TO ¾"	9	8	1	1	1	1	45	46	19	19	11	10
¾ TO ⅜"	8	8	1	1	0	0	31	31	23	23	9	9
											21	20

Remarks:
*This size was not tested since it included less than 10% of sample; assumed to have same percentages of flat and/or elongated particles as next smaller size, as indicated by values in parens.

Figure 6. - Sample calculation form using the measured coarse particles method — weighted averages required.

Spec. or Solic. No. DC-7298	Structure CONCRETE CANAL LINING		Tested by J. HARTWELL	Date 5-15-80
Project CENTRAL ARIZONA	Item FINE AGGREGATE Location STOCKPILE-DENVER LAB		Computed by J. HARTWELL	Date 5-15-80
Feature GRANITE REEF AQUEDUCT-REACH 2	Station ~	Offset ~	Checked by P. KLEIN	Date 5-16-80
	Depth ~	to ~		

FLAT AND ELONGATED PARTICLES IN COARSE AND FINE AGGREGATES

Nominal Sieve Size	Grading, Individual Percent Retained				Particle Count	Flat and/or Elongated Particles		Neither Flat nor Elongated Particles		Total Flat and/or Elongated Particles; Weighted Average,
	Sample as Received			Calculated on Portion Retained,						
	lbm	kg	%	%		No.	%	No.	%	%
PLUS No.4	0		0	0	0	—	—	—	—	—
+4.75mm		0	0							
No.4 TO No.8	0.048		12	12.5	337	17	5	320	98	0.6
4.75 TO 2.36mm		0.0218	12							
No.8 TO No.16	0.080		20	20.8	360	36	10	324	90	2.1
2.36 TO 1.18mm		0.0363	20							
No.16 TO No.30	0.096		24	25.0	339	7	2	332	98	0.5
1.18mm TO 600µm		0.0435	24							
No.30 TO No.50	0.096		24	25.0	246	10	4	236	96	1.0
600 TO 300µm		0.0435	24							
No.50 TO No.100	0.064		16	16.7	188	19	10	169	90	1.7
300 TO 150µm		0.0290	16							
No.100 TO No.200	0.012		3	—	—	—	—	—	—	—
150 TO 75µm		0.0054	3							
MINUS No.200	0.004		1	—	—	—	—	—	—	—
-75µm		0.0018	1							
Totals	0.400	0.1813	100	100.0						5.9
									Use	6

Figure 7. – Sample calculation form using the microscopic and visual inspection of fine particles method.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4904-92

PROCEDURE FOR

PERCENTAGE OF CRUSHED PARTICLES IN COARSE AND FINE AGGREGATES

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4904; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is patterned after Test Method No. 205-E, dated September 14, 1964, published by the State of California, Department of Public Works, Division of Highways.

1. Scope

1.1 This test designation describes the procedures for determining percent by mass and particle count of particles which, by visual or microscopic inspection, have the characteristics of crushed aggregate.

2. Applicable Documents

2.1 *USBR Procedures*:

1012 Calibrating Balances or Scales
1020 Calibrating Ovens
4075 Sampling Aggregates
4117 Materials Finer Than No. 200 (75-µm) Sieve in Mineral Aggregates by Washing
4136 Sieve Analysis of Fine and Coarse Aggregates
4702 Reducing Field Samples of Aggregate to Testing Size
4903 Flat and Elongated Particles in Coarse and Fine Aggregates

2.2 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,3]

3. Terminology

3.1 Terms used in this procedure are as defined in ASTM C 125, and as follows:

3.2 *Crushed Gravel*.–The product resulting from artificial crushing of gravel with substantially all fragments having at least one face resulting from fracture.

3.3 *Crushed Stone*.–The product resulting from artificial crushing of rocks, boulders, or large cobbles with substantially all faces resulting from crushing operation.

3.4 *Weathered Surfaces*.–Surfaces produced by physical-chemical changes in rock, which result in changes in color, texture, composition, firmness, or form; may appear along old fracture surfaces.

3.5 *Unweathered Surfaces*.–Surfaces showing only fresh rock, with no significant physical or chemical alterations; may include freshly broken, previously healed fractures.

3.6 *Coarse Sand*.–Sand-size particles passing the No. 4 (4.75-mm) sieve and retained on the No. 8, 16, and 30 (2.36-mm, 1.18-mm, and 600-µm) sieves.

4. Apparatus

4.1 The apparatus components listed in this section comprise a recommended selection which will permit determination of percentage of crushed particles by mass or particle count.

4.1.1 *Balance*.–A balance or scale with a minimum capacity of 13.23 lbm (6 kg) and sensitivity to 0.0022 lbm (1 g) or less is required when determining mass.

4.1.2 *Sieves*.–The sieves shall be of the woven wire type with square openings, and shall conform to ASTM E 11.

4.1.3 *Splitter*.–Any device may be used as the splitter if it will divide sample into representative portions; however, the riffle-type splitter is preferable to hand quartering.

4.1.4 *Spatula*.–A spatula or similar tool is necessary to aid in sorting aggregate particles when determining percent by mass.

4.1.5 *Stereoscopic Microscope*.–A binocular microscope with objectives and oculars to give final magnifications from about 6 to 60 times the actual size.

4.1.6 *Needleholder and Points, and Forceps*.–These are tools used to aid in sorting coarse sand particles when determining percent by particle count; forceps to be straight-pointed.

5. Precautions

5.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.06, 05.05, 14.02.

responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5.2 Wash and oven-dry dirty aggregates in accordance with USBR 4117 if dirt or dust film obscures surface enough to make it difficult to detect fractured particle faces.

5.3 Material used in this procedure may be reused for other tests when there would otherwise be insufficient material for all required tests.

6. Preparation of Sample

6.1 Samples for this procedure shall be obtained in accordance with USBR 4075.

6.2 Sieve analysis determinations shall be run in accordance with USBR 4136 after material is split down to proper size in accordance with USBR 4702.

6.3 From each aggregate fraction representing 5 percent or more of submitted sample, split a representative portion to within 10 percent of mass specified according to table 1. This mass determination or not less than 300 particles of each size fraction, including coarse sand sizes passing the No. 4 (4.75-mm) sieve and retained on the No. 8, 16, and 30 (2.36-mm, 1.18-mm, and 600-μm) sieves, shall be used for particle count determination. Material passing the No. 30 sieve shall not be tested.

6.4 For further guidelines on handling samples to obtain the mass required to furnish 300 particles, refer to section 8 and tables 1, 2, and 3 of USBR 4903.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

7.2 Balances or scales shall be calibrated in accordance with USBR 1012.

7.3 The ovens used in drying the samples shall be checked in accordance with USBR 1020.

8. Procedure

8.1 Determine mass of each test sample to nearest gram and record as the "Test Sample Mass," or count not less than 300 particles and record as the "Total Number of Particles."

8.2 Spread one test sample on a clean, flat surface large enough to permit material to be spread thinly for inspection.

8.3 Use the knife edge of a large spatula, needleholder, forceps, or similar tool to separate crushed particles from uncrushed particles. Any particle appearing to have one or more freshly fractured faces, regardless of size, shall be considered a crushed particle.

8.4 When separation is complete, determine mass of crushed particles and record as "Mass of Crushed Particles," or count number of crushed particles and record as "Number of Crushed Particles."

8.5 Repeat 8.2, 8.3, and 8.4 for each test sample representing an individual size fraction.

9. Calculations

9.1 Calculate percentage of crushed particles in each respective test sample using the following formulas:

$$P_m = \frac{M_c}{M_s} (100) \qquad (1)$$

where:

P_m = percentage of crushed particles by mass,
M_c = mass of crushed particles, and
M_s = mass of test sample; or:

Table 1. – Mass required on each sieve size for crushed particle determination.

Sieve Sizes for Coarse Aggregate Fraction		Mass of Test Sample, ±10%	
Passing	Retained	lbm	kg
6-inch (150-mm)	3-inch (75-mm)	1,375	625
4-inch (100-mm)	2-inch (50-mm)	400	180
3-inch (75-mm)	1-1/2-inch (37.5-mm)	165	75
2-1/2-inch (63-mm)	1-1/4-inch (31.5-mm)	105	50
2-inch (50-mm)	1-inch (25.0-mm)	50	25
1-1/2-inch (37.5-mm)	3/4-inch (19.0-mm)	21	10
1-1/4-inch (31.5-mm)	1/2-inch (12.5-mm)	10.6	4.8
1-inch (25.0-mm)	No. 4 (4.75-mm)	3.2	1.4
3/4-inch (19.0-mm)	3/8-inch (9.5-mm)	2.8	1.3
3/4-inch (19.0-mm)	No. 4 (4.75-mm)	1.6	0.7
1/2-inch (12.5-mm)	No. 4 (4.75-mm)	0.6	0.27
3/8-inch (9.5-mm)	No. 4 (4.75-mm)	0.33	0.15
No. 4 (4.75-mm)	No. 8 (2.36-mm)	0.04	0.02
No. 8 (2.36-mm)	No. 16 (1.18-mm)	0.005	0.002
No. 16 (1.18-mm)	No. 30 (600-μm)	0.0007	0.0003

$$P_c = \frac{N_c}{N_t} (100) \qquad (2)$$

where:

P_c = percentage of crushed particles by particle count,
N_c = number of crushed particles, and
N_t = total number of particles (not less than 300).

9.2 Calculate percentage of crushed particles in the whole sample or in the coarse portions of the submitted sample by the weighted average method as follows:

Multiply percentage (based on total mass or total particle count of sample) of each size fraction to be included in weighted average by its respective percentage of crushed particles, result from equation (1) or (2). The sum of these products divided by sum of percentage of each of the included size fractions results in the weighted average percentage of crushed particles for that group of fractions included in calculation.

9.3 Some specifications may specify a minimum percentage of at least two fractured faces on each particle for a certain size range. If this is required, the particles between each sieve must be separated; one pile for single-face fractures and another for two or more face fractures. The rest of the procedure remains the same, except this additional data must be recorded.

9.4 Figure 1 shows a suggested work sheet and typical calculations.

10. Report

10.1 Figure 4 of USBR 4075 may be used as a typical reporting form. The report shall include the following information as appropriate:

- Size fractions in submitted sample.
- Percent of each size fraction in submitted sample.
- Percent of crushed particles in each size fraction as determined by either mass or particle count.
- Weighted average percentage of crushed particles retained on the No. 4 (4.75-mm) sieve fraction; passing the No. 4 sieve and retained on the No. 8, 16, and 30 (2.36-mm, 1.18-mm, and 600-μm) sieve fractions, respectively; and total sample as passing the maximum size sieve and retained on the No. 30 sieve.

11. Precision and Bias

11.1 The precision and bias statements for this procedure have not been established.

Spec. or Solic. No. NA	Structure NA	Tested by C. BECHTOLD Date 9-4-84
Project NA	Item TEST PROCED.-CLEAR CREEK AGG. Location DENVER LAB	Computed by C. BECHTOLD Date 9-4-84
Feature NA	Station — Offset — Depth — to —	Checked by P. KLEIN Date 9-4-84

PERCENTAGE OF CRUSHED PARTICLES IN COARSE AND FINE AGGREGATES

Nominal Sieve Size	Grading, Individual Percent Retained on Sample as Received		Total Sample Particles		SINGLE-FACE FRACTURE					
	lbm	P_i %	M_s Sample Mass, lbm	N_t Total No.	M_c Crushed Mass, lbm	N_c Crushed No.	P_m $\frac{M_c}{M_s}(100)$ %	P_c $\frac{N_c}{N_t}(100)$ %	Product of $(P_i)(P_m)$	Product of $(P_i)(P_c)$
3 to 1½"	2.73	3	*	*						
1½ to ¾"	24.57	27	21.56	308						
¾ to ⅜"	17.29	19	2.79	321						
⅜" to No.4	14.56	16	0.32	318						
No.4 to No.8	4.55	5	0.04	303						
No.8 to No.16	6.37	7	0.005	312						
No.16 to No.30	7.28	8	0.0006	319						
MINUS No.30	13.65	15	**	**	*LESS THAN 5% OF FRACTION IN "AS RECEIVED" SAMPLE					
Totals	91.00	100			**NO TEST TO BE RUN ON MINUS NO. 30					
					MULTIPLE-FACE FRACTURE					
					SEPARATE TEST FOR TOTAL PARTICLES WITH FRACTURED FACES					
1½ to ¾"		27			18.97	259	88	84	2,376	2,268
¾ to ⅜"		19			2.59	315	93	98	1,767	1,862
⅜" to No.4		16			0.304	308	95	97	1,520	1,552
No.4 to No.8		5			0.0084	70	21	23	105	115
No.8 to No.16		7			0.0006	41	12	13	84	91
No.16 to No.30		8			0.00004	22	7	7	56	56

WEIGHTED AVERAGES

Sieve Fractions	P_i Summation %	Product Summation		Single-Face Fracture						Multiple-Face Fracture						Total Particles-Fractured Faces					
		Mass	Count	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %
Plus No. 4	$A =$	$D_m =$	$D_c =$																		
Minus No. 4	$B =$	$E_m =$	$E_c =$																		
____ inch to No. 30	$C =$	$F_m =$	$F_c =$																		
Plus No. 4	$A =$	$D_m =$	$D_c =$																		
Minus No. 4	$B =$	$E_m =$	$E_c =$																		
____ inch to No. 30	$C =$	$F_m =$	$F_c =$																		
Plus No. 4	$A =$ 62	$D_m =$ 5663	$D_c =$ 5682													91			92		
Minus No. 4	$B =$ 20	$E_m =$ 245	$E_c =$ 262														12			13	
3 inch to No. 30	$C =$ 82	$F_m =$ 5908	$F_c =$ 5944															72			72

NOTE: *A*, *B*, and *C* indicate summation of fractional individual percent retained (P_i) on the "as received" sample. D_m, E_m, F_m, D_c, E_c, and F_c indicate summation of fractional product $(P_i)(P_m)$ or $(P_i)(P_c)$, respectively.

Figure 1a.–Sample worksheet for determination of crushed particle faces (inch-pound units).

Spec. or Solic. No. NA	Structure NA	Tested by C. BECHTOLD Date 9-4-84
Project NA	Item TEST PROCED.-CLEAR CREEK AGG Location DENVER LAB	Computed by C. BECHTOLD Date 9-4-84
Feature NA	Station — Offset — Depth — to —	Checked by P. KLEIN Date 9-4-84

PERCENTAGE OF CRUSHED PARTICLES IN COARSE AND FINE AGGREGATES

Nominal Sieve Size	Grading, Individual Percent Retained on Sample as Received		Total Sample Particles		SINGLE-FACE FRACTURE					
	kg	P_i %	M_s Sample Mass, kg	N_t Total No.	M_c Crushed Mass, kg	N_c Crushed No.	P_m $\frac{M_c}{M_s}(100)$ %	P_c $\frac{N_c}{N_t}(100)$ %	Product of $(P_i)(P_m)$	Product of $(P_i)(P_c)$
75 to 37.5 mm	1.24	3	*	*						
37.5 to 19.0 mm	11.14	27	9.780	308						
19.0 to 9.5 mm	7.84	19	1.266	321						
9.5 to 4.75 mm	6.60	16	0.145	318						
4.75 to 2.36 mm	2.06	5	0.018	303						
2.36 to 1.18 mm	2.89	7	0.0023	312						
1.18 mm to 600 µm	3.30	8	0.00027	319						
MINUS 600 µm	6.19	15	**	**	*LESS THAN 5% OF FRACTION IN "AS RECEIVED" SAMPLE					
Totals	41.27	100			**NO TEST TO BE RUN ON MINUS 600 µm					
					MULTIPLE-FACE FRACTURE					
					SEPARATE TEST FOR TOTAL PARTICLES WITH FRACTURED FACES					
37.5 to 19.0 mm		27			8.605	259	88	84	2376	2268
19.0 to 9.5 mm		19			1.175	315	93	98	1767	1862
9.5 to 4.75 mm		16			0.138	308	95	97	1520	1552
4.75 to 2.36 mm		5			0.0038	70	21	23	105	115
2.36 to 1.18 mm		7			0.00027	41	12	13	84	91
1.18 mm to 600 µm		8			0.000018	22	7	7	56	56

WEIGHTED AVERAGES

Sieve Fractions	P_i Summation %	Product Summation		Single-Face Fracture						Multiple-Face Fracture						Total Particles-Fractured Faces					
		Mass	Count	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %	$\frac{D_m}{A}$ %	$\frac{E_m}{B}$ %	$\frac{F_m}{C}$ %	$\frac{D_c}{A}$ %	$\frac{E_c}{B}$ %	$\frac{F_c}{C}$ %
Plus 4.75 mm	$A =$	$D_m =$	$D_c =$																		
Minus 4.75 mm	$B =$	$E_m =$	$E_c =$																		
___ mm to 600 µm	$C =$	$F_m =$	$F_c =$																		
Plus 4.75 mm	$A =$	$D_m =$	$D_c =$																		
Minus 4.75 mm	$B =$	$E_m =$	$E_c =$																		
___ mm to 600 µm	$C =$	$F_m =$	$F_c =$																		
Plus 4.75 mm	$A =$ 62	$D_m =$ 5663	$D_c =$ 5682													91			92		
Minus 4.75 mm	$B =$ 20	$E_m =$ 245	$E_c =$ 262														12			13	
75 mm to 600 µm	$C =$ 82	$F_m =$ 5908	$F_c =$ 5944															72			72

NOTE: A, B, and C indicate summation of fractional individual percent retained (P_i) on the "as received" sample. D_m, E_m, F_m, D_c, E_c, and F_c indicate summation of fractional product (P_i) (P_m) or (P_i) (P_c), respectively.

Figure 1b.–Sample worksheet for determination of crushed particle faces (SI-metric units).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4905-92

PROCEDURE FOR

CONSISTENCY AND DENSITY OF NO-SLUMP CONCRETE WITH VIBRATORY TABLE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4905; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM C 1170-91.

1. Scope

1.1 This designation covers the procedures for determining the consistency and density of no-slump concrete when standard slump test procedures, as outlined in USBR 4143, and density procedures, as outlined in USBR 4138, are not applicable. These procedures are applicable in both the laboratory and field.

NOTE 1.–These procedures are considered applicable to plastic concrete having coarse aggregate up to 2 inches (50 mm) in size. If coarse aggregate is larger than 2 inches, procedures are applicable when made on the fraction of concrete passing the 2-inch sieve, with larger aggregate being removed in accordance with USBR 4172 with the exception that a 2-inch sieve is used instead of a 1-1/2-inch (37.5-mm) sieve. The USBR 4172 procedure is not considered applicable for nonplastic and noncohesive concrete.

1.2 These procedures, intended for use in testing roller-compacted concrete, may be applicable to testing other types of concrete such as cement-treated aggregate and mixtures similar to soil-cement.

1.3 Two alternate test methods are provided to determine the consistency and density of concrete using a Vebe vibrating table:

1.3.1 *Test Method A* [using a 50-lbm (22.7-kg) surcharge mass placed on top of the test specimen].–Test Method A shall be used for testing concrete of very stiff to extremely dry consistency in accordance with ACI 211.3-75 (R 1989).

1.3.2 *Test Method B* (no surcharge).–Test Method B shall be used for concrete of stiff to very stiff consistency or when the Vebe time by Test Method A is less than 5 seconds.

1.4 The recommended vibration table for this test procedure is the Vebe vibrating table. To date, all Bureau testing has been performed using this testing apparatus. An alternate vibrating table may be substituted for the Vebe apparatus provided it meets the specifications for the sinusoidal vibration as shown in section 9.3 and the alternate testing requirements of sections 11 and 12.

2. Applicable Documents

2.1 *USBR Procedures*:

4029 Density and Voids in Aggregate
4031 Making and Curing Concrete Test Specimens in Field
4138 Density, Yield, Clean, Separation, and Air Content (Gravimetric) of Concrete
4143 Slump of Concrete
4172 Sampling Freshly Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standards*:

C 1170 Standard Test Methods for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table[1]
E 1 Specification for ASTM Thermometers[2]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[1,3]

2.3 *ACI Standards*:

207.5R-89 Roller-Compacted Concrete[4]
211.3-75R-89 Standard Practice for Selecting Proportions for No-Slump Concrete[4]

3. Summary of Procedure

3.1 This procedure is used to measure the consistency of stiff to extremely dry concrete mixtures (note 2). Consistency is meaasured as the time required for a given mass of concrete to be consolidated by vibrating in a cylindrically shaped mold. Denisty of the compacted specimen is measured by determining the mass of the consolidated specimen and dividing by its volume, which is determined using water-displacement methods.

NOTE 2.–Further description of concrete of this consistency is given in ACI 207.5R-89 and ACI 211.3-75 (R 1989).

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 05.03, 14.03.

[3] *Annual Book of ASTM Standards*, vols. 04.01, 04.06, 04.07, 05.05, 14.02.

[4] *ACI Manual of Concrete Practice*, part 1, 1990. Available from American Concrete Institute, PO Box 19150, Redford Station, Detroit, MI 48219.

4. Significance and Use

4.1 Test methods A and B are intended to be used for determining the consistency and density of stiff to extremely dry concrete mixtures common when using roller-compacted concrete construction.

4.1.1 Because of the stiff to extremely dry consistency of some roller-compacted concrete mixtures, the standard Vebe test method of rodding the specimen in a slump cone is substituted by Test Methods A and B. For Test Method A, the surcharge mass is increased from 6 lbm (2.72 kg) to 50 lbm (22.7 kg); and for Test Method B, the surcharge mass is eliminated.

4.2 Test Method A uses a 50-lbm surcharge and is used for concrete consolidated by roller-compaction methods. The consistency and density of concrete suitable for consolidation by vibrating rollers can be determined using Test Method A.

4.3 Test Method B does not use a surcharge and can be used to determine the consistency and density of some concrete mixtures consolidated by conventional vibration techniques and some concrete mixtures consolidated by vibrating rollers.

5. Terminology

5.1 *Roller-Compacted Concrete.*–Concrete of zero-slump consistency which is placed by depositing loosely in horizontal lifts and consolidated with smooth-drum vibrating rollers.

6. Apparatus

6.1 *Cylindrical Mold.*–The cylindrical mold shall be made of steel or other hard metal resistant to cement paste corrosion and have an inside diameter of 9-1/2±1/16 inches (241±2 mm) and a height of 7-3/4±1/16 inches (197±2 mm). Volume of mold shall be determined in accordance with USBR 4029. The mold shall be equipped with permanently affixed metal slots which can be rigidly clamped to Vebe vibrating table. Top rim of mold shall be smooth, planar, and parallel to bottom of mold; and shall be capable of providing a tight seal. There should be no leakage of air bubbles when mold is filled with water and a smooth glass or plastic plate is placed over top rim.

6.2 *Swivel Arm and Guide Sleeve.*–A metal guide sleeve with clamp assembly or other suitable holding device mounted on a swivel arm. The swivel arm and guide sleeve must be capable of holding a metal shaft attached to a 50-lbm (22.7-kg) surcharge in a position perpendicular to vibrating table, which allows the rod to slide freely when clamp is released. The guide sleeve inside diameter shall be 1/8±1/16 inch (3.2±1.6 mm) larger than the diameter of the metal shaft of the surcharge. The sleeve must be capable of maintaining a locked position with center of sleeve directly over center of vibrating table, and shall also be capable of rotating away from center of table. The Vebe vibrating table comes equipped with this guide sleeve.

6.3 *Surcharge.*–A cylindrical surcharge with a metal shaft at least 18 inches (457 mm) long and 5/8±1/16 inch (16±2mm) diameter attached perpendicularly to the plate and embedded through center of surcharge. The shaft shall slide through the guide sleeve without binding or excessive play. The base of the surcharge shall have a 9±1/8-inch (229±3-mm) diameter. Surcharge shall have a mass of 50±1 lbm (22.7±0.5 kg) including mass of the metal shaft. If the surcharge is hand held, the length of the metal shaft may be reduced to 12 inches (305 mm) and fabricated with a "T" or "D" handle for gripping the surcharge shaft to avoid the hand slipping.

6.4 *Balance or Scale.*–The balance or scale shall be of sufficient capacity to determine total mass of sample and mold, and have sufficient accuracy so that mass of concrete sample may be determined to nearest .01 lbm (4.5 g).

6.5 *Flat Plate.*–A square, flat plate or acrylic plate at least 1/2 inch thick with a length and width at least 1 inch (25 mm) greater than outside diameter of cylincrical mold is required. The plate shall be smooth and planar.

6.6 *Vebe Vibrating Table.*–A vibrating table with a 3/4-inch (19 mm) thick steel deck with dimensions of about 15 inches in length, 10-1/4 inches in width, and 12 inches in height (381- 260- 305-mm). The vibrating table shall be constructed in such a manner as to prevent flexing of the table during operation. The table deck shall be activated by an electromechanical vibrator. The total mass of the vibrator and table shall be approximately 210 lbm (95 kg). The table shall be level and clamped to a concrete floor or base slab having sufficient mass to prevent displacement of the apparatus during performance of the test.

NOTE 3.–The recommended vibrating table for these test procedures is the Vebe vibrating table. To date, testing has been performed using this apparatus. An alternative vibrating table may be substituted for the Vebe apparatus (fig. 1) provided it meets the specifications for the sinusoidal vibration given in subsection 9.3 and is in accordance with the alternative testing requirements of sections 11 and 12. The Vebe apparatus, including cylindrical mold and guide sleeves, is manufactured by Dynapac Maskin (formerly Vibro-Verken), PO Box 1103, 5-171-22, Solna, Sweden; Dynapac Manufacturing, Inc., Stanhope NJ 07874; and Soiltest, Inc., 86 Albrecht Drive, PO Box 8004, Lake Bluff IL 60044-9902.

6.7 *Thermometer.*–ASTM No. 1F or 1C thermometer conforming to the requirements of ASTM specification E 1.

6.8 *Sieve.*–A 2-inch (50-mm) sieve conforming to ASTM specification E 11.

6.9 *Miscellaneous Equipment.*–Also required are a shovel, scoop, slump rod, stopwatch, and flashlight.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. The user is responsible to consult and establish appropriate safety and health practices and to determine applicability of regulatory limitations prior to use.

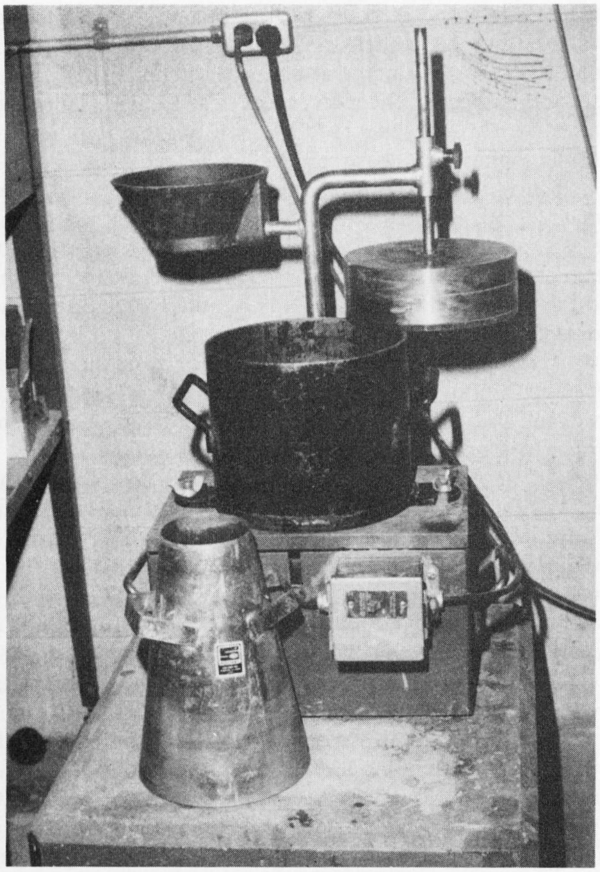


Figure 1. - Vibrating table—consistency test.

8. Sampling, Test Specimens, and Test Units

8.1 Samples of fresh concrete should be obtained in accordance with USBR 4172.

8.2 Concrete samples should have a nominal maximum size aggregate of 2 inches (50 mm) or less. If concrete has aggregate larger than 2 inches, samples shall be obtained by wet sieving over a 2-inch sieve in accordance with USBR 4172.

8.3 Concrete sample testing shall be completed within 45 minutes after the completion of mixing unless otherwise stipulated.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

9.2 *Cylindrical Mold*.–The volume of the cylindrical mold shall be calibrated to the nearest 0.02 ft³ (0.000 57 m³) in accordance with USBR 4029. Calibration shall be performed annually when use is infrequent and monthly during times of heavy use. Mass of cylindrical mold, if used in density computations (i.e., balance with tare unavailable), shall be determined to nearest 0.01 lbm (4.5 g).

9.3 *Vebe Vibrating Table*.–The frequency and amplitude of the vibrating table shall be determined under simulated test conditions prior to initial use, and annually thereafter (note 4). Frequency and amplitude shall be determined in accordance with USBR 4031 or 4192.

NOTE 4.–This determination can be performed by personnel of the Materials Engineering Branch (code D-3735) at the Bureau's Denver Office, and should be coordinated with the calibration of other vibration testing equipment.

9.3.1 The Vebe vibration table or the alternate table shall produce a sinusoidal vibratory motion with a frequency of 3600±100 vibrations per minute (60±1.67 Hz) and an amplitude of vibration of 0.0085±0.0015 inch (0.22±0.04 mm) when a 60±2.5-lbm (27.2±1.1 kg) surcharge is bolted to center of table, as shown on figure 2.

9.4 In addition to the calibration frequency recommended in subsection 9.3, the vibrating table also should be calibrated after any event (including repairs) which might affect its operation and whenever test results are questionable.

9.5 At least, after every 3 months of continuous use, the underside of the vibrating table top should be inspected and cleaned of any hardened concrete or cement paste which may interfere with free movement of the tabletop.

10. Conditioning

10.1 Special conditioning is covered under sections 11 and 12.

TEST METHOD — VEBE TIME

11. Procedure

11.1 *Vebe Consistency Time* (with a surcharge):

11.1.1 Using square-ended shovels and scoops, obtain a representative sample, in accordance with section 8,

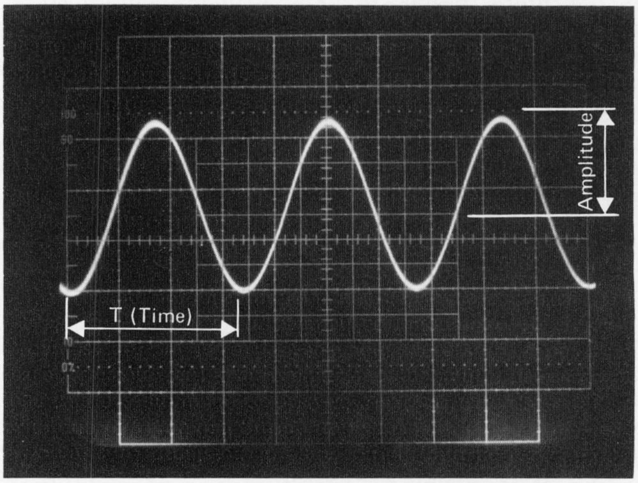


Figure 2. - Sinusoidal vibratory wave motion for vibrating tables. Frequency = 60 Hz, Single amplituide = 0.0085 inch (0.216 mm), and Surchage = 60 lbm (27 kg).

with a minimum mass of 50 lbm (22.7 kg). Handle concrete in such a manner that coarse aggregate does not separate from the mortar.

NOTE 5.-Concrete in the range of no-slump consistency is highly susceptible to segregation during handling. To minimize this, it is essential that care be used in obtaining samples and, during transporting, remixing and testing of the concrete. Square-ended shovels and scoops should be used to obtain a representative sample. Concrete should be handled in such a way that large-sized coarse aggregate does not separate from the mortar.

11.1.2 Dampen the interior of the mold and fill with 29.5±1.5 lbm (13.4±0.7 kg) of concrete. Using a square-edged scoop and tamping rod, place and distribute the concrete evenly to minimize segregation and rock pockets. Level the surface of the loose concrete.

11.1.3 Secure the mold on the Vebe table by hand tightening the wing nuts. Slide the shaft of the surcharge mass through the guide sleeve, and rotate the surcharge to its locked position centered over the mold, ensuring that it will fit inside the mold when released. The surcharge may be lowered into the mold during this procedure to adjust the position of the mold but it shall not be placed on the specimen. Secure the wing nuts of the Vebe table with a wrench to prevent loosening during the test. Gently lower the surcharge onto the surface of the specimen.

11.1.4 If the surcharge cannot be centered in the mold without binding on the inside wall of the mold, place the surcharge directly onto the specimen in the mold without the use of the guide sleeve, and manually hold the surcharge shaft perpendicular to the top of the table. The surcharge shaft must be held manually throughout the remainder of the Vebe test. Do not apply additional hand pressure to the surcharge when manually holding the surcharge.

11.1.5 Start the vibrator and timer. Using a flashlight, observe the concrete in the annular space between the edge of the surcharge and the inside wall of the mold. As the test progresses, mortar will fill in the annular space between the outer edge of the surcharge and the inside mold wall. Observe the mortar until it forms a ring around the total perimeter of the surcharge. When the mortar ring forms completely around the surcharge, stop the vibrator and timer; determine the elapsed time to the nearest minute and second. Record this time as the Vebe consistency time, Test Method A. If the wing nuts loosen during the test, repeat the test with a fresh sample of concrete. If the ring of mortar does not form after 2 minutes of vibration, stop the vibrator and timer; record this condition on the report.

11.1.6 If the following conditions exist after 2 minutes have elapsed, document them in the report, record the elapsed time, and retest if necessary:

11.1.6.1 A rock pocket in the loose specimen prevents the mortar ring from forming at one small location even though the mortar ring forms in all other locations, or:

11.1.6.2 The elapsed time in which the majority of the mortar ring formed is similar to previous readings with the same mixture proportions.

11.1.7 Determine the density of the specimen in accordance with section 11.2.

11.2 *Vebe Density of Freshly Consolidated Concrete*:

11.2.1 Following determination of the Vebe time, remove the surcharge. Vibrate the specimen without the surcharge for an additional 10 seconds to level the top surface of the sample.

11.2.2 Remove the mold with the consolidated specimen from the Vebe table, and wipe any mortar from the inside wall of the cylinder mold above the level of the consolidated concrete. Place the flat plate on the cylinder mold and determine to the nearest 0.01 lbm (4.5 g) the mass of the cylindrical mold, consolidated concrete specimen, and flat plate. Determine the mass of the specimen by subtracting the mass of the cylindrical mold and flat plate from the mass of the cylindrical mold, consolidated specimen, and flat plate. Remove the flat plate.

11.2.3 Place the mold on a level surface and carefully fill the mold with water at room temperature to a meniscus level just above the top rim while minimizing washout of paste from the specimen surface.

11.2.4 Determine the temperature of the water to the nearest 1 °F (1 °C).

11.2.5 Carefully cover the mold with the flat plate in such a way as to eliminate air bubbles and excess water.

11.2.6 Wipe all excess water, and determine the total mass of the cylinder mold, consolidated specimen, water, and flat plate. Determine the mass of the water by subtracting the mass of the mold, specimen, and flat plate as determined in 11.2.2 from the total mass.

11.2.7 Determine the volume of water by dividing the mass of water by the density of water at the recorded temperature in accordance with the values given in tables 1 or 2—interpolating if necessary. Determine the volume of water to the nearest 0.001 ft^3 (0.028 L).

11.2.8 Determine the volume of the specimen by subtracting the volume of the water obtained in 11.2.7 from the volume of the cylinder mold obtained in 9.2.

11.2.9 Determine the density of the specimen in accordance with section 13, Calculations. This is referred to as the Vebe density of the specimen, Test Method A.

11.3 *Vibrating Consistency Time and Density Using an Alternative Vibrating Table, Test Method A*:

11.3.1 Determine the consistency time of concrete in accordance with 11.1. Record the use of an alternative vibrating table, and record the time as vibrating consistency time, Test Method A.

11.3.2 Determine the density of the specimen in accordance with 11.2. Refer to this as the vibrating density of the specimen, Test Method A.

11.3.2.1 When determining the consistency and density of concrete using an alternative vibrating table, it may not be possible to vibrate the specimen without a surcharge. This is due to disturbance of the compacted specimen when large-amplitude, low-frequency vibration waves occur after the vibrator is turned off. If this occurs, leave the surcharge on the specimen after determining the vibrating time, and vibrate the specimen for an additional 10 seconds. Record the use of the surcharge for the density determination.

Table 1. - Absolute density of water in grams per cubic centimeter — °F.[1]

°F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
32	0.999 841	845	848	852	856	860	863	867	871	874
33	.999 878	881	883	886	889	892	894	897	900	902
34	.999 905	908	910	913	915	918	920	923	925	928
35	.999 930	932	933	935	937	939	940	942	944	945
36	.999 947	949	950	952	953	955	956	958	959	961
37	.999 962	963	963	964	965	966	966	967	968	968
38	.999 969	969	970	970	971	971	971	972	972	973
39	.999 973	973	973	973	973	973	972	972	972	972
40	.999 972	971	971	970	969	969	968	967	966	966
41	.999 965	964	962	961	960	959	957	956	955	953
42	.999 952	951	950	949	948	947	945	944	943	942
43	.999 941	939	936	934	931	929	926	924	921	919
44	.999 916	914	911	909	907	905	902	900	898	895
45	.999 893	890	887	883	880	877	874	871	867	864
46	.999 861	858	855	852	849	846	842	839	836	833
47	.999 830	826	822	818	814	810	805	801	797	793
48	.999 789	785	781	778	774	770	766	762	759	755
49	.999 751	746	741	736	731	726	720	715	710	705
50	.999 700	695	689	684	678	673	667	662	656	651
51	.999 645	641	637	633	629	625	621	617	613	609
52	.999 605	598	590	583	575	568	561	553	546	538
53	.999 531	525	520	514	509	503	497	492	486	481
54	.999 475	468	460	453	446	439	431	424	417	409
55	.999 402	396	389	383	377	371	364	358	352	345
56	.999 339	331	323	315	307	299	290	282	274	266
57	.999 258	251	244	237	230	223	216	209	202	195
58	.999 188	179	170	161	152	144	135	126	117	108
59	.999 099	090	081	071	062	053	044	035	025	016
60	.999 007	001	*994	*988	*981	*975	*969	*962	*956	*949
61	.998 943	931	920	908	896	885	873	861	849	838
62	.998 826	817	809	800	791	783	774	765	756	748
63	.998 739	728	718	707	696	686	675	664	653	643
64	.998 632	623	613	604	595	586	576	567	558	548
65	.998 539	528	516	505	493	482	470	459	447	436
66	.998 424	414	404	394	384	375	365	355	345	335
67	.998 325	313	301	288	276	264	252	240	227	215
68	.998 203	191	178	166	153	141	128	116	103	090
69	.998 078	067	056	046	035	024	013	002	*992	*981
70	.997 970	957	943	930	917	904	890	877	864	850
71	.997 837	826	814	803	792	781	769	758	747	735
72	.997 724	710	696	682	668	655	641	627	613	599
73	.997 585	573	561	549	537	526	514	502	490	478
74	.997 466	451	437	422	408	393	378	364	349	335
75	.997 320	308	295	283	270	258	246	233	221	208
76	.997 196	181	166	150	135	120	105	090	074	059
77	.997 044	028	013	*997	*982	*966	*950	*935	*919	*904
78	.996 888	875	862	848	835	822	809	796	782	769
79	.996 756	740	724	707	691	675	659	643	626	610
80	.996 594	583	572	561	550	540	529	518	507	496
81	.996 485	465	446	426	407	387	367	348	328	309
82	.996 289	275	261	246	232	218	204	190	175	161
83	.996 147	130	112	095	077	060	043	025	008	*990
84	.995 973	958	944	929	914	900	885	870	855	841
85	.995 826	808	790	772	754	736	718	700	682	664

[1] To obtain absolute density of water in pound mass per cubic foot, multiply value shown in table by 62.4278578.

* First three significant digits shown in line below.

11.3.2.2 Determine the density of the consolidated specimen in accordance with 11.2.2 through 11.2.9.

TEST METHOD B — VEBE TIME

12. Procedure

12.1 *Vebe Consistency Time* (without a surcharge):

12.1.1 Obtain a representative sample of concrete having a minimum mass of 50 lbm (22.7 kg) in accordance with section 8, and place the concrete in the cylindrical mold in accordance with 11.1.1 and 11.1.2.

12.1.2 Place the mold on the Vebe table, and tighten the wing nuts to prevent loosening during the test.

12.1.3 Start the vibrator and the timer. Observe the contact between the concrete and inside wall of the mold.

Table 2. - Absolute density of water in kilograms per cubic meter — °C.

°C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	999.841	.847	.854	.860	.866	.872	.878	.884	.889	.895
1	.900	.905	.909	.914	.918	.923	.927	.930	.934	.938
2	.941	.944	.947	.950	.953	.955	.958	.960	.962	.964
3	.965	.967	.968	.969	.970	.971	.972	.972	.973	.973
4	.973	.973	.973	.972	.972	.972	.970	.969	.968	.966
5	.965	.963	.961	.959	.957	.955	.952	.950	.947	.944
6	.941	.938	.935	.931	.927	.924	.920	.916	.911	.907
7	.902	.898	.893	.888	.883	.877	.872	.866	.861	.855
8	.849	.843	.837	.830	.824	.817	.810	.803	.796	.789
9	.781	.774	.766	.758	.751	.742	.734	.726	.717	.709
10	.700	.691	.682	.673	.664	.654	.645	.635	.625	.615
11	.605	.595	.585	.574	.564	.553	.542	.531	.520	.509
12	.498	.486	.475	.463	.451	.439	.427	.415	.402	.390
13	.377	.364	.352	.339	.326	.312	.299	.285	.272	.258
14	.244	.230	.216	.202	.188	.173	.159	.144	.129	.114
15	.099	.084	.069	.054	.038	.023	.007	*.991	*.975	*.959
16	998.943	.926	.910	.893	.877	.860	.843	.826	.809	.792
17	.774	.757	.739	.722	.704	.686	.668	.650	.632	.613
18	.595	.576	.558	.539	.520	.501	.482	.463	.444	.424
19	.405	.385	.365	.345	.325	.305	.285	.265	.244	.224
20	.203	.183	.162	.141	.120	.099	.078	.056	.035	.013
21	997.992	.970	.948	.926	.904	.882	.860	.837	.815	.792
22	.770	.747	.724	.701	.678	.655	.632	.608	.585	.561
23	.538	.514	.490	.466	.442	.418	.394	.369	.345	.320
24	.296	.271	.246	.221	.196	.171	.146	.120	.095	.069
25	.044	.018	*.992	*.967	*.941	*.914	*.888	*.862	*.836	*.809
26	996.783	.756	.729	.703	.676	.649	.621	.594	.567	.540
27	.512	.485	.457	.429	.401	.373	.345	.317	.289	.261
28	.232	.204	.175	.147	.118	.089	.060	.031	.002	*.973
29	995.944	.914	.885	.855	.826	.796	.766	.736	.706	.676
30	.646	.616	.586	.555	.525	.494	.464	.433	.402	.371

* First three significant digits shown in line below.

As the specimen consolidates, a ring of mortar will form around the perimeter of the specimen against the inside wall of the mold and will fill in between coarse aggregates. Observe the formation of the mortar ring around the perimeter of the mold. When the mortar ring is completely formed, stop the vibrator and timer; determine the elapsed time to the nearest minute and second. Record this time as the Vebe consistency time, Test Method B. If the mortar ring does not form after 2 minutes, stop the vibrator. Record this condition on the report, and repeat the test with a fresh sample of concrete using Test Method A if necessary. If the wing nuts loosen during the test, repeat the test with a fresh sample of concrete.

12.1.4 Record the conditions of 11.1.6, if appropriate.

12.2 *Density of Fresh Concrete, Test Method B*:

12.2.1 Determine the density of the specimen in accordance with 11.2. Refer to the density as Vebe density of the specimen, Test Method B.

12.3 *Vibration Consistency Time and Density Using Alternate Vibrating Table, Test Method B*:

12.3.1 *Vibrating Consistency Time, Test Method B*:

12.3.1.1 Determine the vibrating consistency time, Test Method B, in accordance with 12.1.1 through 12.1.4. Record the use of an alternate vibrating table.

12.3.1.2 If the conditions of 11.3.2.1 are observed, discontinue the test and do not use Test Method B for vibrating consistency time or density.

12.3.2 *Density of Fresh Concrete, Test Method B*:

12.3.2.1 Determine the density of fresh concrete in accordance with 11.2. Refer to the density as vibrating density of the specimen, Test Method B.

13. Calculations

13.1 Following determination of the Vebe consistency time, determine density of sample as follows:

$$D = \frac{M_s}{V_s}$$

where:

D = density in pound mass per cubic foot [kilograms per cubic meter or kilograms per cubic decameter (note 6)]
M_s = mass of sample in pound mass (kilograms), and
V_s = volume of sample in cubic feet (cubic meters or cubic decameters)

13.2 Figure 3 shows a suggested calculation form.

NOTE 6.–To convert from cubic decameters to cubic meters, multiply by 1000.

Spec. or Solic. No. DC-7558	Structure DAM	Tested by T. DOLEN Date 4-19-85
Project CENTRAL UTAH	Item MIX DESIGN Location DENVER LAB	Computed by K.MITCHELL Date 4-19-85
Feature UPPER STILLWATER DAM	Station ~ Offset ~ Depth ~ to ~	Checked by T. DOLEN Date 4-19-85

CONSISTENCY AND DENSITY OF NO-SLUMP CONCRETE WITH VIBRATORY TABLE

Mix No.:	Shift:	Batch or Test No.:
Date:	Time:	Inspector:

Volumetric Calibration

Mold No.: 1

(1) Mass of mold, plate, and water 54.001 lbm
(2) Mass of mold and plate 33.560 lbm
(3) Mass of water, (1) - (2) 20.441 lbm
(4) Temperature of water 70.0 °F
(5) Absolute density of water:
From table 1: (62.4278578) (0.997970) 62.301 lbm/ft^3
(6) Volume of mold, (3)/(5) 0.328 ft^3

Vebe (or Alternate) Determination

Vibrating Time: 0 min 21 sec
Surcharge: ☑Yes ☐ No, mass 51.440 lbm
Method: ☑A ☐ B
Comments:
NONE AVAILABLE FOR THIS TEST

Density Determination

(7) Mass of mold, sample, and plate 63.100 lbm
(8) Mass of mold and plate 33.560 lbm
(9) Mass of sample, (7) - (8) 29.540 lbm
(10) Mass of mold, sample, plate, and water 71.140 lbm
(11) Mass of water, (10) - (7) 8.040 lbm
(12) Temperature of water 70.0 °F
(13) Absolue density of water:
From table 1: (62.4278578) (0.997970) 62.301 lbm/ft^3
(14) Volume of water, (11)/(13) 0.129 ft^3
(15) Volume of sample, (6) - (14) 0.199 ft^3
(16) Density of sample, (9)/(15) 148.44 lbm/ft^3

Figure 3a. - Sample data and calculation form (inch-pound units).

Spec. or Solic. No. DC-7558	Structure DAM	Tested by T. DOLEN Date 4-19-85
Project CENTRAL UTAH	Item MIX DESIGN Location DENVER LAB	Computed by K. MITCHELL Date 4-19-85
Feature UPPER STILLWATER DAM	Station ~ Offset ~ Depth ~ to ~	Checked by T. DOLEN Date 4-19-85

CONSISTENCY AND DENSITY OF NO-SLUMP CONCRETE WITH VIBRATORY TABLE

Mix No.:	Shift:	Batch or Test No.:
Date:	Time:	Inspector:

Volumetric Calibration

Mold No.: 1

(1)	Mass of mold, plate, and water	24.495	kg
(2)	Mass of mold and plate	15.223	kg
(3)	Mass of water, (1) - (2)	9.272	kg
(4)	Temperature of water	21.1	°C
(5)	Absolute density of water: From table 2:	997.970	kg/m^3
(6)	Volume of mold, (3)/(5)	0.009291	m^3

Vebe (or Alternate) Determination

Vibrating Time: 0 min 21 sec

Surcharge: ☑Yes ☐ No, mass 23.379 kg

Method: ☑A ☐ B

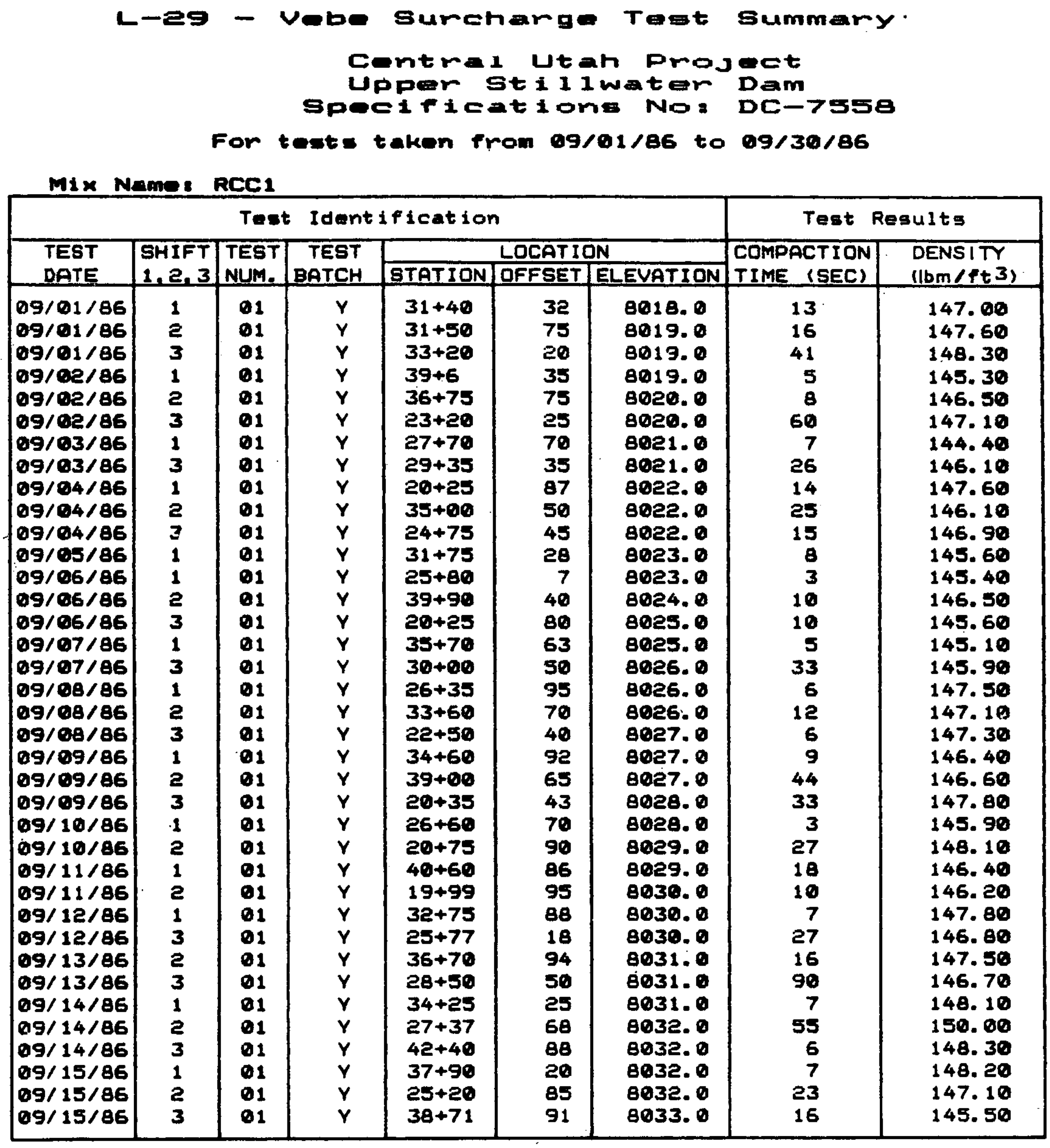
Comments:

NONE AVAILABLE FOR THIS TEST

Density Determination

(7)	Mass of mold, sample, and plate	28.622	kg
(8)	Mass of mold and plate	15.223	kg
(9)	Mass of sample, (7) - (8)	13.399	kg
(10)	Mass of mold, sample, plate, and water	32.269	kg
(11)	Mass of water, (10) - (7)	3.647	kg
(12)	Temperature of water	21.1	°C
(13)	Absolue density of water: From table 2:	997.970	kg/m^3
(14)	Volume of water, (11)/(13)	0.003654	m^3
(15)	Volume of sample, (6) - (14)	0.005637	m^3
(16)	Density of sample, (9)/(15)	2377	kg/m^3

Figure 3b. - Sample data and calculation form (SI-metric).



L-29 - Vebe Surcharge Test Summary

Central Utah Project
Upper Stillwater Dam
Specifications No: DC-7558

For tests taken from 09/01/86 to 09/30/86

Mix Name: RCC1

Test Identification							Test Results	
TEST DATE	SHIFT 1,2,3	TEST NUM.	TEST BATCH	LOCATION			COMPACTION TIME (SEC)	DENSITY (lbm/ft^3)
				STATION	OFFSET	ELEVATION		
09/01/86	1	01	Y	31+40	32	8018.0	13	147.00
09/01/86	2	01	Y	31+50	75	8019.0	16	147.60
09/01/86	3	01	Y	33+20	20	8019.0	41	148.30
09/02/86	1	01	Y	39+6	35	8019.0	5	145.30
09/02/86	2	01	Y	36+75	75	8020.0	8	146.50
09/02/86	3	01	Y	23+20	25	8020.0	60	147.10
09/03/86	1	01	Y	27+70	70	8021.0	7	144.40
09/03/86	3	01	Y	29+35	35	8021.0	26	146.10
09/04/86	1	01	Y	20+25	87	8022.0	14	147.60
09/04/86	2	01	Y	35+00	50	8022.0	25	146.10
09/04/86	3	01	Y	24+75	45	8022.0	15	146.90
09/05/86	1	01	Y	31+75	28	8023.0	8	145.60
09/06/86	1	01	Y	25+80	7	8023.0	3	145.40
09/06/86	2	01	Y	39+90	40	8024.0	10	146.50
09/06/86	3	01	Y	20+25	80	8025.0	10	145.60
09/07/86	1	01	Y	35+70	63	8025.0	5	145.10
09/07/86	3	01	Y	30+00	50	8026.0	33	145.90
09/08/86	1	01	Y	26+35	95	8026.0	6	147.50
09/08/86	2	01	Y	33+60	70	8026.0	12	147.10
09/08/86	3	01	Y	22+50	40	8027.0	6	147.30
09/09/86	1	01	Y	34+60	92	8027.0	9	146.40
09/09/86	2	01	Y	39+00	65	8027.0	44	146.60
09/09/86	3	01	Y	20+35	43	8028.0	33	147.80
09/10/86	1	01	Y	26+60	70	8028.0	3	145.90
09/10/86	2	01	Y	20+75	90	8029.0	27	148.10
09/11/86	1	01	Y	40+60	86	8029.0	18	146.40
09/11/86	2	01	Y	19+99	95	8030.0	10	146.20
09/12/86	1	01	Y	32+75	88	8030.0	7	147.80
09/12/86	3	01	Y	25+77	18	8030.0	27	146.80
09/13/86	2	01	Y	36+70	94	8031.0	16	147.50
09/13/86	3	01	Y	28+50	50	8031.0	90	146.70
09/14/86	1	01	Y	34+25	25	8031.0	7	148.10
09/14/86	2	01	Y	27+37	68	8032.0	55	150.00
09/14/86	3	01	Y	42+40	88	8032.0	6	148.30
09/15/86	1	01	Y	37+90	20	8032.0	7	148.20
09/15/86	2	01	Y	25+20	85	8032.0	23	147.10
09/15/86	3	01	Y	38+71	91	8033.0	16	145.50

Figure 4. – Typical reporting form.

14. Report

14.1 Figure 4 shows a typical reporting form that was produced by computer.

15. Precision and Bias

15.1 *Precision.*–The precision for this procedure is currently unknown.

15.2 *Bias.*–The procedure in these test methods for determining consistency and density of roller-compacted concrete has no bias because consistency and density can only be defined in terms of these test methods.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4906-92

PROCEDURE FOR

CASTING NO-SLUMP CONCRETE IN CYLINDER MOLDS USING VIBRATORY TABLE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4906; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of ASTM C 1176-91.

1. Scope

1.1 This designation covers the test procedure for making cylindrical test specimens from no-slump concrete when standard procedures by rodding and internal vibration, as described in USBR 4031 and 4192, are not practicable.

NOTE 1.-This procedure is considered applicable for plastic concrete with a coarse aggregate content less than 2 inches (50 mm) in maximum size. If coarse aggregate is larger than 2 inches, the procedure is applicable when made on the fraction of concrete passing the 2-inch sieve, with larger aggregate being removed in accordance with USBR 4172 with the exception that the 2-inch sieve is used instead of the 1-1/2-inch (37.5-mm) seive.

1.2 These procedures, intended for use in testing roller-compacted concrete, may be applicable to testing other types of concrete such as cement-treated aggregate and mixtures similar to soil-cement.

1.3 Method A describes procedures for making test specimens in a steel mold attached to Vebe vibrating table. Method B describes procedures for making test specimens in disposable plastic molds inserted into a rigid sleeve attached to Vebe vibrating table.

1.4 The recommended vibration table for this test procedure is the Vebe vibrating table. To date, all Bureau testing has been performed using this testing apparatus. An alternate vibration table may be substituted for the Vebe apparatus provided it meets the specifications for the sinusoidal vibration as shown in section 9.2.1.

2. Applicable Documents

2.1 *USBR Procedures*:
4031 Making and Curing Concrete Test Specimens in Field
4039 Compressive Strength of Cylindrical Concrete Specimens
4172 Sampling Freshly Mixed Concrete
4192 Making and Curing Concrete Test Specimens in Laboratory
4496 Splitting Tensile Strength of Cylindrical Concrete Specimens

2.2 *ASTM Standard*:
C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically[1]
C 1170 Standard Test Methods for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table[1]
C 1176 Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[1,2]

2.3 *ACI Standards*:
207.5R-89 Roller Compacted Concrete[3]
211.3-75R-89 Standard Practice for Selecting Proportions for No-Slump Concrete[3]

3. Summary of Procedure

3.1 This test procedure is for making cylindrical concrete test specimens using the Vebe vibrating table. Test specimens are cast vertically in cylindrical molds ridigly attached to the vibrating table under a 20-lbm (9.07-kg) surcharge to facilitate consolidation.

4. Significance and Use

4.1 This procedure is intended to be used for stiff to extremely dry concrete mixtures commonly used in roller-compacted concrete construction. This procedure is used instead of rodding or internal vibration, which cannot properly consolidate concrete of this consistency.

NOTE 2.-Further description of this concrete consistency is given in ACI 207.5R-89 and 211.3-75 (R 1989).[3] The consistency of concrete may be determined in accordance with ASTM C 1170.[1]

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.06, 04.07, 05.05, 14.02.

[3] *ACI Manual of Concrete Practice*, part 1, 1990, available from American Concrete Institute, PO Box 19150, Redford Station, Detroit, MI 48219.

5. Terminology

5.1 *Roller Compacted Concrete.*-Concrete of zero-slump consistency which is placed by depositing loosely in horizontal lifts and consolidated with smooth-drum vibrating rollers.

6. Apparatus

6.1 *Molds*:

6.1.1 *Type A Mold.*-A cylindrical mold conforming to the requirements of ASTM C 470 for 6-inch (152-mm) diameter by 12-inch (305-mm) high reusable molds. Molds shall be made of steel or other hard metal not readily attacked by the cement paste. Aluminum molds shall not be used. Molds shall be equipped with permanently affixed metal slotted brackets on the baseplate so the molds can be rigidly clamped to a vibrating table. The top rim of the mold shall be smooth, plane, and parallel to the bottom of the mold. The bottom of the mold shall provide a watertight seal.

6.1.2 *Type B Mold.*-A single-use plastic, cylindrical mold 6 inches in diameter and a height of 12 inches (152 by 305 mm). The mold specifications shall conform to ASTM C 470 for single-use plastic molds.

6.1.2.1 *Mold Sleeve.*-A Type B cylindrical mold shall be inserted into a rigid cylindrical sleeve with a bottom baseplate that is clamped to the vibrating table. The mold sleeve shall be made of steel or other hard metal that does not react with concrete containing portland or other hydraulic cement. The sleeve shall be capable of firmly and vertically holding the plastic mold in place without deformation and shall be slotted vertically with adjustable clamps for tightening around the mold. The sleeve shall be hinged so that it can be opened to remove the mold (fig. 1) and shall also have permanently affixed slotted metal brackets so the sleeve may be rigidly clamped to the vibrating table. The mold sleeve shall have a minimum wall thickness of 1/8 inch (3.2 mm), and a minimum baseplate thickness of 1/4 inch (6.4 mm). The inside diameter of the mold sleeve shall be 1/8 ± 1/16 inch (3.2±1.6 mm) larger than the outside diameter of the Type B mold and have a height 1/2 to 1/4 inch (12.8 to 6.4 mm) less than the height of the Type B mold.

6.2 *Vebe Vibrating Table.*-A vibrating table with a 3/4-inch (19-mm) thick steel deck with dimensions of 15 inches in length, 10-1/4 inches in width, and 12 inches in height (381- 260- 305-mm). The vibrating table shall be constructed in such a manner as to prevent flexing of the table during operation. The table deck shall be activated by an electromechanical vibrator. The total mass of the vibrator and table shall be approximately 210 lbm (95 kg). The table shall be level and clamped to a concrete floor or base slab having sufficient mass to prevent displacement of the apparatus during specimen preparation.

NOTE 3.-The recommended vibrating table for these test procedures is the Vebe vibrating table.[4] To date, testing has been performed using this apparatus. An alternative vibrating table may be substituted for the Vebe apparatus provided it meets the specifications for the sinusoidal vibration given in 9.2 and is in accordance with the alternative testing requirements of section 11. The Vebe apparatus, including cylindrical mold and guide sleeves, is manufactured by Dynapac Maskin (formerly Vibro-Verken), PO Box 1103, 5-171-22, Solna, Sweden; Dynapac Manufacturing, Inc., Stanhope NJ 07874; and Soiltest, 86 Albrecht Drive, PO Box 8004, Lake Bluff IL 60044-9902.

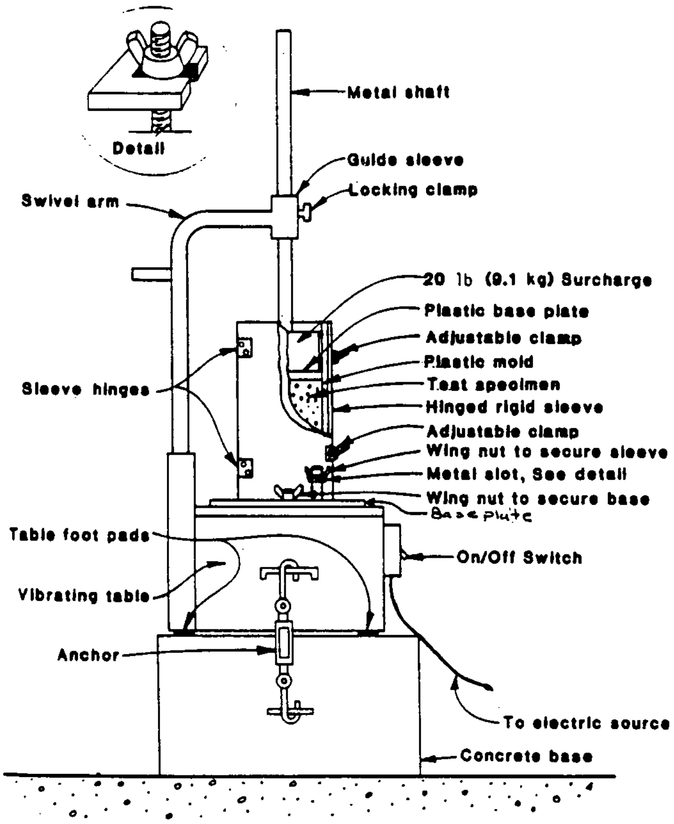

Figure 1. – Vibrating table—cylinder preparation (Type B mold).

6.3 *Swivel Arm and Guide Sleeve.*-A metal guide sleeve with a clamp assembly or other suitable holding device mounted on a swivel arm. The swivel arm and guide sleeve must be capable of holding a metal shaft attached to a 20-lbm (9.1-kg) cylindrical mass in a position perpendicular to the vibrating surface which allows the shaft to slide freely when the clamp is released. The swivel arm must be capable of maintaining the guide sleeve in a locked position directly over the center of the specimens to be vibrated. The swivel arm shall also be capable of being rotated away from the center of the table.

NOTE 4.-The Vebe vibrating table comes equipped with the swivel arm and guide sleeve.

6.4 *Surcharge.*-A cylindrical surcharge with a metal shaft at least 18 inches (457 mm) long and 5/8 ± 1/16 inch (16±2 mm) diameter attached perpendicularly to the plate and embedded through the center of surcharge. The shaft shall slide through the guide sleeve without binding or excessive play. The base of the surcharge shall have a

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[4] The Vebe vibrating table, including cylindrical mold and guide sleeves, is manufactured by Soiltest, 86 Albrecht Drive, PO Box 8004, Lake Bluff IL 60044-9902.

5-3/4 ± 1/8-inch (146±3 mm) diameter. Surcharge shall have a mass of 20±0.5 lbm (9.1±0.25 kg) including the mass of the metal shaft (fig. 1). If the surcharge is hand held, the length of the shaft may be reduced to 12 inches (305 mm) and fabricated with a "T" or "D" handle to grip the surcharge shaft to avoid the hand slipping.

6.5 *Sieve.*-A 2-inch (50-mm) sieve conforming to ASTM E 11.

6.6 *Small Tools.*-Trowels, square-ended shovel and hand scoops, steel trowel, wooden float, wrench, tamping rod, and flashlight as required.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. The user is responsible to consult and establish appropriate safety and health practices and to determine applicability of regulatory limitations prior to use.

8. Sampling, Test Specimens, and Test Units

8.1 Samples of fresh concrete should be obtained in accordance with USBR 4172.

8.2 Concrete samples should have 2-inch (50-mm) maximum size aggregate. If concrete has aggregate larger than 2 inches, sample shall be obtained by wet sieving over a 2-inch sieve in accordance with USBR 4172.

8.3 Concrete test specimens shall be made within 45 minutes after the completion of mixing concrete unless otherwise stipulated.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

9.2 *Vebe Vibrating Table.*-The frequency and amplitude of the vibrating table shall be determined under simulated test conditions prior to initial use, and annually thereafter (note 5). Frequency and amplitude shall be determined in accordance with USBR 4031 or 4192.

NOTE 5.-This determination can be performed by personnel of the Materials Engineering Branch [code D-3735] at the Bureau's Denver Office, and should be coordinated with the calibration of other vibration testing equipment.

9.2.1 The vibrating table shall produce a sinusoidal vibratory motion with a frequency of at least 3600±100 vibrations per minute (60±1.67 Hz) and an amplitude of vibration of 0.0085±0.0015 inch (0.22±0.04 mm) when a 60.0±2.5-lbm (27.2±1.1-kg) surcharge is rigidly bolted to the center of the table.

9.3 *Cylindrical Molds.*-The cylindrical molds shall conform to the dimensional requirements of ASTM C 470.

9.4 At least, after every 3 months of continuous use, the underside of the vibrating table top should be inspected and cleaned of any hardened concrete or cement paste which may interface with free movement of the table top.

10. Conditioning

10.1 No special conditioning process is required for this procedure.

11. Procedure

11.1 *Method A—Type A Molds*:

11.1.1 Coat Type A molds with a suitable lubricant or bond breaker prior to casting the test specimens to facilitate removal from the mold.

11.1.2 Place the mold on Vebe table, and center the surcharge so that the edges of the plastic plate do not touch the walls of the mold. Lower the surcharge into the mold to check for proper clearance. Attach the mold to the Vebe table, and firmly tighten the wing nuts. Move the surcharge away from the mold.

11.1.3 Place enough concrete in the mold so that the mold will be filled to one-third of its volume after consolidation [about 9.5 lbm (4.3 kg)]. A tamping rod may be used to distribute the loose concrete as it is added. During filling, use square-ended shovels and scoops to obtain representative samples, and handle the concrete in such a manner that larger sized coarse aggregate particles do not separate from the mortar.

11.1.4 Move the surcharge over the center of the mold, release the guide sleeve clamp, and place the surcharge gently on the loose concrete. The surcharge shall be able to vertically slide free without binding on the guide sleeve.

11.1.5 If the surcharge cannot be centered in the mold without binding on the inside wall of the mold, place the surcharge directly onto the specimen in the mold without use of the guide sleeve, and hold the surcharge shaft perpendicular to the top of the table. Hold the surcharge shaft manually while vibrating the specimen.

11.1.6 Start the vibrator, and allow the concrete to consolidate under the surcharge. Using a flashlight, observe the concrete in the annular space between the edge of the surcharge and the inside wall of the mold. As the concrete consolidates, mortar will fill in the annular space between the outer edge of the surcharge and the inside mold wall. Observe the mortar until it forms a ring around the total perimeter of the surcharge. When the mortar ring forms completely around the surcharge, stop the vibrator. If the wing nuts loosen while casting the specimen, retighten the wing nuts, then continue vibrating to ensure complete consolidation of the specimen.

11.1.7 If a rock pocket prevents the mortar ring from forming at one small location, even though it has formed in all other locations, the vibrator can be stopped and another layer of concrete added. If a significant portion of the mortar ring does not form, this indicates the concrete may have insufficient mortar due to either improper sampling, segregation, or improper mixture proportioning. In these instances, the concrete specimen should be visually inspected after stripping from the mold, and a decision then made whether to accept or reject the specimen.

11.1.8 Repeat the procedure in 11.1.3 through 11.1.7 for the second lift of concrete, filling the mold to about two-thirds its volume. For the third lift, overfill the mold by mounding the concrete above the top of the mold. Again, place the surcharge on the loose concrete and consolidate. If the surcharge consolidates concrete below the top level of the mold, turn off the vibrating table. Place additional concrete in the mold so that, when consolidated, the concrete will be about 1/8 inch (3 mm) above the top of the mold. Continue vibrating, and slide the surcharge back and forth across the top of the mold until the compacted concrete is level with the top of the mold. This replaces strikeoff with a float since stiff concrete cannot be easily floated. Do not allow the srucharge to remain in one position when the concrete is being finished because this can cause aggregates to be forced down and mortar to be forced out of the mold resulting in a nonrepresentative test specimen. After the surface has been screeded with the surcharge, vibrate the specimen for 4±1 seconds without the surcharge to fill in minor surface tears unless damage to the specimen by large-amplitude oscillations of the vibrator is anticipated.

11.1.8.1 When making test specimens using an alternative vibrating table, it may not be possible to vibrate the specimen without a surcharge. This is due to the disturbance of the compacted specimen when large-amplitude, low-frequency oscillations occur after the vibrator has been turned off. If this occurs, keep the surcharge in place until the vibrating table has completely stopped.

11.1.9 Remove the mold with the consolidated specimen from the vibrating table, and finish the top surface of the specimen with a steel trowel or wooden float. Avoid dislodging aggregate particles from the surface when using a wooden float.

11.2 *Method B—Type B Molds*:

11.2.1 Make concrete test specimens in Type B molds in accordance with 11.1. Prior to making test specimens, insert a Type B mold into the metal sleeve ensuring a close fit but not deforming the plastic mold. A sleeve assembly made from an existing steel cylindrical mold is shown on figure 1. Rigidly clamp the entire assembly to the Vebe table, and make the test specimen in accordance with procedures in 11.1.2 through 11.1.9.

12. Curing

12.1 Unless otherwise specified, all specimens shall be cured in accordance with the sections on curing in USBR 4031 or 4192, whichever is applicable. Specimens tested for compressive strength and splitting tensile strength shall be in accordance with USBR 4039 and 4496, respectively.

13. Calculations

13.1 There are no calculations involved in this test procedure.

14. Report

14.1 A reporting form is not required for this procedure.

15. Precision and Bias

15.1 Currently, the precision and bias for this procedure is unknown.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4907-92

PROCEDURE FOR

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4907; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers a procedure for determining the mean specific heat of concrete, aggregates, and other materials. While the description of this procedure mentions only concrete, it is applicable to any material that will fit in the calorimeter.

2. Applicable Documents

2.1 *USBR Procedures*:
4192 Making and Curing Concrete Test Specimens in Laboratory
2.2. *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]
C 168 Standard Definitions of Terms Relating to Thermal Insulating Materials[2]

3. Summary of Procedure

3.1 A sample of known mass is placed in a calorimeter, and a known amount of heat is then applied to calorimeter. The specific heat of the specimen is calculated from its temperature rise after applying corrections to heat input to calorimeter.

4. Significance and Use

4.1 Specific heat, which is the amount of heat required to raise the temperature of a unit mass of material by 1°, is expressed in this procedure as British thermal units per pound mass degree Fahrenheit and as joules per kilogram degree Celsius. This determination is made by measuring the net heat required to raise the temperature of a specimen by a given amount.

4.2 The temperature regime and resulting thermal stresses in mass concrete, during its early life, are a function of the rate of heat evolution produced by cement hydration, specific heat, thermal conductivity, and density of the concrete. Thus a knowledge of the thermal properties of concrete is necessary for establishing temperature control procedures during construction. Because aggregate comprises most of the volume of concrete, a measurement of the specific heat of the aggregate gives a good indication of the specific heat of the concrete.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 168.

6. Apparatus

6.1 *Calorimeter.*–The calorimeter described in this procedure was designed for concrete, and uses an 8- by 16-inch (203- by 406-mm) cylindrical specimen cast with a 1.5-inch (38-mm) diameter hole extending the length of the specimen. However, the calorimeter can be used for any material where the test specimen can be adapted to fit.

6.1.1 The calorimeter shall consist of two containers separated by a layer of insulation. The inner container, which holds specimen and water, shall be made of stainless steel or copper. The outer container may be made of sheet steel. Specimen shall rest on a support that will permit circulation of water and minimize thermal conduction between specimen and calorimeter wall. A micarta base has been found to be satisfactory for this support.

6.2 *Stirrer.*–A brass stirrer capable of maintaining circulation of water through inner container of calorimeter.

6.3 *Heater.*–An immersion heater, with associated equipment to measure heat input, capable of raising temperature of inner container of calorimeter, including specimen and water, by 20 °F (11 °C) in 45 minutes.

6.4 *Thermometer.*–A thermometer graduated to 0.1 °F (0.06 °C), or a recording thermometer capable of being read to this same precision in the range from 32 to 150 °F (0 to 65.6 °C).

6.5 *Scales.*–Scales shall be capable of determining mass of sample within an accuracy of 0.1 percent.

NOTE 1.–The specific heat apparatus currently in use at the Bureau's Denver Office has been automated to include data

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[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.

[2] *Annual Book of ASTM Standards*, vol. 04.06.

acquisition, calculation, and control. Power to the immersion heater is measured by a watt-hour calibration standard reading to 0.0006 watt-hour. Temperature is determined using a platinum RTD (resistance temperature detector). The operation of this controlling and recording unit is described in section 12. Figure 1 shows an RTD with a calorimeter that has been found satisfactory for 8- by 16-inch (203- by 406-mm) cylinders. Figure 2 shows the propeller inside the calorimeter.

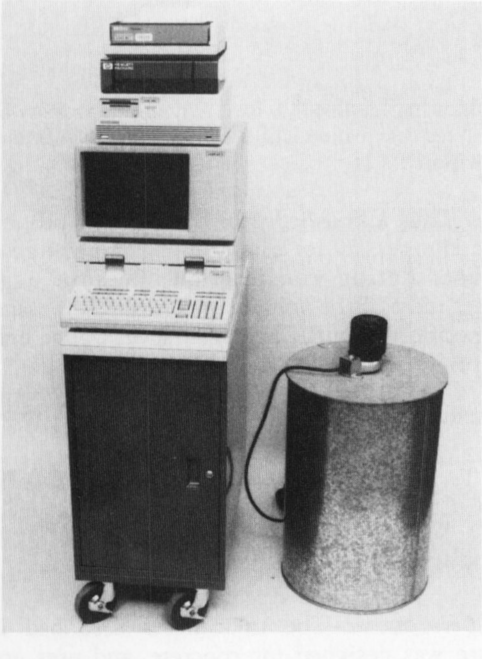


Figure 1. – Controlling and recording instrumentation for conducting tests to determine specific heat of concrete.

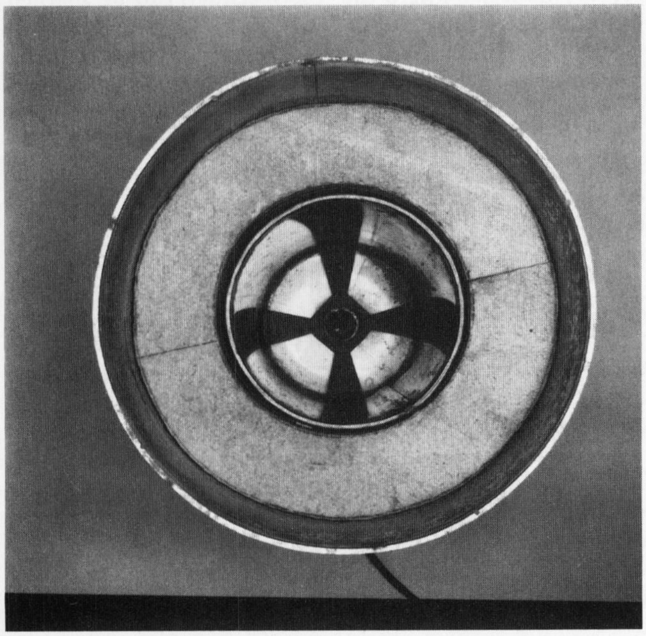


Figure 2. – Propeller.

7. Materials

7.1 Any material capable of being placed in the calorimeter may be tested.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Test Specimens

9.1 While any shape specimen may be tested, the 8- by 16-inch (203- by 406-mm) cylinder with a 1.5-inch (38-mm) hole through the center provides excellent circulation of water and accurate results, see figure 3.

9.2 Concrete specimens shall be fabricated in accordance with the applicable provisions of USBR 4192.

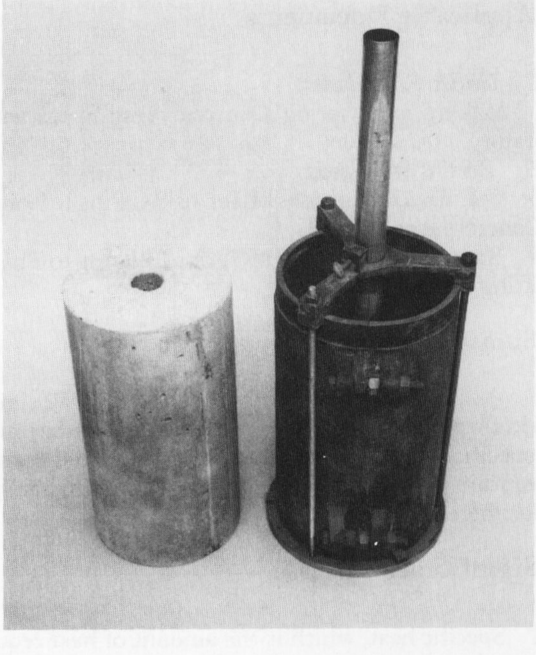


Figure 3. – Mold and 8- by 16-inch (203- by 406-mm) cylinder with a 1.5-inch (38-mm) hole through the center.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

10.2 Determine the water equivalent of the calorimeter by substituting water for the test specimen and making a normal run. It is recommended that the average results of several runs be used.

11. Conditioning

11.1 No conditioning of the saturated specimen is necessary; however, if specimen temperature is about the same as the water bath temperature, initial equilibrium will be attained sooner.

12. Procedure

12.1 Initially, determine mass of specimen. The specimen should then be immersed in an accurately measured quantity of water in the inner container. Heater and propeller should then be inserted, cover placed on container, and heater connections made.

12.2 Start stirrer and continue stirring until equilibrium temperature has been reached as indicated by time-temperature curve becoming linear, as shown on figure 4. This may require 1 to 2 hours.

12.3 Read initial temperature T_i. Continue stirring for 30 minutes and then read temperature T_o. The temperature change during this 30-minute interval will be used in the calculations as a correction for heat loss or gain from calorimeter during test.

12.4 Turn on heater for 45 minutes or until a temperature rise of about 20 °F (11 °C) has occurred. Record total heat input.

12.5 Turn off heater, continue stirring, and make temperature readings until time-temperature curve is again linear. Record the temperature when curve is linear as T_n.

12.6 Continue stirring for 30 minutes and make another temperature reading, which is recorded as T_f. This final 30-minute interval will be used as a correction factor along with the initial 30-minute interval.

12.7 When using the automatic data acquisition and control unit to monitor and control the test, follow the steps in 12.7.1.

12.7.1 Connect the RTD to the data acquisition and control unit. The four-wire ohms technique is used to measure resistance of RTD. A computer controls the control unit and records temperature data from RTD. A high-order polynomial equation is used to convert RTD resistance to temperature. After initial equilibrium is reached, computer is instructed by operator to apply power to heater. The computer commands the control unit to close a relay, which in turn closes a solid-state power relay to apply power to heater. At this point, the watt-hour standard starts sending out pulses which are counted by control unit. The computer records the temperature and, when temperature has increased by 20 °F (11.2 °C), computer commands control unit to remove power from heater. The total pulse count is transferred to the computer and the apparatus is again allowed to reach equilibrium. At this point, computer calculates the specific heat and generates a graph of the temperature data. A block diagram of the apparatus and computer control is shown on figure 5.

12.8 Perform the test at each of two mean temperatures of about 50 and 140 °F (10 and 60 °C).

13. Calculations

13.1 When using the automatic data acquisition system described in section 12.7.1, the computer calculates the specific heat and generates a graph of the temperature data.

13.2 Calculations for a typical test are shown on figure 6. For this example test, 5-minute intervals were used; however, any interval can be used. For most automated procedures, such as the one described in 12.7.1, 1-minute intervals are used.

13.3 To calculate the true temperature rise, the test should be divided into three temperature periods: an initial period from T_i to T_o, heating period from T_o to T_n, and final period from T_n to T_f. The temperature rise is equal to $T_n - T_o + T_c$, where T_c is a calculated temperature correction. This correction is actually a summation, of opposite sign, of the temperature drifts per interval during the heating period calculated from drifts determined during the initial and final periods. The increase in temperature drift between the initial and any intermediate interval is to the increase in temperature drift between initial and final periods as the average temperature difference between initial and same intermediate interval is to the average temperature difference between initial and final periods. Mathematically, this proportion can be stated:

$$T_c = -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{n-1}) + \frac{T_o + T_n}{2}(-nT_a)\right] \tag{1}$$

where:

T_c = temperature correction factor,
n = number of intervals during heating period (usually 1- or 5-minute intervals),
C_a = average temperature drift (algebraic) per interval during initial period,
C_b = average temperature drift (algebraic) per interval during final period,
T_a = average temperature during initial period,
T_b = average temperature during final period,
T_o = temperature at end of initial period and at start of heating period,
T_n = temperature at end of heating period and at start of final period, and
$T_1, T_2, \ldots T_3$ = temperature at intervals of heating period.

13.4 The specific heat of the concrete in British thermal units per pound mass degree Fahrenheit or joules per kilogram degree Celsius is equal to the total heat input minus the heat required to raise temperature of water and calorimeter divided by corrected temperature rise and mass of specimen (fig. 6).

13.5 Figures 7 and 8 are included to establish factors used in the example shown on figure 6.

13.6 The water equivalent of the calorimeter, as shown on figures 8a and 8b, must be reestablished for each calorimeter used. The water equivalent of the calorimeter currently used by the Bureau is shown on figures 8c and 8d.

13.7 When using the automatic data acquisition system described in section 12.7.1, the computer has been programmed to compute the factors internally to provide data similar to that shown on figures 7 and 8.

13.7.1 A computer printout utilizing the automatic data acquisition system described in section 12.7.1 is illustrated on figure 9.

13.7.2 A summarization of cycle runs for two specimens is shown in table 1 that generates the regression equations for the linear (straight line) versus parabolic curves illustrated on figure 10.

14. Report

14.1 Figure 11 shows a typical reporting form for the thermal properties, which consists of conductivity, diffusivity, and specific heat. The report shall include:

- Identification of constituents of sample.
- Mixture proportions, if concrete.
- Two average temperatures.
- Specific heat at each temperature.

15. Precision and Bias

15.1 The precision for this procedure has not been determined.

15.2 There is no known bias.

Table 1. - Summarization of cycle runs.

Specimen	Cycle No.	Start Temp., °F	End Temp., °F	Average Temp., °F	Specific Heat, Btu/(lbm • °F)
Specimen No. 2	1	31.08	50.01	40.46	0.378
9-25-85	2	49.80	67.94	58.97	.248
68.78 lbm	3	67.94	84.89	76.52	.254
	4	85.09	100.49	92.90	.260
	5	100.90	115.06	108.08	.266
	6	115.67	128.20	122.07	.270
	7	129.09	140.57	134.92	.278
	8	141.65	152.35	147.05	.291
Specimen No. 3	1	31.19	51.43	41.17	.325
9-25-85	2	51.14	70.80	61.07	.254
68.84 lbm	3	70.71	88.64	79.80	.256
	4	88.80	104.95	97.00	.262
	4	105.36	119.55	112.55	.276
	6	120.15	132.93	126.66	.280
	7	133.77	145.73	139.84	.284

Specimen No.	Average Temp. (T), °F	Specific Heat (S), Btu/(lbm • °F)
2	58.97	0.248
3	61.07	.254
2	76.52	.254
3	79.80	.256
2	92.90	.260
3	97.00	.262
2	108.08	.266
3	112.55	.276
2	122.07	.270
3	126.66	.280
2	134.92	.278
3	139.84	.284
2	147.05	.291

Specific heat equations:

$S = 0.221947 + 0.0004373\ T$, or

$S = 0.245342 - 0.0000588\ T + 0.00000243\ T^2$

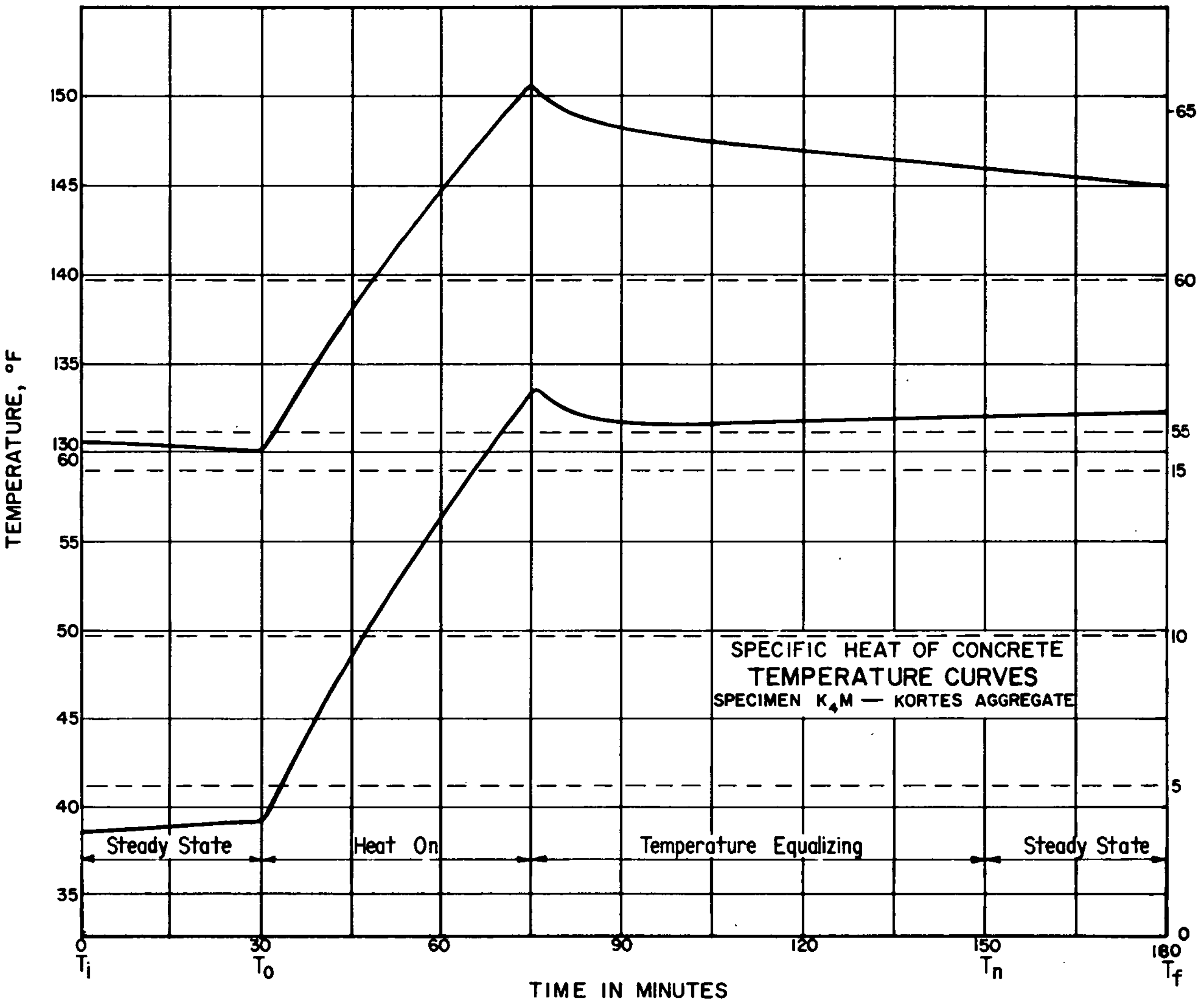


Figure 4. – Typical temperature curves during specific heat test.

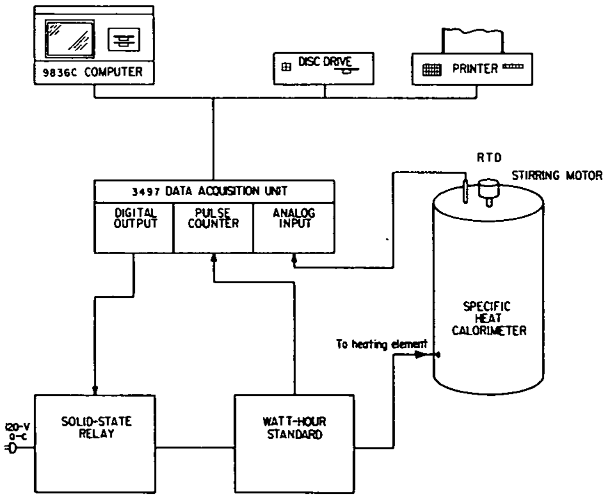


Figure 5. – Block diagram of data acquisition and control system.

Spec. or Solic. No.	Structure DAM	Tested by E. HARBOE Date 11-8-48
Project CANYON FERRY UNIT	Item CONCRETE Location	Computed by E. HARBOE Date 11-8-48
Feature CANYON FERRY DAM & PWR. PL.	Station Offset Depth to	Checked by G. HOAGLAND Date 11-8-48

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

Specimen No.: CFMo No. 1

Mass of specimen = 68.23 lbm
Mass of water = 12.96 lbm

Heat input = 225.495 revolutions
Revolutions times 2.056 = Btu's

Temp.	Time, min.	Temp., °F
T_i	0	37.22
	5	
	10	
	15	
	20	
	25	
T_o	30	37.70
T_1	35	39.60
T_2	40	42.38
T_3	45	44.61
T_4	50	46.83
T_5	55	48.81
T_6	60	50.67
T_7	65	52.85
T_8	70	54.71
T_9	75	56.34
T_{10}	80	55.24
T_{11}	85	54.77
T_{12}	90	54.56
T_{13}	95	54.47
T_{14}	100	54.43
T_{15}	105	54.43
T_{16}	110	54.44
T_{17}	115	54.47
T_{18}	120	54.50
T_{19}	125	54.55
T_{20}	130	54.58
T_{21}	135	54.62
T_{22}	140	54.65
T_{23}	145	54.69
T_n	150	54.73
	155	
	160	
	165	
	170	
	175	
T_f	180	54.95

$$C_a = \frac{T_o - T_i}{n} = \frac{37.70-37.22}{6} = \frac{0.48}{6} = 0.080\,°F$$

$$C_b = \frac{T_f - T_n}{n} = \frac{54.95-54.73}{6} = \frac{0.22}{6} = 0.037\,°F$$

$$C_b - C_a = -0.043\,°F$$

$$T_a = \frac{T_i + T_o}{2} = \frac{37.22+37.70}{2} = 37.46\,°F$$

$$T_b = \frac{T_f + T_n}{2} = \frac{54.95+54.73}{2} = 54.84\,°F$$

$$T_b - T_a = 17.38\,°F$$

$$T_c = -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{23}) + \left(\frac{T_o + T_n}{2}\right)(-nT_a)\right]$$

$$= -24(0.080) - \left[\frac{-0.043}{17.38}\right]\left[1201.20 + \left(\frac{37.70+54.73}{2}\right) - 24(37.46)\right]$$

$$= -1.920 + (0.002474)(348.38)$$

$$= -1.920 + 0.862 = -1.058\,°F$$

Temperature rise = $T_n - T_o + T_c$ = 54.73 − 37.70 − 1.06 = 15.97 °F

Average temperature = $\frac{T_o + T_n}{2} = \frac{37.70 + 54.73}{2}$ = 46.22 °F

Heat input = (225.495)(2.056) = 463.618 Btu

*Heat to water = (1.0028)(12.96)(15.97) = 207.551 Btu

**Heat to calorimeter = (1.707)(15.97) = 27.261 Btu

Heat to concrete = 463.618 − 207.551 − 27.261 = 228.806 Btu

Specific heat = $\frac{228.806}{(68.23)(15.97)}$ = 0.2100 Btu/(lbm·°F)

* Obtain factor from figure 7a.
** Obtain factor from figure 8a.

Figure 6a. – Typical calculation form (inch-pound units).

Spec. or Solic. No.	Structure DAM	Tested by E. HARBOE Date 11-8-48
Project CANYON FERRY UNIT	Item CONCRETE Location	Computed by E. HARBOE Date 11-8-48
Feature CANYON FERRY DAM & PWR PL.	Station Offset Depth to	Checked by G. HOAGLAND Date 11-8-48

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

Specimen No.: CFMo No. 1

Temp.	Time, min.	Temp., °C
T_i	0	2.90
	5	
	10	
	15	
	20	
	25	
T_o	30	3.17
T_1	35	4.22
T_2	40	5.77
T_3	45	7.01
T_4	50	8.24
T_5	55	9.34
T_6	60	10.37
T_7	65	11.58
T_8	70	12.62
T_9	75	13.52
T_{10}	80	12.91
T_{11}	85	12.65
T_{12}	90	12.53
T_{13}	95	12.48
T_{14}	100	12.46
T_{15}	105	12.46
T_{16}	110	12.47
T_{17}	115	12.48
T_{18}	120	12.50
T_{19}	125	12.53
T_{20}	130	12.54
T_{21}	135	12.57
T_{22}	140	12.58
T_{23}	145	12.61
T_n	150	12.63
	155	
	160	
	165	
	170	
	175	
T_f	180	12.75

Mass of specimen = 30.95 kg
Mass of water = 5.88 kg

Heat input = 225.495 revolutions
Revolutions times 2.169 = kJ

$$C_a = \frac{T_o - T_i}{n} = \frac{3.17 - 2.90}{6} = \frac{0.27}{6} = 0.045\,^\circ\mathrm{C}$$

$$C_b = \frac{T_f - T_n}{n} = \frac{12.75 - 12.63}{6} = \frac{0.12}{6} = 0.020\,^\circ\mathrm{C}$$

$$C_b - C_a = -0.025\,^\circ\mathrm{C}$$

$$T_a = \frac{T_i + T_o}{2} = \frac{2.90 + 3.17}{2} = 3.04\,^\circ\mathrm{C}$$

$$T_b = \frac{T_f + T_n}{2} = \frac{12.75 + 12.63}{2} = 12.69\,^\circ\mathrm{C}$$

$$T_b - T_a = 9.65\,^\circ\mathrm{C}$$

$$\begin{aligned} T_c &= -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{23}) + \left(\frac{T_o + T_n}{2}\right)(-nT_a)\right] \\ &= -24(0.045) - \left[\frac{-0.025}{9.65}\right]\left[258.44 + \left(\frac{3.17 + 12.63}{2}\right) - 24(3.04)\right] \\ &= -1.080 + (0.002591)(193.38) \\ &= -1.080 + 0.501 = -0.579\,^\circ\mathrm{C} \end{aligned}$$

Temperature rise = $T_n - T_o + T_c$ = 12.63 − 3.17 − 0.579 = 8.88 °C

$$\text{Average temperature} = \frac{T_o + T_n}{2} = \frac{3.17 + 12.63}{2} = 7.90\,^\circ\mathrm{C}$$

Heat input = (225.495)(2.169) = 489.099 kJ

*Heat to water = (1.1985)(5.88)(8.88) = 219.222 kJ

**Heat to calorimeter = (3.239)(8.88) = 28.762 kJ

Heat to concrete = 489.099 − 219.222 − 28.762 = 241.115 kJ

$$\text{Specific heat} = \frac{241.115}{(30.95)(8.88)} = 0.8773\ \mathrm{kJ/(kg\cdot{}^\circ C)}$$

* Obtain factor from figure 7b.
** Obtain factor from figure 8b.

Figure 6b. - Typical calculation form (SI-metric).

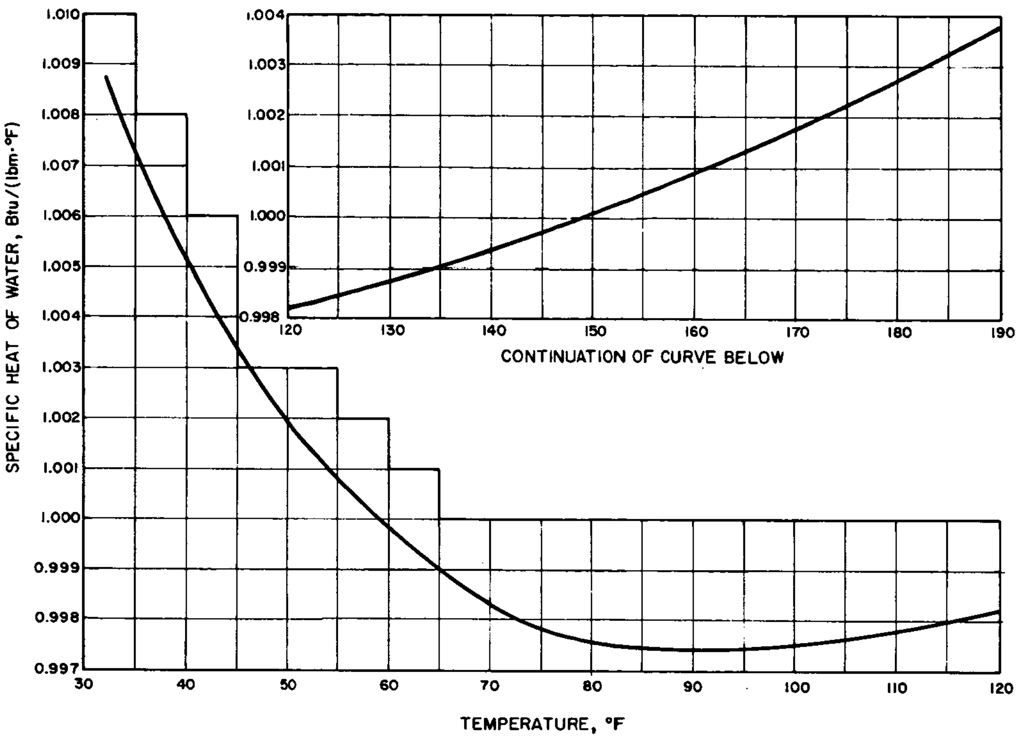


Figure 7a. - Specific heat of distilled water (inch-pound units).

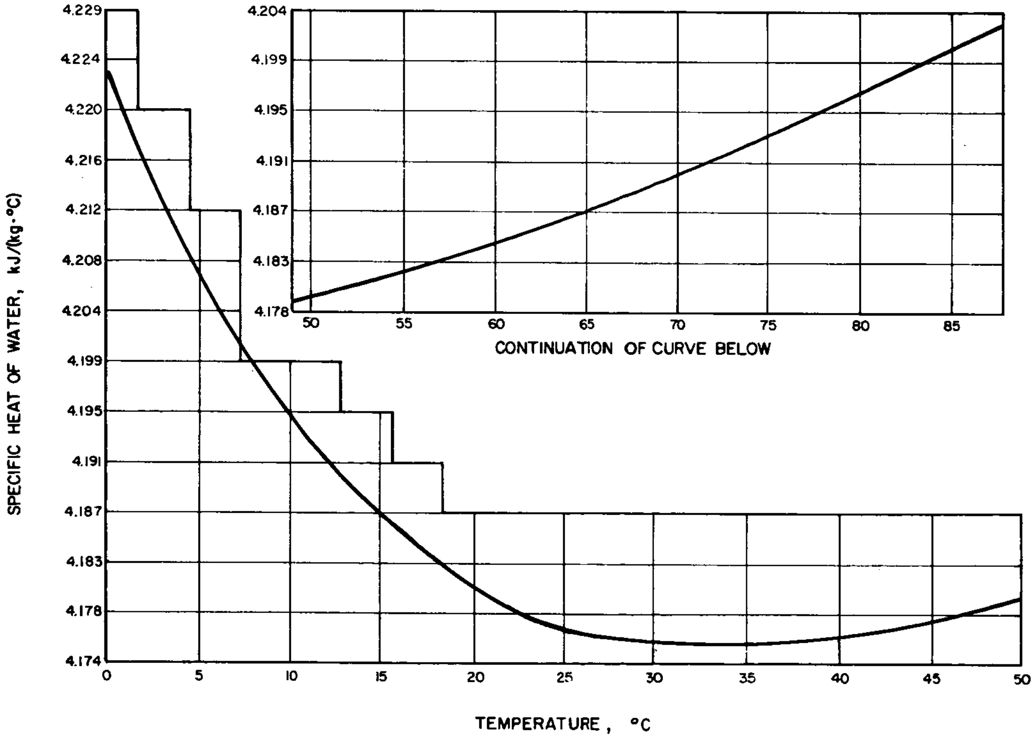


Figure 7b. - Specific heat of distilled water (SI-metric).

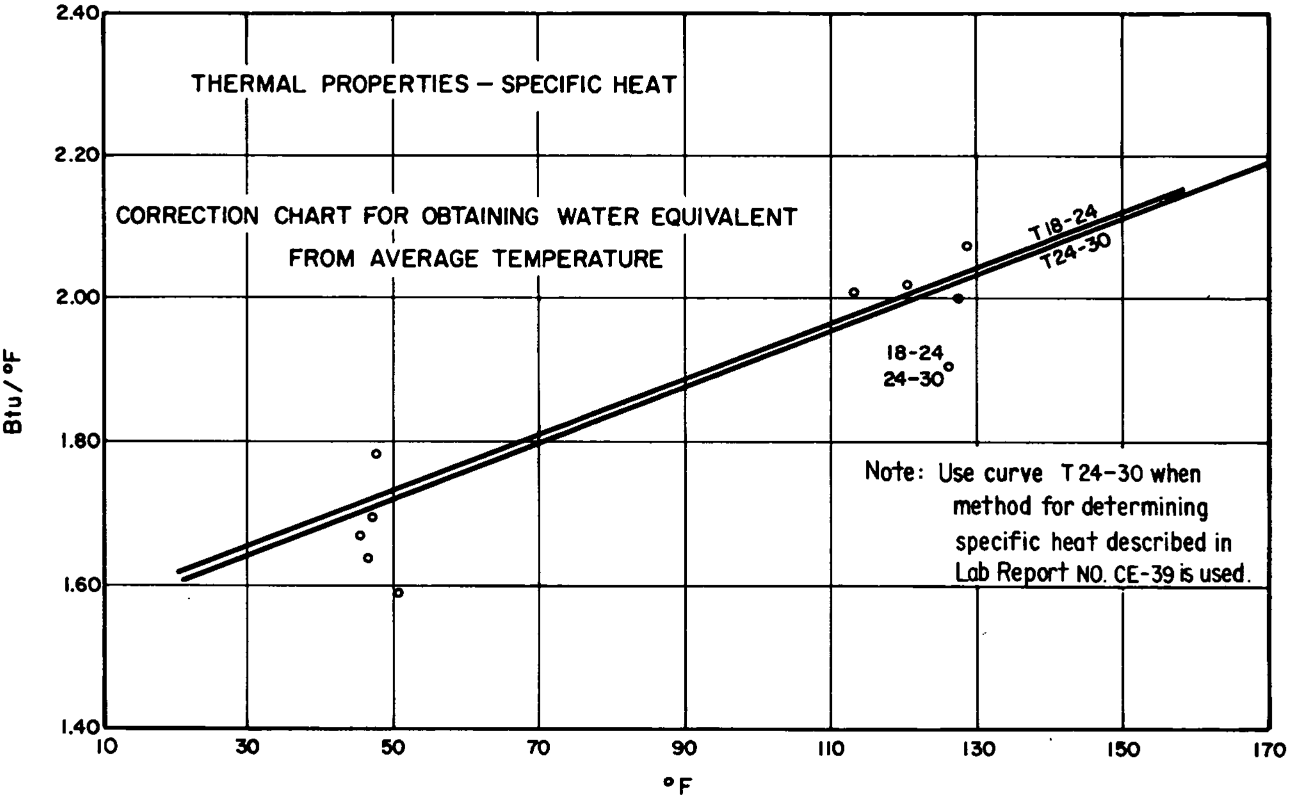


Figure 8a. – Water equivalent of a calorimeter (inch-pound units).

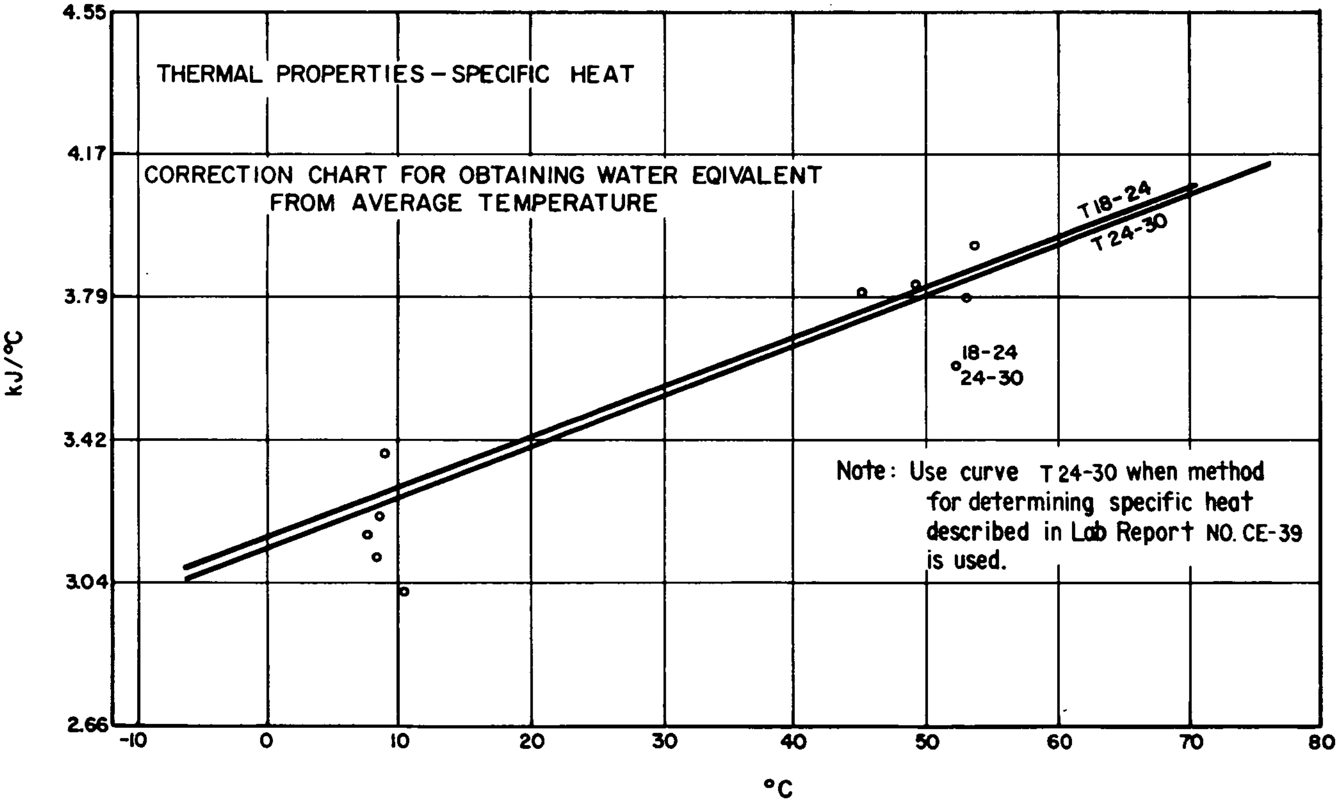


Figure 8b. – Water equivalent of a calorimeter (SI-metric).

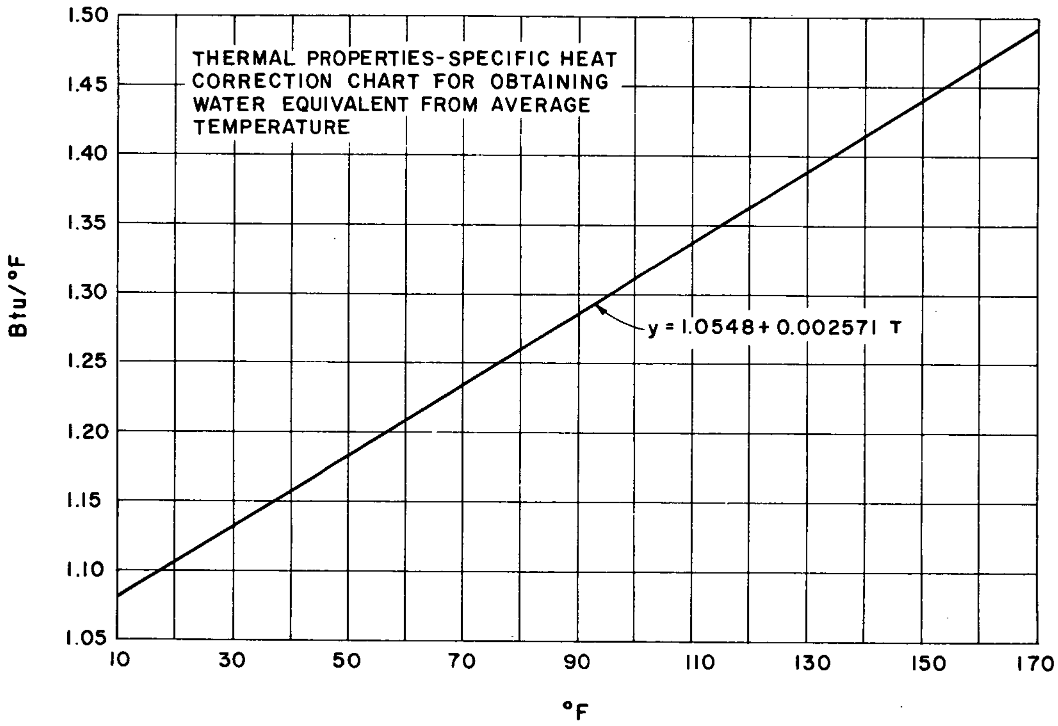


Figure 8c. – Water equivalent of a calorimeter currently used by Bureau of Reclamation (inch-pound units).

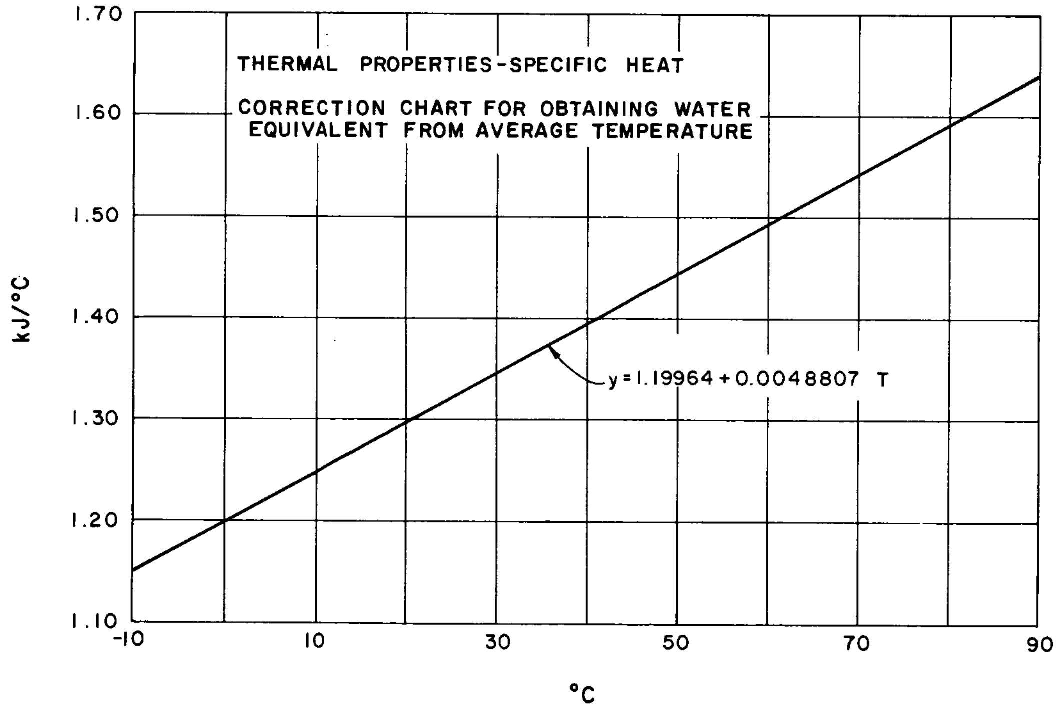
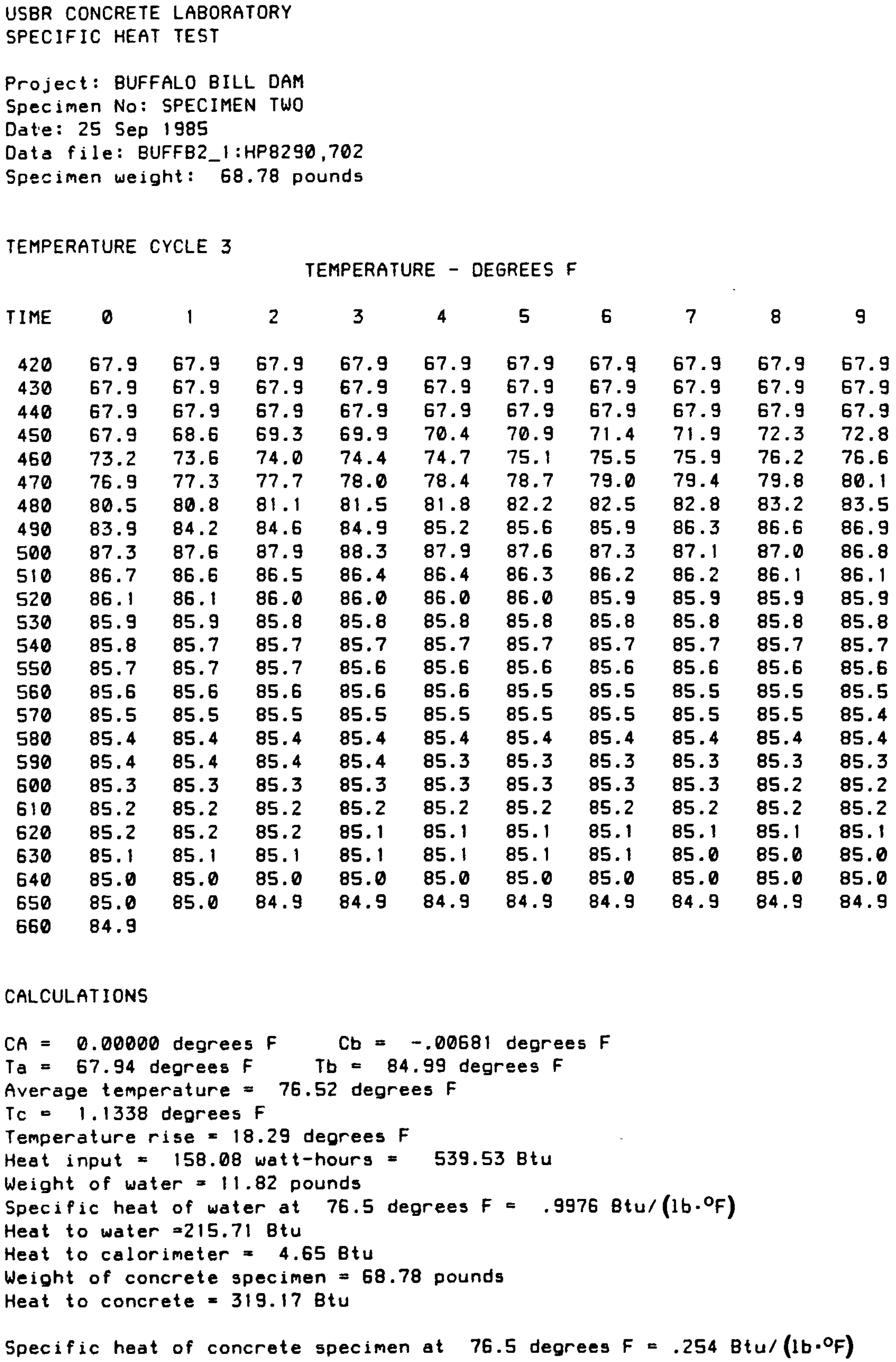


Figure 8d. – Water equivalent of a calorimeter currently used by Bureau of Reclamation (SI-metric).



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USBR CONCRETE LABORATORY
SPECIFIC HEAT TEST

Project: BUFFALO BILL DAM
Specimen No: SPECIMEN TWO
Date: 25 Sep 1985
Data file: BUFFB2_1:HP8290,702
Specimen weight:  68.78 pounds


TEMPERATURE CYCLE 3
                         TEMPERATURE - DEGREES F

TIME    0      1      2      3      4      5      6      7      8      9

 420   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9
 430   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9
 440   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9   67.9
 450   67.9   68.6   69.3   69.9   70.4   70.9   71.4   71.9   72.3   72.8
 460   73.2   73.6   74.0   74.4   74.7   75.1   75.5   75.9   76.2   76.6
 470   76.9   77.3   77.7   78.0   78.4   78.7   79.0   79.4   79.8   80.1
 480   80.5   80.8   81.1   81.5   81.8   82.2   82.5   82.8   83.2   83.5
 490   83.9   84.2   84.6   84.9   85.2   85.6   85.9   86.3   86.6   86.9
 500   87.3   87.6   87.9   88.3   87.9   87.6   87.3   87.1   87.0   86.8
 510   86.7   86.6   86.5   86.4   86.4   86.3   86.2   86.2   86.1   86.1
 520   86.1   86.1   86.0   86.0   86.0   86.0   85.9   85.9   85.9   85.9
 530   85.9   85.9   85.8   85.8   85.8   85.8   85.8   85.8   85.8   85.8
 540   85.8   85.7   85.7   85.7   85.7   85.7   85.7   85.7   85.7   85.7
 550   85.7   85.7   85.7   85.6   85.6   85.6   85.6   85.6   85.6   85.6
 560   85.6   85.6   85.6   85.6   85.6   85.5   85.5   85.5   85.5   85.5
 570   85.5   85.5   85.5   85.5   85.5   85.5   85.5   85.5   85.5   85.4
 580   85.4   85.4   85.4   85.4   85.4   85.4   85.4   85.4   85.4   85.4
 590   85.4   85.4   85.4   85.4   85.3   85.3   85.3   85.3   85.3   85.3
 600   85.3   85.3   85.3   85.3   85.3   85.3   85.3   85.3   85.2   85.2
 610   85.2   85.2   85.2   85.2   85.2   85.2   85.2   85.2   85.2   85.2
 620   85.2   85.2   85.2   85.1   85.1   85.1   85.1   85.1   85.1   85.1
 630   85.1   85.1   85.1   85.1   85.1   85.1   85.1   85.0   85.0   85.0
 640   85.0   85.0   85.0   85.0   85.0   85.0   85.0   85.0   85.0   85.0
 650   85.0   85.0   84.9   84.9   84.9   84.9   84.9   84.9   84.9   84.9
 660   84.9

CALCULATIONS

CA =  0.00000 degrees F     Cb =  -.00681 degrees F
Ta =  67.94 degrees F     Tb =  84.99 degrees F
Average temperature =  76.52 degrees F
Tc =  1.1338 degrees F
Temperature rise = 18.29 degrees F
Heat input =  158.08 watt-hours =   539.53 Btu
Weight of water = 11.82 pounds
Specific heat of water at  76.5 degrees F =  .9976 Btu/(lb·°F)
Heat to water =215.71 Btu
Heat to calorimeter =  4.65 Btu
Weight of concrete specimen = 68.78 pounds
Heat to concrete = 319.17 Btu

Specific heat of concrete specimen at  76.5 degrees F = .254 Btu/(lb·°F)
```

Figure 9. – Typical computer output generated from automatic data acquisition system.

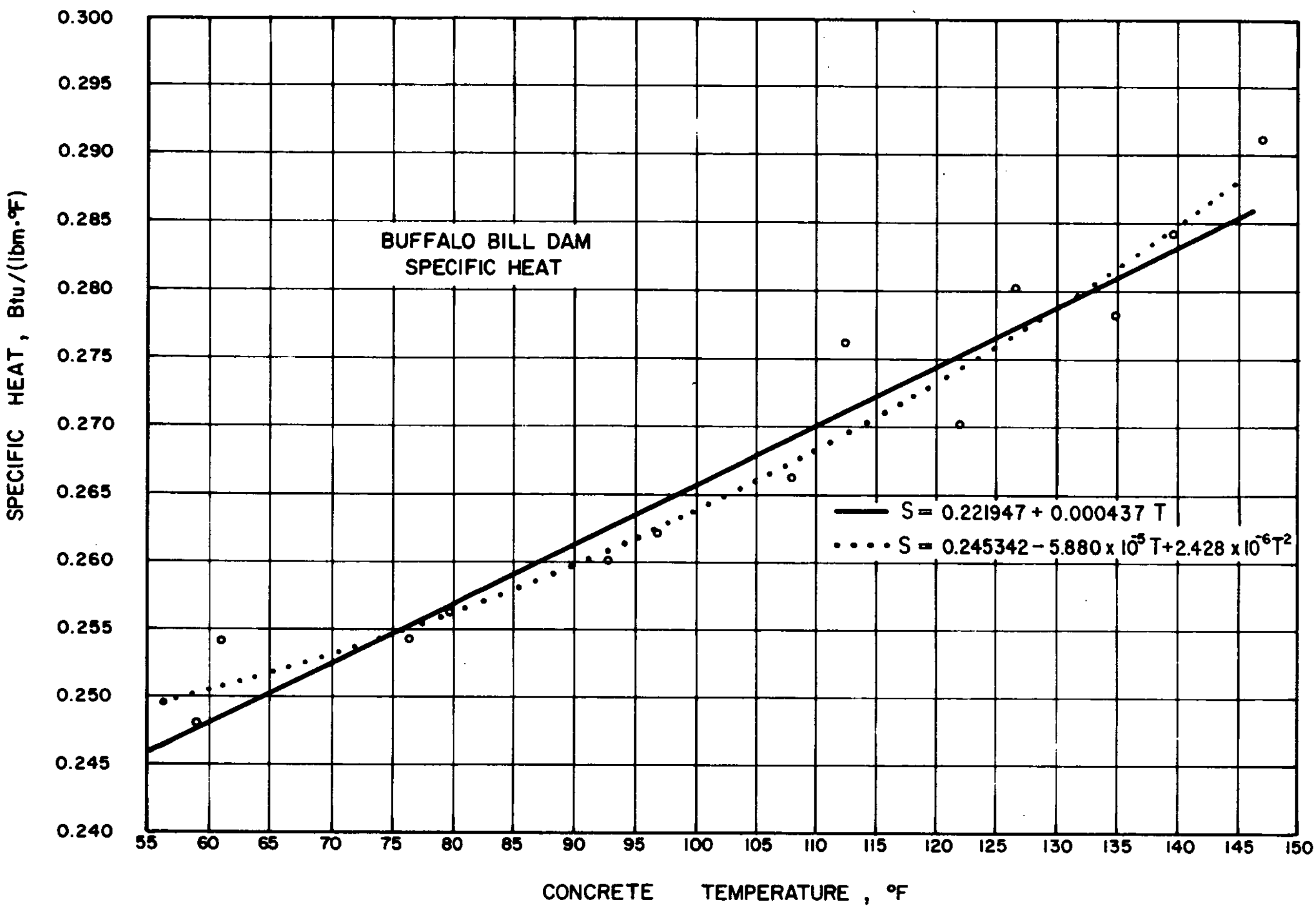

Figure 10. – Linear (straight line) versus parabolic curves plot of specific heat.

Spec. or Solic. No. DESIGN STAGE	Structure DAM MODIFICATION	Tested by M. PEABODY, M. CASH, D. ARNEY, F. TRAVERS Date 9-10-85
Project SHOSHONE	Item CONCRETE MIX DESIGN Location E&R CENTER, DENVER	Computed by COMPUTER Date 9-10-85
Feature BUFFALO BILL DAM	Station —— Offset —— Depth —— to ——	Checked by M. PEABODY Date 9-10-85

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

MIX DATA

	lbm	kg	mL
Water	160		
Type I/II cement	245		
Class F fly ash	105		
Fine aggregate	926		
Coarse aggregate	2,615		
Volume of air-entraining admixture, 5.5 oz/94 lbm (kg), $C+P$			605
Volume of water-reducing admixture, 4.0 oz/94 lbm (kg), $C+P$			490

Mineralogic makeup of aggregate: PRIMARILY LIMESTONE

THERMAL PROPERTIES

Concrete Temp. (T)		Saturated density (P)		Diffusivity (D)		Specific heat (S)		Conductivity (C)	
°C	°F	lbm/ft³	kg/m³	ft²/h	m²/h	Btu/(lbm·°F)	kJ/(kg·°C)	Btu/(ft·h·°F)	kJ/(m·h·°C)
	50	—		0.038		0.244		1.40	
	100	151.5		0.036		0.266		1.45	
	150	—		0.034		0.288		1.48	

NOTE: $D = 0.039636 - 0.0000396\ T$

$S = 0.221947 + 0.0004373\ T$

$C = PDS$

Figure 11. – Typical reporting form for thermal properties.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4908-92

PROCEDURE FOR

LENGTH CHANGE OF HARDENED CONCRETE EXPOSED TO ALKALI SULFATES

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4908; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers the procedure for determining the length change of hardened concrete when exposed to alkali-sulfate solutions.

1.2 This procedure exposes concrete specimens to sodium-sulfate solutions but can also be used with magnesium-sulfate solutions or a combination of sodium and magnesium sulfate.

2. Applicable Documents

2.1 *USBR Procedures*:

4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standards*:

C 490 Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete[1]

3. Summary of Procedure

3.1 Three methods are described:

3.1.1 Method A consists of continuous soaking of test specimens in a 2.1-percent, sodium-sulfate solution at room temperature. This exposure corresponds to a severe field exposure.

3.1.2 Method B consists of continuous soaking of test specimens in a 10-percent, sodium-sulfate solution at room temperature. This method will produce failure in about one-sixth the time required in method A.

3.1.3 Method C consists of alternately soaking test specimens for 16 hours in a 2.1-percent, sodium-sulfate solution at about 73 °F (23 °C), and drying the test specimens for 8 hours in air under a forced draft at about 130 °F (54 °C). This method produces failure in about one-sixth the time required in method A and about the same time required in method B.

3.2 All test specimens are measured for length change at periodic intervals. An expansion of 0.5 percent is considered failure. The relative resistance to sulfate attack is based on the time of exposure to produce failure.

4. Significance and Use

4.1 Sulfate attack is a chemical reaction between cementitious materials and alkali-sulfate water, and results in a swelling of the concrete and sometimes complete disintegration. This procedure measures the extent of sulfate attack as indicated by a linear expansion of the test specimen.

4.2 This procedure permits the evaluation of sulfate resistance of blends of cements and blends of portland cement, pozzolans, and slags under sulfate exposure conditions.

5. Apparatus

5.1 *Mixer.*–Shall conform to requirements of USBR 4192.

5.2 *Vibrator.*–The vibrator shall have a 3/8-inch (10-mm) spud.

5.3 *Molds.*–Molds are required for casting the 3- by 6-inch (76- by 152-mm) cylinders, and shall conform to requirements of USBR 4192. A typical mold arrangement is shown on figure 1.

5.4 *Comparator.*–Shall conform to requirements of ASTM C 490.

5.5 *Solution Tanks*:

5.5.1 Tanks of stainless steel or other corrosion-resistant material are required for containing the sulfate solutions in methods A and B. The tanks shall be of such depth that the 3- by 6-inch test specimens are completely immersed during soaking period.

5.5.2 Automatically operated equipment for method C consists of an elevated sulfate solution storage tank, an insulated specimen storage cabinet equipped with time-controlled equipment for pumping sulfate solution from specimen tank into elevated storage tank, and an electric or steam heater and blower for circulating warm air through the specimen storage tank. Storage racks shall hold and separate the test specimens in such manner as to ensure complete coverage by sulfate solution during soaking cycle and free flow of air around each specimen during drying cycle. Tank linings, specimen racks, piping, and other parts of equipment in contact with the sulfate solution shall be of stainless steel or other corrosion-resistant material.

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02.

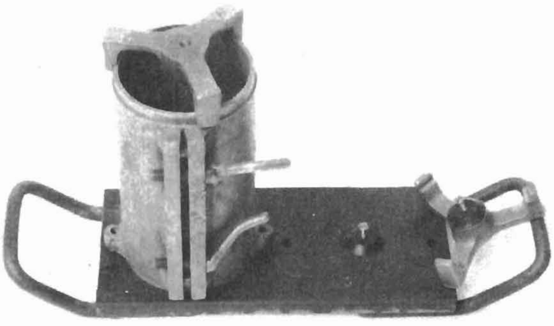


Figure 1. - Typical casting mold.

6. Reagents and Materials

6.1 Reagent grade chemicals shall be used in all tests. Any anhydrous or hydrated sodium sulfate may be used if water content of salt is checked by loss on ignition and proper corrections made to give sodium-sulfate concentrations of 2.1 percent for methods A and C and 10 percent for method B.

6.2 Gauge stud inserts (fig. 2) shall be stainless steel as specified in ASTM C 490.

7. Precautions

7.1 This procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and to determine applicability of regulatory limitations prior to use.

8. Sampling, Test Specimens, and Test Units

8.1 Test specimens shall be 3- by 6-inch (76- by 152-mm) cylinders cast in accordance with USBR 4192.

8.2 Place molds on rubber covered steel baseplates with rubber mounted gauge stud inserts attached to covering; attach mold to baseplates with screws. Place corrosion resistant metal identification tags in bottom of molds with reading sides downward so that when cylinders are demolded the tags are embedded in the concrete cylinders and readable.

8.3 Fill mold in two layers, with each layer being about one-half the volume of mold. Consolidate each layer by vibration using an internal vibrator with a 3/8-inch (10-mm) spud. Set top spider, with rubber mounted gauge stud insert attached, in place by tapping with butt end of a tamping rod until close contact between spider and mold is obtained.

8.4 Three specimens are generally cast for testing using the gang mold shown on figure 1.

9. Calibration and Standardization

9.1 The comparator for measuring length changes shall be checked against a standard reference bar before and after taking readings and at regular intervals during readings if a large number of specimens are to be measured.

9.2 Check concentration of sulfate solution at intervals frequent enough to assure that concentration does not vary more than 1 percent.

10. Conditioning

10.1 After fabrication, place specimens in molds in a moist environment at 73 °F (22.8 °C). After 24 hours, remove specimens from molds and cure them for an additional 13 days at 73.4±3 °F (23.0±1.7 °C) and 100 percent relative humidity, or in a tank of saturated limewater at 73.4±3 °F. At 14-day age, remove specimens from the moist environment and cure for 14 days at 73.4±3 °F and 50±2 percent relative humidity.

11. Procedure

11.1 *Method A*:

11.1.1 At completion of 28-day curing period, measure specimens for length to nearest 0.001 inch (0.025 mm) using comparator. Place specimens in solution tank for 24 hours, then remove specimens from tank, surface dry, and measure again for length. This latter reading is used to compute expansion due to sulfate attack. The difference between the two measurements is the expansion due to absorption. After taking the second measurement, return specimens to the solution tank. Measure specimens for length again after 30 days and every 3 months thereafter. Some materials with poor resistance to sulfate attack may require more frequent measurement.

11.1.2 Clean hole in base anvil of comparator into which the gauge stud of the specimens is inserted. This bottom gauge fitting tends to collect water and sand, and should be cleaned after every reading. Wipe gauge studs of specimen before placing in comparator. Read and record indicated length on comparator for each specimen and the reference bar. Slowly spin specimen in comparator while taking a reading. Specimens should be placed in comparator with same end up each time a length measurement is taken.

11.2 *Method B*:

11.2.1 Method B follows same procedure as method A except specimens are placed in a tank containing a 10-percent, sodium-sulfate solution.

11.3 *Method C*:

11.3.1 Method C follows same procedure as method A except exposure consists of alternately soaking test specimens for 16 hours in a 2.1-percent, sodium-sulfate solution at room temperature, about 73 °F (23 °C), and drying for 8 hours in air under a forced draft at about 130 °F (54 °C). The specimens shall be removed from solution tank for length measurements at or near end of soaking period so that they are saturated and near room temperature when measured.

11.4 The concentrations of solution in methods A and C shall be maintained between 2.0 and 2.2 percent, and in method B between 9.8 and 10.2 percent. Periodic checks of the concentration shall be made as necessary to maintain sulfate concentration between these limits. The entire solution shall be replaced with a new solution annually.

12. Calculations

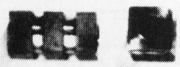
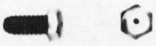
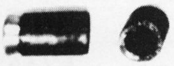
12.1 Figure 3 shows a typical data and calculation form.

12.2 Record expansion of each specimen individually, but report percent expansion as average of three specimens.

12.3 To convert from expansion in inches to percent expansion, divide by 5 and multiply by 100. Although specimen length is 6 inches, effective gauge length is 5 inches. If measurements are made in metric units, convert from expansion in millimeters to percent expansion by dividing by 127 (5 inches = 127 mm) and multiplying by 100.

13. Report

13.1 Figure 3 may also serve as a typical reporting form when used as an attachment with a cover letter. Report the type of cement and, if blending materials are used, the amount and identification of blending material. Report expansion as percent expansion using length after 1 day in solution as base length. The amount of expansion due to absorption during 1 day in solution may be reported as additional information.

No.	INSERT	GAUGE POINTS FOR		THREAD	REMARKS
		FULCRUM PLATE STRAIN GAUGE	10-, 15-, & 30-INCH COMPARATORS		
1	A 	B 		$\frac{1}{4}$ Inch diameter, 28 NF per inch	Insert and gauge point for 18-by 36-inch volume change cylinders. Gauge length predetermined in mold.
2	A 	B1 	B2 	$\frac{1}{4}$ Inch diameter, 28 NF per inch	Insert for 2-by 2-by 0.33-foot slabs, and for 4-by 4-by 30-inch and 8-by 8-by 48-inch bars. Gauge point B1 used in large bars and slab, and B2 used in small bars.
3	A 		B 	$\frac{1}{4}$ Inch diameter, 28 NF per inch	Insert for one end of 1-by 1-by 10-inch and 3-by 3-by 15-inch bars. Gauge length predetermined in mold. Gauge point B and lock-nut provide adjustment to constant overall length.
4	C 		C 	$\frac{1}{4}$ Inch diameter, 28 NF per inch	Insert and gauge point for opposite end of 1-by 1-by 10-inch mortar bars, as in No. 3 above.
5	C 		C 	$\frac{1}{4}$ Inch diameter, 20 NC per inch	Insert and gauge point for opposite end of 3-by 3-by 15-inch wetting and drying test specimens. Gauge length predetermined in mold.
6	C 		C 	No. 6 diameter, 32 NC per inch	Insert and gauge point for 3-by 6-inch freezing and thawing test specimens. Gauge length predetermined in mold.
7	A 			$\frac{1}{4}$ Inch diameter, 28 NF per inch	Insert for 18-by 36-inch cylinders for strength and elasticity determinations. Supports for longitudinal gauge rods and lateral ring.

NOTES: Insert No.'s 1, 2, and 3 are brass, No.'s 4, 5, and 6 are stainless steel, and No. 7 is a lead cinch-anchor.
All gauge points are stainless steel, and locknuts are brass.
"A" inserts are cast or set inplace, "B" gauge points indicate that gauge stud is screwed into insert, and "C" indicates that gauge stud insert is cast or set inplace.
All values shown in inch-pound units, 1 foot = 0.3048 m, and 1 inch = 25.4 mm.

Figure 2. – Inserts and gauge points used in concrete and mortar specimens for length and volumetric determination.

Spec. or Solic. No. NA	Structure CONCRETE PIPE	Tested by J. OWENS, B. DUFFUS, A. COLLING 8-13-64 Date THRU 10-16-73
Project RESEARCH	Item TYPE V CEMENT Location DENVER LAB	Computed by K. MITCHELL 8-13-64 Date THRU 10-16-73
Feature DURABILITY STUDIES	Station ~ Offset ~ Depth ~ to ~	Checked by A. COLLING 8-13-64 Date THRU 10-16-73

LENGTH CHANGE OF HARDENED CONCRETE EXPOSED TO ALKALI SULFATES

Cement No. M-4293 (LAB STD) Brand Name SOUTH DAKOTA CEMENT CO. Plant Ident. RAPID CITY, S. DAK Type V
Pozzolan No. NONE Brand Name NA Plant Ident. NA Class NA
Slag No. NONE Brand Name NA Plant Ident. NA Type NA

Aggregate Source CLEAR CREEK (LAB STD); MSA 3/4 inch (~~mm~~); Grading: USBR 42 % SAND
Cement Content 658 lbm/yd^3 (~~kg/m^3~~); Pozzolan Content NA lbm/yd^3 (kg/m^3); Slag Content NA lbm/yd^3 (kg/m^3)
AEA: VINSOL RESIN ; Amount 29 oz/yd^3 (~~mm/m^3~~); Air Content 6.0 %; Slump 3 inches (~~mm~~)
Other Admixtures: NONE Amount NA oz/yd^3 (mm/m^3); Specimen Size CYL. 3 BY 6 inches (~~mm~~)
Amount ____ oz/yd^3 (mm/m^3); Specimen No. FA8-A, B, & C
Date Cast 7-16-64 ; Concrete Curing: 14-DAY FOG PLUS 14-DAY DRY
Date Immersed 8-13-64 ; Immersion Solution: METHOD C: 2.1% SODIUM SULFATE

Date	Age in Days	No. FA8-A		No. FA8-B		No. FA8-C		No.		No.		No.		Average Expansion	
		Dial Reading	Exp., inches ×10^{-4}	Dial Reading	Exp., inches ×10^{-4}	Dial Reading	Exp., inches ×10^{-4}	Dial Reading	Exp., mm ×10^{-4}	Dial Reading	Exp., mm ×10^{-4}	Dial Reading	Exp., mm ×10^{-4}	inches or ~~mm~~ ×10^{-4}	Percent
1964 8-13	0	2698		2501		2745									
8-14	1	2712	0	2516	0	2763	0							0	0.000
8-20	7	2712	0	2516	0	2766	3							1	0.002
9-10	28	2713	1	2514	-2	2763	0							0	0.000
11-18	97	2711	-1	2518	2	2765	2							1	0.002
1965 1-5	145	2710	-2	2513	-3	2767	4							0	0.000
3-10	209	2712	0	2514	-2	2764	1							0	0.000
5-21	280	2712	0	2514	-2	2765	2							0	0.000
7-7	327	2715	3	2520	4	2768	5							4	0.008
9-10	391	2712	0	2516	0	2770	7							2	0.004
11-9	451	2713	1	2516	0	2767	4							2	0.004
1966 2-9	543	2725	13	2520	4	2772	9							9	0.018
5-12	636	2725	13	2522	6	2778	15							11	0.022
8-11	727	2730	18	2526	10	2785	22							17	0.034
1967 2-8	908	2734	22	2525	9	2788	25							19	0.038
8-7	1089	2736	24	2528	12	2789	26							21	0.042
1968 2-9	1274	2751	39	2552	36	2837	74							50	0.100
8-9	1455	2771	59	2563	47	2863	100							69	0.138
1969 4-14	1703	2822	110	2612	96	2903	140							115	0.230
10-27	1899	2869	157	2645	129	2942	179							155	0.310
1970 10-14	2252	2905	193	2688	172	2984	221							195	0.390
1971 10-8	2611	2947	235	2700	184	3013	250							223	0.446
1972 11-28	3027	2956	244	2707	191	3014	277							237	0.474
1973 10-16	3353	2996	284	2717	201	3043	280							255	0.510

Figure 3. – Typical data and calculation form for determining the sulfate resistance of concrete.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4909-92

PROCEDURE FOR

THERMAL DIFFUSIVITY OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4909; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of CRD Method C 36-73.

1. Scope

1.1 This designation outlines a procedure for determining the thermal diffusivity of concrete. The thermal diffusivity is equal to the thermal conductivity divided by the heat capacity per unit volume, or thermal conductivity divided by the product of specific heat and saturated density of the hardened concrete, and may be used as an index of the facility with which the material will undergo temperature change.

2. Applicable Documents

2.1 *USBR Procedures*:
4192 Making and Curing Concrete Test Specimens in Laboratory
4907 Specific Heat of Aggregates, Concrete, and Other Materials
2.2 *CRD Method*:
C 36 Method of Test for Thermal Diffusivity of Concrete[1]

3. Apparatus

3.1 *Heating Bath*.–A constant-temperature tank in which concrete cylinders can be maintained at a uniform temperature. The tank shall have a capacity of at least 35 gallons (132 L), and shall have automatically controlled heating elements to maintain the water temperature within ±0.5° F (±0.27° C) at set temperatures up to the boiling point of water.

3.2 *Refrigerator-Oven Chamber*.–A chamber where the temperature of concrete cylinders can be lowered to 35° F (1.7° C).

3.3 *Computer*.–A portable computer with an appropriate data acquisition system for taking data over a time frame from copper-constantan thermocouples immersed in the heating bath, refrigerator-oven chamber, and attached to the side of and imbedded in the specimen.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Conditioning

5.1 Conditioning of the specimens is covered under section 7.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or method.

6.2 The constant-temperature water bath must be checked for compliance with section 3.1 by using thermometers certified by the manufacturer.

6.3 The refrigerator-oven chamber must be checked for compliance with section 3.2 by using thermometers certified by the manufacturer.

7. Procedure

7.1 *Number of Specimens*.–At least three specimens shall be tested at each temperature range.

7.2 *Preparation of Specimen*.–The test specimen shall be a 6- by 12-inch (152- by 305-mm) cylinder. For specimens other than this shape, refer to CRD Method C 36. If molded, specimen shall be made in accordance with the applicable provisions of USBR 4192, and shall contain a thermocouple placed at the center of mass or, if prepared from a hardened concrete core, shall contain a similarly placed thermocouple inserted in an axially drilled hole 3/8 inch (9.5 mm) or smaller in diameter for the 6-inch-diameter cylinder or 1-1/2 inches (38 mm) or smaller in diameter for the 8-inch-diameter cylinder, which has been subsequently grouted. Molded specimens shall be moist cured for at least 14 days prior to testing in accordance with USBR 4192. If concrete mixture proposed for study contains aggregate larger than 1-1/2 inches (37.5 mm), the coarser aggregate should be crushed to 3/8- to 1-1/2-inch (9.5- to 37.5-mm) sizes and proportioned into the minus 1-1/2-inch mix at the same percentage as the plus 1-1/2-inch size proposed (note 1).

---

[1] *Handbook for Concrete and Cement*, Corps of Engineers, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi.

NOTE 1.–The larger size aggregate is crushed to preserve the mineralogic composition for smaller test specimens.

7.3 *Heating and Cooling*.–Test each specimen over four temperature ranges (note 2). The low range shall be from 35 to 75 ± 3 °F (1.7 to 23.9 ± 1.7 °C), the first intermediate range from 75 to 115 ± 3 °F (23.9 to 46.1 ± 1.7 °C), the second intermediate range from 115 to 155 ± 3 °F (46.1 to 68.3 ± 1.7 °C), and the high range from 155 to 195 ± 3 °F (68.3 to 90.6 ± 1.7 °C). Place concrete cylinder in a lifting frame and lower into a container that has enough water to cover specimen, at least 5 gallons (19 L). Place container with specimen into the refrigerator-oven and bring to desired starting temperature at lower end of temperature range. Maintain temperature of water bath at upper end of temperature range. The temperature of chamber, water in container, and center and outside of specimen must all be in a steady-state condition prior to proceeding with test. Then, remove specimen from refrigerator-oven using the lifting frame and place immediately into high-temperature water bath.

NOTE 2.–The thermal diffusivity of concrete varies with temperature of concrete. Performing the test over four temperature ranges provides four points to delineate this variation, although only one or two ranges are usually adequate to provide values for diffusivity within the required accuracy. With the equipment described in this procedure, best results are obtained by conducting the test from low to high temperatures; however, when using other equipment the reverse may be true.

7.4 *Measurements*.–The heating history shall be obtained at 1-minute intervals from time specimen is placed in high-temperature bath until temperature difference between center of specimen and water bath is 3°F (or 2°C), or less. As a check on repeatability, two heating histories could be obtained for each test specimen at each temperature range. The calculated diffusivities shall check within ±0.002 ft²/h (0.00018 m²/h) when run at same temperature. At least three specimens shall be tested at each temperature range. Appendix X1 gives the operation instructions for the data acquisition program. Figure X1.1 shows a schematic of the program, table X1.1 shows a typical data printout, and figure X1.2 shows a computer-generated graphical plot.

8. Calculations

8.1 The temperature difference in degrees (°F or °C) between center and circumference of specimen shall be plotted against the time in minutes on a semilogarithmic scale (fig X1.2). A time interval shall be selected from the straight portion of this plot, and the center-circumference temperature difference between start and end of this selected time interval shall be recorded. The time elapsed between the center-circumference temperature difference of 20 and 5 °F (68 and 41 °C) is commonly used. These values shall be used in equation (1), from which the thermal diffusivity can be calculated:

$$\alpha = \frac{M}{t_2 - t_1} \qquad (1)$$

where:

α = thermal diffusivity in square feet per hour (square meters per hour),
M = a factor depending on size and shape of specimen [1][2], and
t_1 and t_2 = times in minutes at which specified temperature differences between center and circumference of specimen are reached.

For a cylinder,

$$M = \frac{60 \ln\left(\frac{T_1}{T_2}\right)}{\frac{5.783}{r^2} + \frac{\pi^2}{L^2}} \qquad (2)$$

where:

T_1 and T_2 = temperature differences at times t_1 and t_2,
$\ln\left(\frac{T_1}{T_2}\right)$ = natural logarithm of temperature difference ratio,
r = radius of cylinder in feet (meters), and
L = length of cylinder in feet (meters).

8.2 The average temperature of the specimen is calculated:

$$T_t = 0.707\,(T_{ci} - T_{ce}) + T_{ce} \qquad (3)$$

where:

T_t = average specimen temperature at t_1 or t_2, in °F (°C);
T_{ci} = circumference temperature at t_1 or t_2, in °F (°C); and
T_{ce} = center temperature at t_1 or t_2, in °F (°C).

NOTE 3.–The factor 0.707 has been determined as the point where the internal volume is equal to the external volume of any cylindrical specimen.

The average specimen temperature over a time range is calculated:

$$T = \frac{T_{t1} + T_{t2}}{2} \qquad (4)$$

where:

T = average specimen temperature over a time range, in °F (°C);
T_{t1} = T_t at time t_1, in °F (°C); and
T_{t2} = T_t at time t_2, in °F (°C).

---

[2] Numbers in brackets refer to entries in References, section 11.

A sample worksheet is shown on figure 1 using data from appendix table X1.1 and figure X1.2. The average diffusivity should be plotted against the average temperature on a single graph for all three specimens over all four temperature ranges. A linear or second-order parabolic curve should be fit to this data by the method of least squares, and the curve equation should appear on the graph; refer to computer-generated data (table 1) and the resulting graph (fig. 2).

Table 1. - Measured diffusivity data points used in regression analysis and diffusivity regression equations.[1]

Specimen No.	Temperature Range, °F	Average Temperature, °F	Measured Diffusivity, ft²/h
1	155 to 195	191.76	0.0226
2	155 to 195	191.86	.0230
3	155 to 195	191.91	.0229
1	115 to 155	151.77	.0226
2	115 to 155	151.73	.0227
3	115 to 155	151.71	.0225
1	75 to 115	110.58	.0224
2	75 to 115	110.69	.0229
3	75 to 115	110.44	.0229
1	35 to 75	70.70	.0215
2	35 to 75	71.44	.0227
3	35 to 75	71.50	.0223

[1] Data points were not used in regression analysis.

Diffusivity regression equations:

$D = 22.0 \times 10^{-3} + 46.3 \times 10^{-7}\ T$, or

$D = 21.2 \times 10^{-3} + 18.8 \times 10^{-6}\ T - 53.7 \times 10^{-9}\ T^2$

$D = 21.5 \times 10^{-3} + 11.3 \times 10^{-6}\ T - 40.5 \times 10^{-12}\ T^2$
$- 12.1 \times 10^{-11}\ T^3$

where:

D = diffusivity in square feet per hour, and
T = temperature in °F.

8.3 *Sample Calculations.*–The following calculations are on a 6-inch (152-mm) diameter, 1-foot (0.3048-m) long cylinder. The temperature and time values were obtained from table X1.1 and figure X1.2.

8.3.1 The computer program is currently programmed for inch-pound units only:

T_{ci} = 74.98 °F and T_{ce} = 54.81 °F at t_1
T_t = 0.707 (74.98-54.81) + 54.81 = 69.07 °F
T_{t1} = 69.07 °F at 28.05 minutes
T_{t2} = 73.93 °F at 65.05 minutes

$$T = \frac{69.07 + 73.93}{2} = 71.50\ ^\circ\mathrm{F}$$

Then,

T_1 = 20.17 °F at t_1 = 28.05 minutes
T_2 = 4.94 °F at t_2 = 65.05 minutes

$$M = \frac{60 \ln \left(\frac{20.17}{4.94}\right)}{\frac{5.783}{0.25^2} + \frac{3.1416^2}{1^2}} = \frac{60 \ln 4.083}{92.528 + 9.870}$$

$$= \frac{(60)(1.407)}{102.398} = 0.82433$$

$$\alpha = \frac{0.82433}{65.05 - 28.05} = 0.0223\ \mathrm{ft^2/h}$$

9. Report

9.1 Values of diffusivity, as produced by the curve equation, shall be reported at 50, 100, and 150 °F (10, 38, and 66 °C). The curve equation shall not be used to estimate diffusivity beyond the range of measured data. For a typical reporting form, refer to figure 11 in USBR 4907.

10. Precision and Bias

10.1 The precision and bias have not been established for this procedure at this time.

11. References

[1] Ingersoll, L. R. and A. C., and O. J. Zobel, *Heat Conduction*, pp. 183-185 and appended tables, McGraw-Hill Book Co., Inc., 1948. Usable charts are also found in: (a) Williamson and Adams, *Phys. Rev.* XIV, p. 99 (1919), and (b) McAdams, W. H., *Heat Transmission*, pp. 27-44, McGraw-Hill Book Co., Inc., 1942.

Spec. or Solic. No. DC-7728	Structure BUFFALO BILL DAM CAP	Tested by K. MITCHELL N. JOHNSON Date FEB & MAR 1989
Project PSMBP	Item RESEARCH STUDY USING HIGH SAND MIX Location DENVER LAB	Computed by COMPUTER PRINT-OUT Date FEB & MAR 1989
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by M. PEABODY Date MARCH 1989

THERMAL DIFFUSIVITY OF CONCRETE

Specimen No. and Temp. Range, [✓ °F] °C	r Specimen Radius, [✓ ft] m	L Specimen Length, [✓ ft] m	T_{ce} Center Temp. at t_1 or t_2 [✓ °F] °C	T_{ci} Circumference Temp. at t_1 or t_2 [✓ °F] °C	T_t Average Temp. at t_1 or t_2 [✓ °F] °C	T Average Temp. Over Time Range, [✓ °F] °C	T_1 $T_{ci} - T_{ce}$ Center-Circum. Temp. Diff. at t_1 [✓ °F] °C	t_1 Elapsed Time, minutes	T_2 $T_{ci} - T_{ce}$ Center-Circum. Temp. Diff. at t_2 [✓ °F] °C	t_2 Elapsed Time, minutes	M Specimen Size and Shape Factor	∝ Diffusivity $\frac{M}{t_2 - t_1}$ [✓ ft²/h] m²/h
35 TO 75			54.81	74.98	69.07		20.17	28.05				
3	0.25	1				71.50					0.8243	0.0223
35 TO 75			70.44	75.38	73.93				4.94	65.05		
75 TO 115			93.91	114.09	108.18		20.18	30.05				
3						110.44					0.8234	0.0229
75 TO 115			109.21	114.16	112.71				4.95	66.05		
115 TO 155			135.08	155.43	149.47		20.35	31.05				
3						151.71					0.8319	0.0225
115 TO 155			150.47	155.39	153.95				4.92	68.05		
155 TO 195			175.60	195.59	189.74		19.99	30.05				
3						191.91					0.8027	0.0229
155 TO 195			190.49	195.57	194.08				5.08	65.05		
35 TO 75			54.97	74.83	69.01		19.86	29.05				
2	0.25	1				71.44					0.8199	0.0227
35 TO 75			70.39	75.30	73.86				4.91	65.05		
75 TO 115			94.34	114.22	108.40		19.88	30.05				
2						110.69					0.8029	0.0229
75 TO 115			109.41	114.46	112.98				5.05	65.05		
115 TO 155			135.36	155.38	149.52		20.02	30.05				
2						151.73					0.8176	0.0227
115 TO 155			150.43	155.39	153.94				4.96	66.05		
155 TO 195			175.38	195.49	189.60		20.11	29.75				

Figure 1. – Sample data and calculation form for thermal diffusivity of concrete (sheet 1 of 2)

Spec. or Solic. No. DC-7728	Structure BUFFALO BILL DAM CAP	Tested by K. MITCHELL N. JOHNSON Date FEB & MAR 1989
Project PSMBP	Item RESEARCH STUDY USING HIGH SAND MIX Location DENVER LAB	Computed by COMPUTER PRINT-OUT Date FEB & MAR 1989
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by M. PEABODY Date MARCH 1989

THERMAL DIFFUSIVITY OF CONCRETE

Specimen No. and Temp. Range, [✓ °F] °C	r Specimen Radius, [✓ ft] m	L Specimen Length, [✓ ft] m	T_{ce} Center Temp. at t_1 or t_2 [✓ °F] °C	T_{ci} Circumference Temp. at t_1 or t_2 [✓ °F] °C	T_t Average Temp. at t_1 or t_2 [✓ °F] °C	T Average Temp. Over Time Range, [✓ °F] °C	T_1 $T_{ci} - T_{ce}$ Center-Circum. Temp. Diff. at t_1 [✓ °F] °C	t_1 Elapsed Time, minutes	T_2 $T_{ci} - T_{ce}$ Center-Circum. Temp. Diff. at t_2 [✓ °F] °C	t_2 Elapsed Time, minutes	M Specimen Size and Shape Factor	α Diffusivity $\frac{M}{t_2 - t_1}$ [✓ ft²/h] m²/h
2						191.86					0.8108	0.0230
155 TO 195			190.56	195.60	194.12				5.04	65.05		
35 TO 75			54.13	74.08	68.24		19.95	29.05				
1	0.25	1				70.70					0.7969	0.0215
35 TO 75			69.55	74.67	73.17				5.12	66.07		
75 TO 115			94.26	114.15	108.32		19.89	30.05				
1						110.58					0.8067	0.0224
75 TO 115			109.29	114.31	112.84				5.02	66.05		
115 TO 155			135.53	155.50	149.65		19.97	31.05				
1						151.77					0.8138	0.0226
115 TO 155			150.37	155.35	153.89				4.98	67.05		
155 TO 175			175.13	195.49	189.53		20.36	30.05				
1						191.76					0.8123	0.0226
175 TO 195			190.40	195.49	194.00				5.09	66.05		

Figure 1. – Sample data and calculation form for thermal diffusivity of concrete (sheet 2 of 2)

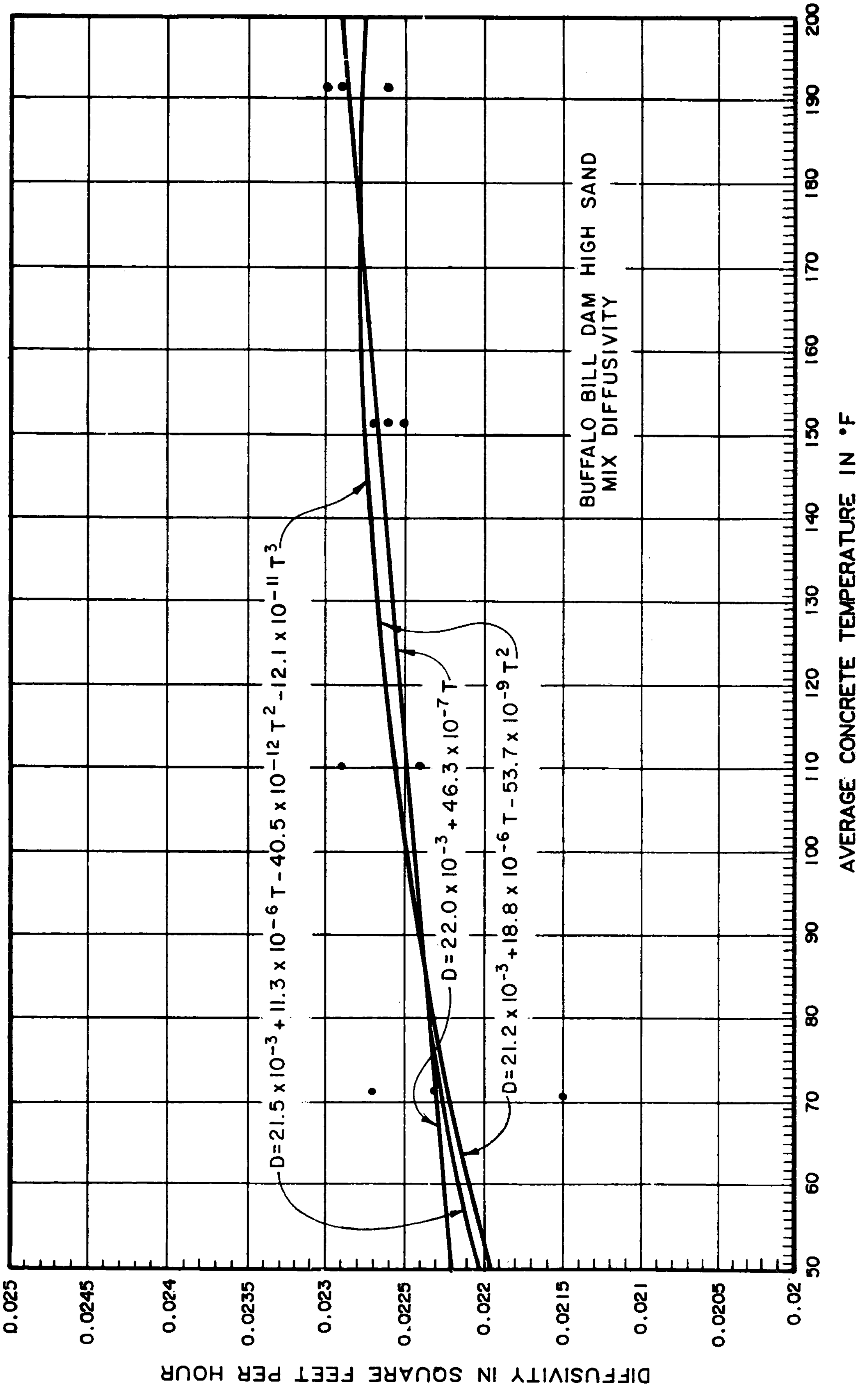


Figure 2. - Graph of computer-generated data shown in table 1.

APPENDIX

X1. OPERATION INSTRUCTIONS
(Mandatory Information)

1. Turn ON.

2. Type in LOAD "TDIFF", and push END LINE.

3. To start program, push RUN key.

4. When screen shows:

```
——————————————————————
TEST                      GET DATA
                          OFF TAPE
```

Push TEST (this is k1 button).

5. When asked to input test title, type in test title (up to 25 characters), then push END LINE.

Example: MIDDLE FORK DAM END LINE

6. When asked to input specimen ID, type in specimen ID (up to 25 characters), then push END LINE.

Example: CYLINDER J1 END LINE

7. When asked to input date, type in as shown, then push END LINE.

Example: 12/16/83 END LINE

8. Program will now measure all temperatures and print them out each time you press FRIG TEMP (button k1).

This button may be pressed as many times as needed to ensure that everything has reached steady state.

9. When everything has reached steady state, you are ready to start test:

Place specimen in hot bath and press START (button k4) as soon as possible.

10. Computer will start taking data as soon as you press START, and will take a reading every 15 seconds. After a few readings, temperature will not change as fast and 15 seconds between readings is too short. The screen will show:

```
——————————————
TIME + TIME -    FINISHED
```

To double the time between readings, push TIME+ (button k1). Push this button only once, then wait. The next time a reading is taken, the reading interval will change to 30 seconds. If you then push TIME+ again, the reading interval will change to 60 seconds the next time it reads. To shorten the time between readings, push TIME- (button k2). This will cut the reading interval in half.

11. When test is finished (center temperature and water temperature about equal), press FINISHED (button k4). The computer will then stop taking data.

12. The screen will now ask what's next? To store the data, press STORE (button k1).

13. You will now be asked for a data file name. Type in file name (up to six characters), and press END LINE.

Example: M F D S 1 H END LINE

This example file name is MFD (Middle Fork Dam), S1 (Specimen 1), and H (high temperature).

14. Computer will store data on tape, which will take several minutes. When screen stops blinking, data has been stored.

15. You are now ready for next test. Press NEWTEST (button k4).

16. You will be warned that the previous data will be lost if it has not been stored. If data has been stored, type in Y END LINE. If you type in N END LINE, screen will show same as in step 12, and you can press STORE (button k1) if you have not stored the data.

17. You are now ready for next test, go back to step 5 and repeat sequence.

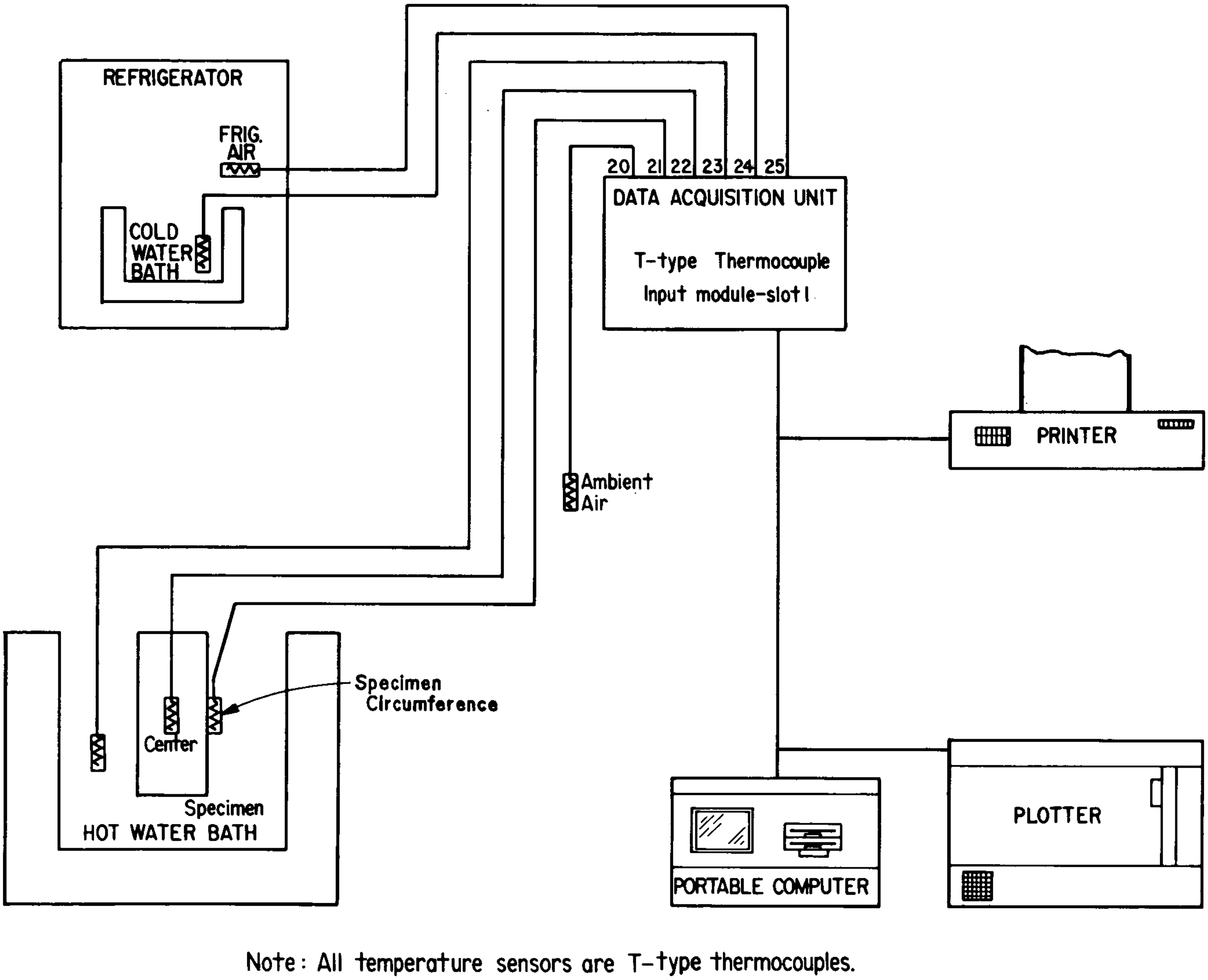


Figure X1.1. - Schematic of data acquisition system for thermal diffusivity test.

Table X1.1. - Sample data printout on a thermal diffusivity test.

Elapsed Time, minutes	Specimen Temperature		Center-Circumference Temperature Difference, °F	Water Temperature, °F
	Center, °F	Circumference, °F		
0.00	34.62	75.28	40.67	75.20
0.25	34.63	75.18	40.55	75.10
0.50	34.63	75.14	40.52	75.07
0.75	34.65	75.13	40.48	75.11
1.00	34.67	75.13	40.46	75.03
1.25	34.68	75.11	40.42	75.09
1.50	34.72	75.09	40.37	75.05
1.75	34.76	75.07	40.31	75.05
2.00	34.79	75.06	40.27	75.03
2.52	34.87	75.03	40.17	74.99
3.02	34.96	75.01	40.05	74.97
4.05	35.17	75.00	39.83	74.98
5.05	35.45	74.97	39.52	74.95
6.05	35.79	74.97	39.18	74.94
7.05	36.24	74.95	38.71	74.94
8.05	36.80	74.96	38.16	74.92
9.05	37.43	74.94	37.51	74.92
10.05	38.18	74.93	36.74	74.90
11.05	39.01	74.94	35.92	74.89
12.05	39.90	74.92	35.02	74.87
13.05	40.84	74.92	34.08	74.90
14.05	41.81	74.93	33.11	74.91
15.05	42.83	74.92	32.09	74.89
16.05	43.84	74.92	31.08	74.93
17.05	44.84	74.96	30.12	74.92
18.05	45.85	74.96	29.12	74.93
19.05	46.82	74.95	28.13	74.92
20.05	47.81	74.93	27.12	74.93
21.05	48.77	74.95	26.18	74.93
22.05	49.69	74.95	25.26	74.93
23.05	50.60	74.95	24.34	74.94
24.05	51.49	74.94	23.44	74.94
25.05	52.34	74.96	22.63	74.94
26.05	53.19	74.98	21.79	74.95
27.05	54.02	74.98	20.96	74.95
28.05	54.81	74.98	20.17	74.96
29.05	55.56	74.96	19.41	74.96
30.05	56.28	75.00	18.72	74.97
31.05	56.98	74.99	18.01	74.97
32.05	57.65	75.01	17.35	75.03
33.05	58.31	75.01	16.69	74.98
34.05	58.95	75.03	16.07	74.99
35.05	59.57	75.01	15.44	75.00
36.05	60.17	75.02	14.85	75.00
37.05	60.73	75.03	14.30	75.02
38.05	61.27	75.03	13.76	75.02
39.05	61.82	75.03	13.22	75.03
40.05	62.32	75.06	12.74	75.03
41.05	62.83	75.09	12.26	75.06
42.05	63.30	75.07	11.77	75.06
43.05	63.74	75.10	11.36	75.07
44.05	64.19	75.08	10.89	75.06
45.05	64.60	75.11	10.51	75.08
46.05	65.00	75.10	10.09	75.11
47.05	65.41	75.12	9.72	75.11
48.05	65.79	75.16	9.37	75.12
49.05	66.15	75.12	8.97	75.14
50.05	66.50	75.17	8.67	75.14
51.05	66.83	75.14	8.31	75.14
52.05	67.16	75.16	8.00	75.15
53.05	67.46	75.17	7.70	75.17
54.05	67.77	75.20	7.44	75.19
55.05	68.05	75.22	7.17	75.21
56.05	68.35	75.24	6.89	75.22
57.05	68.61	75.23	6.62	75.22
58.05	68.86	75.26	6.40	75.25
59.05	69.11	75.28	6.17	75.29
60.05	69.36	75.30	5.94	75.29
61.05	69.59	75.31	5.72	75.30
62.05	69.82	75.34	5.53	75.34
63.05	70.01	75.35	5.34	75.35
64.05	70.23	75.37	5.14	75.34
65.05	70.44	75.38	4.94	75.36
66.05	70.62	75.42	4.80	75.41
67.05	70.80	75.42	4.63	75.42
68.05	70.99	75.43	4.45	75.43
69.05	71.15	75.43	4.28	75.43
70.05	71.32	75.46	4.14	75.43

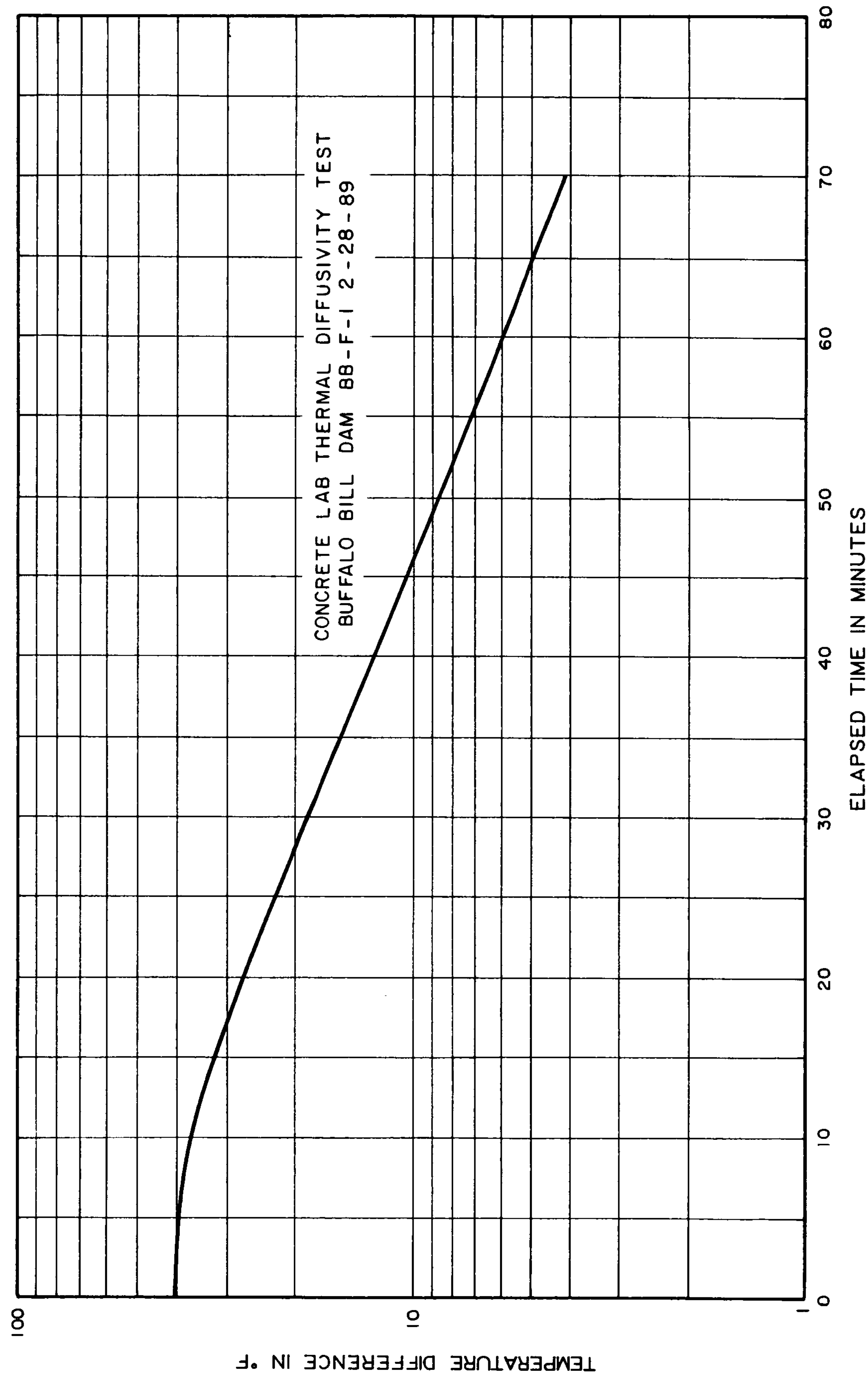


Figure X1.2. – Graph of computer-generated data shown in table X1.1.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4910–92

PROCEDURE FOR

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4910; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 Most unrestrained engineering materials expand when heated and contract when cooled. The strain due to a 1°-temperature change is known as the coefficient of thermal expansion. This coefficient is approximately constant for a considerable range of temperatures, and generally increases with an increase in temperature. For a homogeneous, isotropic material, the coefficient applies to all dimensions in all directions. This test designation covers a procedure for determining the thermal coefficient of expansion for hardened concrete in a saturated, intermediate, or dry-moisture condition.

2. Applicable Documents

2.1 *USBR Procedures*:

4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete

4192 Making and Curing Concrete Test Specimens in Laboratory

3. Apparatus

3.1 *Holding Tank*.–An insulated, copper-lined tank to hold circulating water.

3.2 *Water Tank*.–A water tank containing electric immersion heaters and refrigeration coils capable of maintaining circulating water at constant temperatures between 35 and 90 °F (1.7 and 32.2 °C).

3.3 *Recorder*.–A thermocouple recorder to record water temperature versus time.

3.4 *Refrigeration Unit*.–A freon refrigeration unit for lowering water temperature.

3.5 *Controller*.–A controller for regulating water temperature. Controller should automatically turn heater and refrigeration units on and off.

3.6 *Steel Frames*.–Invar steel, level frames for holding concrete test specimens as they are lowered into water (six required).

3.7 *Thermometer*.–A thermometer with a range of 35 to 90 °F (1.7 to 32.2 °C), and with an accuracy of 0.1 °F (0.16 °C).

3.8 *Transformers*.–For measuring length change during testing, six LVDT's (linear variable differential transformers) are required.

3.9 *Transducer Indicators*.–Two amplifier transducer indicators are required. These indicators are high-sensitivity, differential transformer, input modules for reading summation of length change occurring in three of the test specimens. The normal length change range selection for concrete is set so that a full scale division is 0.01 inch (0.25 mm); the scale is divided into 100 divisions.

3.10 Other types of sensing, controlling, and recording equipment and instrumentation can also provide satisfactory results. This system is being described somewhat in detail for the benefit of Bureau personnel who will be conducting the test with this equipment.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Sampling and Test Specimens

5.1 Six concrete test specimens are sawed as 2- by 2- by 4-inch (50- by 50- by 100-mm) prisms obtained in accordance with USBR 4042, or cast as 2- by 4-inch (50- by 100-mm) cylinders made in accordance with USBR 4192. Invar buttons are then epoxied onto the ends of the specimens. The buttons are recessed to accommodate the tips of the holding frame during testing. Length measurements are made to nearest 0.01 inch (0.25 mm), and testing normally occurs in a 100-percent vacuum saturated condition, as close to zero load as possible.

5.2 In our previous test procedures, mass concrete has been tested at three different moisture conditions to determine difference in thermal coefficients at each state. These three conditions are 100 percent dry, 100 percent vacuum saturated, and 75 percent vacuum saturated. If testing by these conditions is requested, 12 specimens are prepared in 2 groups of 6 each. All specimens are oven dried at 190 °F (87.8 °C) to initiate testing under equal conditions.

5.2.1 During initial drying of first set of specimens, mass is determined until no loss of the mass is observed. Specimens are immediately dipped in heated paraffin wax to sustain this 100 percent dry condition.

5.2.2 After initial drying, second set of specimens are vacuum saturated and their mass determined until no increase in mass is observed. Specimens are immediately submerged in a water bath of constant temperature to sustain this 100 percent saturated condition.

5.2.3 The second set of specimens, which were previously tested in a fully saturated state, are also used for obtaining data in a partially saturated condition. The fully saturated specimens are dried and their mass determined until they reach a condition of 75 percent saturation. To remain in this state, specimens are immediately dipped in heated paraffin wax. The highest values for coefficient of thermal expansion are normally obtained in this 75 percent saturated condition.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure.

6.2 The LVDT's are calibrated on the thermal expansion testing apparatus as follows:

Step 1.–Place test specimens in tank.

Step 2.–Set ABC selector switch to A of TAI (Transducer Amplifier-Indicator).

Step 3.–Set range selector to STANDBY. Adjust meter screw for zero reading.

Step 4.–Turn sensitivity to maximum (clockwise) and set zero knobs to center point (arrows point upward).

Step 5.–Repeat steps 1 through 4 for second TAI.

Step 6.–Turn range selector to NULL.

Step 7.–Unlock adjustment knob on frame and set LVDT for zero meter reading, lock LVDT, and adjust with "mechanical adjustment knob" to bring needle as close to zero as possible. Lock manual adjustment knob.

Step 8.–Fine adjust to zero with proper null screw.

Step 9.–If necessary, alternate mechanical and null adjustment to bring needle as close to zero as possible.

Step 10.–Set ABC selector switch to B, and repeat steps 7 through 9.

Step 11.–Set ABC selector switch to C, and repeat steps 7 through 9.

Step 12.–Turn second TAI range selector to NULL.

Step 13.–Repeat steps 7 through 11 for second amplitude.

Step 14.–Set range selector to 10.

Step 15.–Adjust zero for A with fine-zero controls. Repeat for B and C.

Step 16.–Check zero of A+B+C.

Step 17.–Repeat steps 14 through 16 with second TAI.

Step 18.–Set ABC selector switch to A.

Step 19.–Insert 0.01-inch (0.25-mm) shim between first LVDT and mechanical adjuster with a sawing motion.

Step 20.–Adjust sensitivity to bring needle to 100.

Step 21.–Set range selector to CAL and bring needle to 100 with CAL SET adjustment.

Step 22.–Bring range selector back to 10.

Step 23.–Set ABC selector switch to B. Insert shim.

Step 24.–Adjust needle to 100 with span B adjustment screw.

Step 25.–Set ABC selector switch to C. Insert shim.

Step 26.–Repeat step 24 with span C screw.

Step 27.–Check zero of A+B+C.

Step 28.–Repeat steps 18 through 27 with second amplitude.

Step 29.–With range selector at 10 and ABC selector switch at A+B+C, begin test by moving rheostat to about 55 and turning on all other switches. Turn recorder to "select-o-print."

Step 30.–Temperature is adjusted with knob on temperature controller.

6.3 Temperature control shall be verified as conforming with section 3 by adequate thermometers certified by manufacturer.

7. Conditioning

7.1 Tests should be conducted in a room environment where temperature change is held to a minimum. Other conditioning is covered under section 5.

8. Procedure

8.1 Test specimens in a fully dry, fully saturated, or partially saturated state are placed in their holding frames and lowered into a water bath of constant temperature 1 day prior to testing. This allows all components to reach a temperature equilibrium.

8.2 Fill in heading of Data and Computation Sheet (fig. 1) and begin test.

8.3 The initial time, water temperature, and amplified meter readings are taken and temperature controller is set to 70 or 80 °F (21.1 or 26.7 °C) depending upon initial room temperature.

8.4 When water reaches set temperature, hold temperature constant for 5 to 7 minutes while entries are made on data sheet of length changes, temperatures, and time.

8.5 Increase temperature to 90 °F (32.2 °C) and repeat data entries.

8.6 Lower temperature to 85 °F (29.4 °C) and read in 10 °F (5.6 °C) increments down to 35 °F (1.7 °C). Increase temperature to 40 °F (4.4 °C) and read in 10 °F increments back to the initial set temperature. In this manner, data points are obtained for every 5 °F (2.8 °C) interval between 35 and 90 °F as temperature is fluctuated.

8.7 Meter versus temperature readings are plotted and a linear curve is drawn (fig. 2).

9. Calculations

9.1 Figure 1 shows a typical data and calculation form.

9.2 Figure 2 shows the curve discussed in section 8.7. The length or projected meter readings are determined from the curve at the intersect point of 35 °F (1.7 °C) and 90 °F (32.2 °C).

9.2.1 Calculate the coefficient of thermal expansion as follows:

$$CE = \frac{y_2 - y_1}{0.55\ S} \qquad (1)$$

where:

CE = coefficient of thermal expansion, in (in/in)/°F × 10^{-6} or (cm/cm)/°C × 10^{-6};
y_1 = intercept of line at 35 °F (1.7 °C);
y_2 = intercept of line at 90 °F (32.2 °C); and
S = summation of gauge lengths, in inches (millimeters).

9.2.2 A more precise method of calculating the coefficient of thermal expansion is by the least squares method of calculation for determining the slope of a line (fig. 3):

$$CE = \frac{y_2 - y_1}{0.55\ S} \qquad (1)$$

$$y_1 = -c + 35b \qquad (2)$$

$$y_2 = -c + 90b \qquad (3)$$

$$c = a - \bar{y} \qquad (4)$$

$$b = \frac{\Sigma\,(x - \bar{x})\,(y - \bar{y})}{\Sigma\,(x - \bar{x})^2} \qquad (5)$$

$$a = \bar{x} b \qquad (6)$$

where:

a = constant derived from the average temperature multiplied by the slope of the line,
b = slope of line,
c = constant derived from a, minus the average meter readings,
x = temperature in °F (°C),
$\bar{x}$ = average temperature in °F (°C),
y = measurement in inches per inch (centimeters per centimeter),
$\bar{y}$ = average measurement in inches per inch (centimeters per centimeter), and
CE, S, y_1, and y_2 = as previously defined.

10. Report

10.1 A cover letter along with figures 1 and 2 or figure 3 should serve as a report for this procedure.

11. Precision and Bias

11.1 The precision and bias for this procedure have not been established.

Spec. or Solic. No. PRECONSTRUCTION STUDIES	Structure BUFFALO BILL DAM	Tested by D. ARNEY Date 9-8-85
Project PSMBP	Item CONCRETE THERMAL EXP. Location DENVER LAB	Computed by D. ARNEY Date 9-8-85
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by E. HARBOE Date 9-8-85

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

Specimen: ☒ Prism ☐ Cylinder; ☒ Sawed ☐ Fabricated; Nominal Size 2- BY 2- BY 4 inches ~~(mm)~~

Aggregate Source: Coarse ALTHOFF CONST.* Fine ALTHOFF CONST. (26%)

MSA: 1½ inches ~~(mm)~~ 1½ TO 3-INCH CRUSHED

☒ 100% Vacuum Saturated ☐ 75% Vacuum Saturated ☐ 100% Oven Dried

Gauge Lengths: (1) 4 1/16 (2) 4.0 (3) 4.0 (4) 4 1/16 (5) 4.0 (6) 4.0 inches ~~(mm)~~ Summation: 24.125 inches ~~(mm)~~

Time	Temperature °F	Temperature °C	No. 1 Range 10 0.01 INCH x 100 Meter Reading	No. 2 Range 10 0.01 INCH x 100 Meter Reading	Average Meter Reading	Remarks
8:20	71.4		0	0	0	*3/8 (15%), 3/4 (25%), 1½ (35%), 3 (25%)
9:03	74.9		+5.2	+5.3	+5.3	
9:31	80.2		+10.7	+11.1	+10.9	
10:05	89.6		+20.5	+20.9	+20.7	
10:36	84.8		+15.2	+14.8	+15.0	
10:59	69.2		+0.7	+0.2	+0.5	
11:30	65.0		-4.4	-4.0	-4.2	
11:56	59.7		-11.7	-11.1	-11.4	
12:30	55.4		-14.0	-13.9	-14.0	
1:11	45.1		-24.1	-23.9	-24.0	
2:50	37.8		-31.5	-30.8	-31.2	
3:12	39.9		-29.9	-29.3	-29.6	
3:44	50.5		-20.3	-19.6	-20.0	

$$CE = \frac{y_2 - y_1}{0.55\,S} = \frac{20.3 - (-34.6)}{0.55(24.125)} = 4.138 \text{ millionths, inch/inch/°F}$$

Figure 1. - Typical data and calculation form for measurement of expansion.

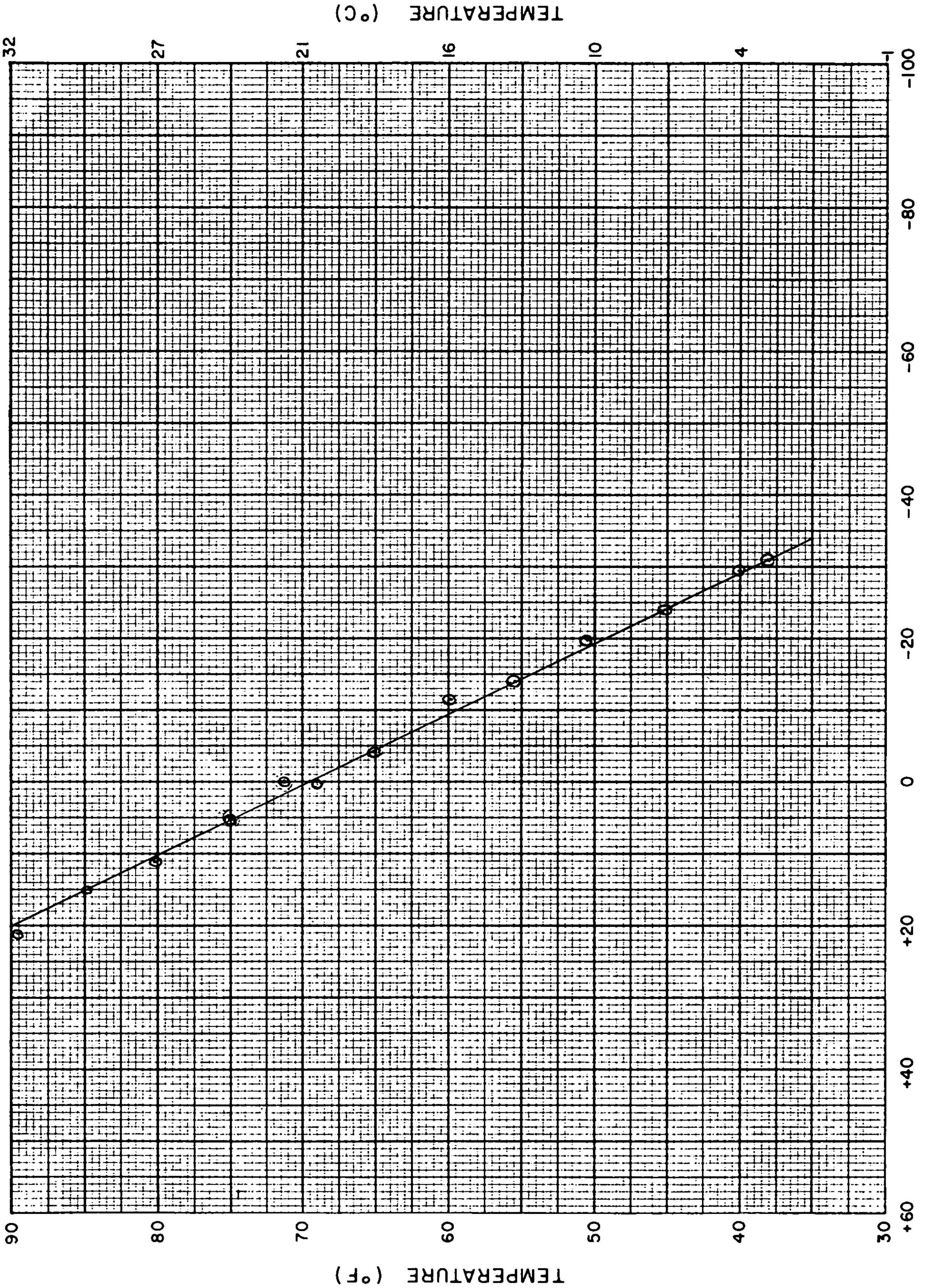


Figure 2. – Graph of meter versus temperature readings.

Spec. or Solic. No. PRECONSTRUCTION STUDIES	Structure BUFFALO BILL DAM	Tested by D. ARNEY	Date 9-8-85
Project PSMBP	Item CONCRETE THERMAL EXP. Location DENVER LAB	Computed by D. ARNEY	Date 9-8-85
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Station ~ Offset ~ Depth ~ to ~	Checked by E. HARBOE	Date 9-8-85

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

x Temperature °F	x Temperature °C	y Meter Reading	$x - \bar{x}$	$(x - \bar{x})^2$	$y - \bar{y}$	$(x - \bar{x})(y - \bar{y})$
71.4		0	+8.1	65.61	+6.3	+51.03
44.9		+5.3	+11.6	134.56	+11.5	+133.40
80.2		+10.9	+16.9	285.61	+17.2	+290.68
89.6		+20.7	+26.3	691.69	+27.0	+710.10
84.8		+15.0	+21.5	462.25	+21.3	+457.95
69.2		+0.5	+5.9	34.81	+6.7	+ 40.12
65.0		-4.2	+1.7	2.89	+2.1	+ 3.57
59.7		-11.4	-3.6	12.96	-5.1	+18.36
55.4		-14.0	-7.9	62.41	-7.7	+60.83
45.1		-24.0	-18.2	331.24	-17.7	+322.14
37.8		-31.2	-25.5	650.25	-24.9	+634.95
39.9		-29.6	-23.4	547.56	-23.3	+545.22
50.5		-20.0	-12.8	163.84	-13.7	+ 175.36
Σ = 823.5	Σ =	Σ = - 82.4		Σ = 3,445.68		Σ = 3,443.71

$\bar{x}$ = 63.3   S = 24.125 inches

$\bar{y}$ = -6.34   a = 63.3 (0.99943) = 63.3

y_1 = -69.6+35(0.99943)=-34.6   b = 3443.71/3445.68 $\bar{x}$ 0.99943

y_2 = -69.6+90(0.99943)=20.4   c = 63.3-(-6.34)=69.6

$CE = \frac{y_2 - y_1}{0.55 S} = \frac{20.3 -(-34.6)}{0.55(24.125} = 4.138$ millionths, inch/inch/°F

Figure 3. – Least squares method of calculation for determining slope of line.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4911-92

PROCEDURE FOR

TEMPERATURE RISE OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4911; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers a procedure for determining the temperature rise in concrete under adiabatic conditions primarily due to heat generated by cement and pozzolan during hydration.

2. Applicable Documents

2.1 *USBR Procedures*:

4172 Sampling Freshly Mixed Concrete
4186 Heat of Hydration of Hydraulic Cement
4192 Making and Curing Concrete Test Specimens in Laboratory
4907 Specific Heat of Aggregates, Concrete, and Other Materials

3. Summary of Procedure

3.1 Temperature rise tests are conducted on 700-lbm (318-kg) concrete specimens sealed in 21-1/2- by 21-1/2-inch (546- by 546-mm) cylindrical metal containers and placed in a calorimeter chamber. Temperature of air within chamber is maintained at same temperature as specimen by automatic control equipment, which keeps an electrical resistance thermometer exposed to chamber air in balance with a resistance thermometer in a well extending to center of concrete specimen. As a result, any heat generated by cement and/or pozzolan results in a temperature rise in the concrete and a corresponding rise in chamber temperature.

4. Significance and Use

4.1 When concrete is rapidly placed in a large mass structure, heat generated by hydration of cement and pozzolan cannot readily be dissipated. Consequently, structure reaches a high temperature while concrete is still in a relatively plastic state. When subsequent cooling to normal mean temperature occurs, concrete is less plastic and structure cannot respond to accompanying volume change. Thus, stresses are set up in the concrete which, if allowed to exceed tensile strength of concrete, may result in cracking the structure. Accordingly, special design and construction practices are required to prevent cracking of the structure due to initial temperature rise. These practices include artificial cooling of materials prior to mixing and/or the concrete by using cooling pipes after placing. The extent to which these practices must be carried is determined from tests on the temperature rise of concrete.

4.2 A direct method of measuring temperature rise of concrete due to hydration of cement is furnished by the adiabatic calorimeter. Heat of hydration of cement may be calculated when temperature rise and specific heat (USBR 4907) of the concrete are known. Since it is frequently useful to know the heat of hydration, the calculations to determine this value from the temperature rise test data is included in section 10 of this procedure. Other methods, such as heat of solution (USBR 4186), have also been found satisfactory to determine heat of hydration. However, when a pozzolanic material which reacts with the hydrated cement is also used in the concrete, it is necessary to conduct a temperature rise test as herein described to measure the *amount* and *rate* of heat generation.

5. Apparatus

5.1 *Specimen Container.*–The specimen container (figure 1) shall be 21-1/2 inches (546 mm) high by 21-1/2 inches in diameter, and is made of 20-gauge black iron with a 7-inch (178-mm) diameter hole in the top for filling. Two brass tubes shall be soldered through the lid of this container and shall extend 12 inches (305 mm) into the container. When lid is placed on container, these tubes extend down into center of specimen to form wells into which controlling and reading thermometers are placed. In addition, an air valve and sometimes a manometer tube are soldered into lid. The air valve is used to admit air pressure into the container, after it has been filled and soldered, to confirm that the container is completely sealed. The manometer tube permits study of pressure or vacuum developments during the process of hydration.

5.2 *Adiabatic Calorimeter Curing Room.*–The calorimeter curing room is a chamber heavily insulated to minimize outside temperature influences, and can therefore be controlled to a very precise temperature. One such chamber is described as follows:

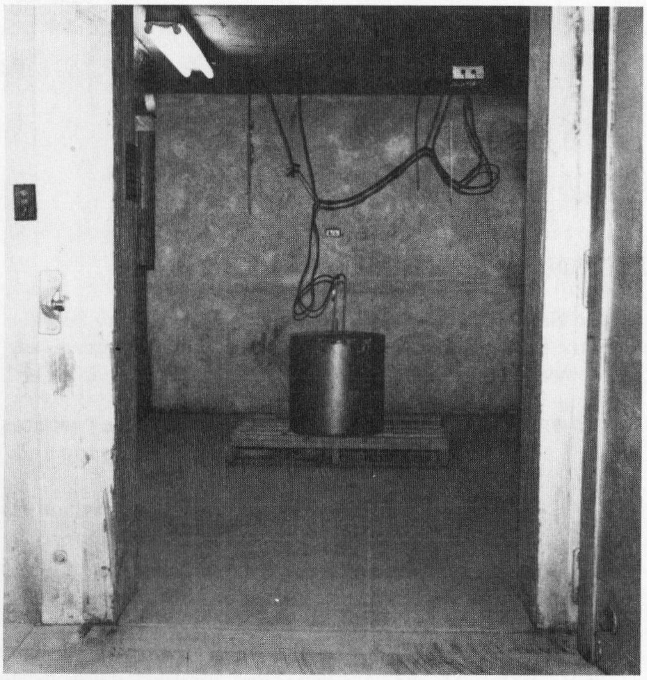


Figure 1. – Temperature rise specimen container.

5.2.1 Figure 2 shows a cross section of the calorimeter room construction. The walls are of double hollow masonry unit construction with 7 inches (178 mm) of rock-wool insulation between the cinder blocks on walls between rooms, and 5 inches (127 mm) of rock-wool insulation on outside walls. The floor is constructed with a 4-inch (102-mm) concrete base, over which is a 10-inch (254-mm) layer of insulating vermiculite concrete, topped with another 4 inches of reinforced concrete. The vermiculite concrete has a thermal conductivity coefficient about one-twelfth that of regular concrete. Ceiling construction consists of 2- by 6-inch (50- by 150-mm) joists on 16-inch (406-mm) centers, over which is laid wood flooring. All the space between rafters is filled with rock-wool insulation, which provides 6 inches (152 mm) of insulation through the ceiling. All interior walls and ceilings are constructed with a 1-inch (25-mm) layer of plaster spray painted with aluminum paint. Air circulation is provided by 15- by 48-inch (381- by 1219-mm) openings through the ceiling on either side of the room, with a duct over the room connecting these two openings. In this duct are placed brine coils and electrical heaters for controlling air temperature and a blower for circulating the air.

5.2.2 Air from blower enters room behind a perforated wall jacket covering one side of room. Behind the jacket are metal baffles which distribute air from blower

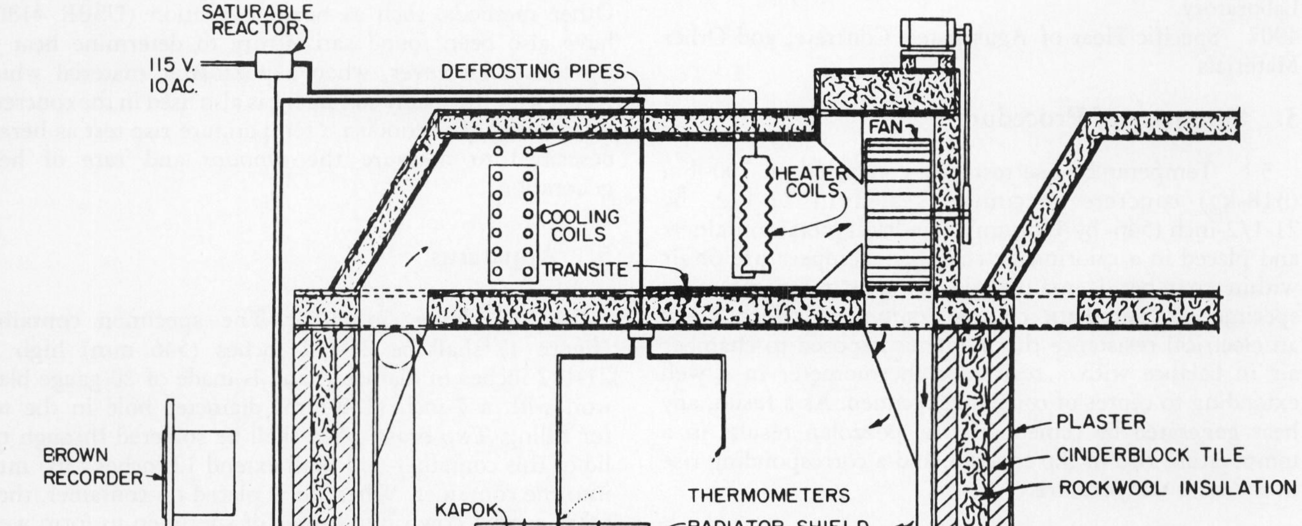


Figure 2. – Cross section of calorimeter room. Present configuration of the calorimeter room in use at the present time is slightly different, but adequately portrays the functional purpose.

so that air enters room uniformly across entire side of room. A similar jacket is placed on return side of room. With this uniform method of air circulation, all temperature gradients throughout room are reduced to a minimum. The perforated wall jackets in some of the rooms are made of No. 20 gauge galvanized iron with 5/16-inch (8-mm) diameter holes on 2-1/8-inch (54-mm) centers. In other rooms, 1/8-inch (3-mm) tempered masonite is used with 1/2-inch (13-mm) holes on 2.4-inch (61-mm) centers (note 1). All inside surfaces are coated with aluminum paint.

NOTE 1.–The metal wall jackets are preferred because masonite has been found to expand and buckle from use at high temperatures.

5.2.3 Ample access into the calorimeter room for small electric lift trucks and for handling large specimens is provided by a Stevenson overlap-type, cold-storage door with a 4- by 7-foot (1.2- by 2.1-m) opening (figure 3).

5.2.4 Temperature control is maintained by drawing air over cooling coils and heater units located in duct over calorimeter room. The fin-type cooling coils are capable of transferring 18,000 Btu/h (5272 W) with a 22 °F (12.2 °C) differential between brine and room temperature. Brine refrigerant comes from a supply maintained at about 16 °F (–9 °C). Electrically operated valves provide refrigeration adjustment. The heating unit consists of a frame on which are mounted helical coils of No. 19 Chromel "A" wire designed for a peak temperature of 400 °F (204 °C) at 4 hp (2983 W) and 115 V. The air in the room is changed four times per minute by an American Blower Co. Model No. 350 centrifugal multivane blower, belt driven at 380 r/min by a 1.5-hp (1119-W) induction motor.

5.2.5 The temperature-controlling instruments consist of what is known as the "Honeywell Electronik 15 proportioning recording controllers." The elements of this system consist of:

- A matched pair of electrical resistance thermometers.
- Honeywell strip chart proportioning controller.
- Honeywell Electr-o-volt unit.
- Saturable reactor, 3 kV•A, General Electric Model No. 9XM38A1.

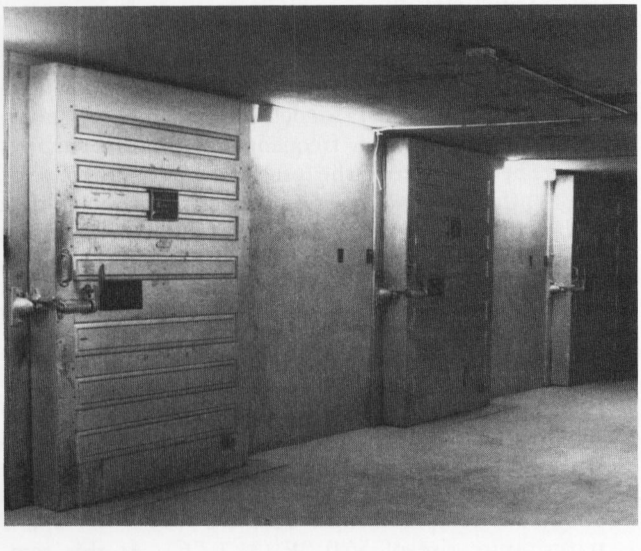


Figure 3. – Adiabatic calorimeter rooms.

5.2.6 The resistance thermometers are nickel-wire bulbs with a resistance of about 600 ohms at 100 °F (37.8 °C). The thermometers are a balanced pair matched to within 0.1 °F (0.06 °C) throughout their range. The specimen thermometer, which is encased in a close-fitting stainless-steel tube 21 inches (533 mm) long for protection, is a Honeywell Instrument Co. Part 73724. The air thermometer has the same sensitive element encased in stainless-steel tubing.

5.2.7 The temperature sensing and recording instrument is a Honeywell Electronik proportioning recording controller. The initial null point of this instrument is at the center of the scale, and the full-scale deflection is –10 to + 10 °C.

5.2.8 Power to the room heaters is regulated through the Electr-o-volt unit of the controller. This produces a varying d-c control voltage which regulates the power flow through the saturable reactor.

5.2.9 To read temperature in room, two additional thermometers similar to the thermometers used in the control circuit are used, one for reading room air temperature and one for reading specimen temperature. Leads from these thermometers are brought to the computer controlled data acquisition system in control room. This system makes a four-wire resistance measurement on each of the thermometers.

5.2.10 Other types of control systems and instrumentation can also provide satisfactory control. This system has been described somewhat in detail for the benefit of Bureau personnel who will be conducting the test with this installation. The system used must control the temperature within a tolerance of ±0.01 °F (±0.0055 °C).

5.3 *Internal Vibrators.*–Internal-type vibrators with 2-inch (51-mm) poker vibrator heads operating at a minimum of 10,000 vibrations per minute.

5.4 *Tamping Rod.*–The tamping rod shall be 5/8-inch (16-mm) diameter with a 24-inch (610-mm) long bullet-nosed rod.

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7. Calibration and Standardization

7.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure directly or by reference.

7.2 Thermometers shall be calibrated by taping the thermometers together along with a standard calibrated thermometer and placing them in an oil bath within the calorimeter room or chamber. Calibration shall be made at each 10 °F (6 °C) increment within the expected range of the temperature rise.

8. Conditioning

8.1 Concrete test mixtures containing aggregate in the 3- to 6-inch (75- to 150-mm) size fraction should be selectively batched to produce a 4-1/2-inch (114-mm) maximum size aggregate.

8.2 Two percent additional cement, pozzolan, and water shall be added to the temperature rise specimens to compensate for heat absorbed by metal container and one-half the insulation surrounding specimen. This 2 percent is a correction factor and should not be included when reportng mixture proportions.

8.3 The calorimeter room should be under temperature control the day before a temperature rise test is to be initiated. This provides an opportunity to check operation of controller and readings of thermometers and to bring all equipment in room, as well as room itself, to starting temperature. The test may be started at any initial temperature of the concrete; however, the initial temperature greatly affects the rate of hydration during the first few days. Accordingly, concrete aggregate and mixing water should be tempered to produce an initial temperature as close to 70 °F (21.1 °C) as can be obtained unless rate of hydration at some other initial temperature is specifically desired. To maintain temperature of room at 70 °F prior to test, the specimen controlling thermometer should be replaced with a decade-resistance box.

8.4 Before starting test, the specimen and air-reading thermometers shall be matched by placing them so that their sensitive elements are together and at same temperature. Several readings should be taken on each thermometer and the difference in their resistance reading noted. Accordingly, when test is started, the control should be set to maintain this difference between the air and specimen thermometer resistance readings.

9. Procedure

9.1 Concrete shall be prepared for testing in accordance with USBR 4192. Prime mixer before making test batch. Test batch shall be about 700 lbm (320 kg) of concrete made in a sample batch. The entire batch shall be placed in the specimen container so that exact quantities are known.

9.2 Immediately after mixing, make an initial temperature reading on concrete with a precision mercury thermometer. Place concrete in container through the 7-inch (178-mm) diameter lid opening in two layers, with each layer being about one-half the volume of container. Compact each layer with the internal vibrator.

9.3 After entire test batch has been placed in the container, it may be necessary to use the tamping rod to form holes for the brass tubes that are soldered to the container lid (sec. 5.1).

9.4 Put lid on specimen container and solder in place. Attach a tire pump to air valve and induce air to a pressure of 2 to 3 inches (50 to 75 mm) of mercury into container. Test solder joints for leaks using a soap solution. Disconnect pump and release air pressure. Add a few drops of light oil to each thermometer well to form a liquid contact between thermometer and well. Place insulation jacket around container. Place control thermometer in one of the wells and connect to control instrument after disconnecting the decade resistance box which has been maintaining the room temperature at 70 °F (21.1 °C). The room temperature will now be controlled by temperature of specimen. Place specimen reading thermometer in second well and take readings of the air and specimen temperatures so that control index on controller can be adjusted to maintain the room temperature to exactly the same temperature of the specimen.

9.5 Record temperatures hourly at beginning of test period and at greater intervals as test progresses. Test should continue for 28 days, and values of temperature rise and heat of hydration of cement reported at 1, 3, 7, 14, and 28 days. Because of the slightly different characteristics of the thermometers, the specimen and air reading thermometers shall be matched after the first day of testing and at greater intervals as test proceeds. This matching operation shall be done by wiping the oil film from the surface of the specimen thermometer, and suspending it with the air thermometer so that their sensitive elements are together as described previously. Any variation of the air temperature from that of the specimen should be corrected by adjusting the control index.

10. Calculations

10.1 Typical values of temperature rise and heat of hydration for various types of cement are shown on figure 4, and typical data for determining same are shown on figure 5. Although frequent temperature readings should be taken during the test to maintain close control, only sufficient readings need be calculated to plot a smooth curve of temperature rise. The heat of hydration is equal to temperature rise times average specific heat, times total mass of mix divided by mass of cement. The result is a value in British thermal units per pound mass of cement (or joules per kilogram). The average specific heat for a given temperature range is used because the specific heat of the concrete varies with temperature. For example, at the initial temperature, the specific heat of the concrete was 0.2139 Btu/(lbm·°F) [895.5 J/(kg·°C))]. At age of 28 days, the concrete had attained a temperature of 127.8 °F (53.2 °C) and a temperature rise of 56.0 °F (31.1 °C). At this temperature, the specific heat of the concrete was 0.2281

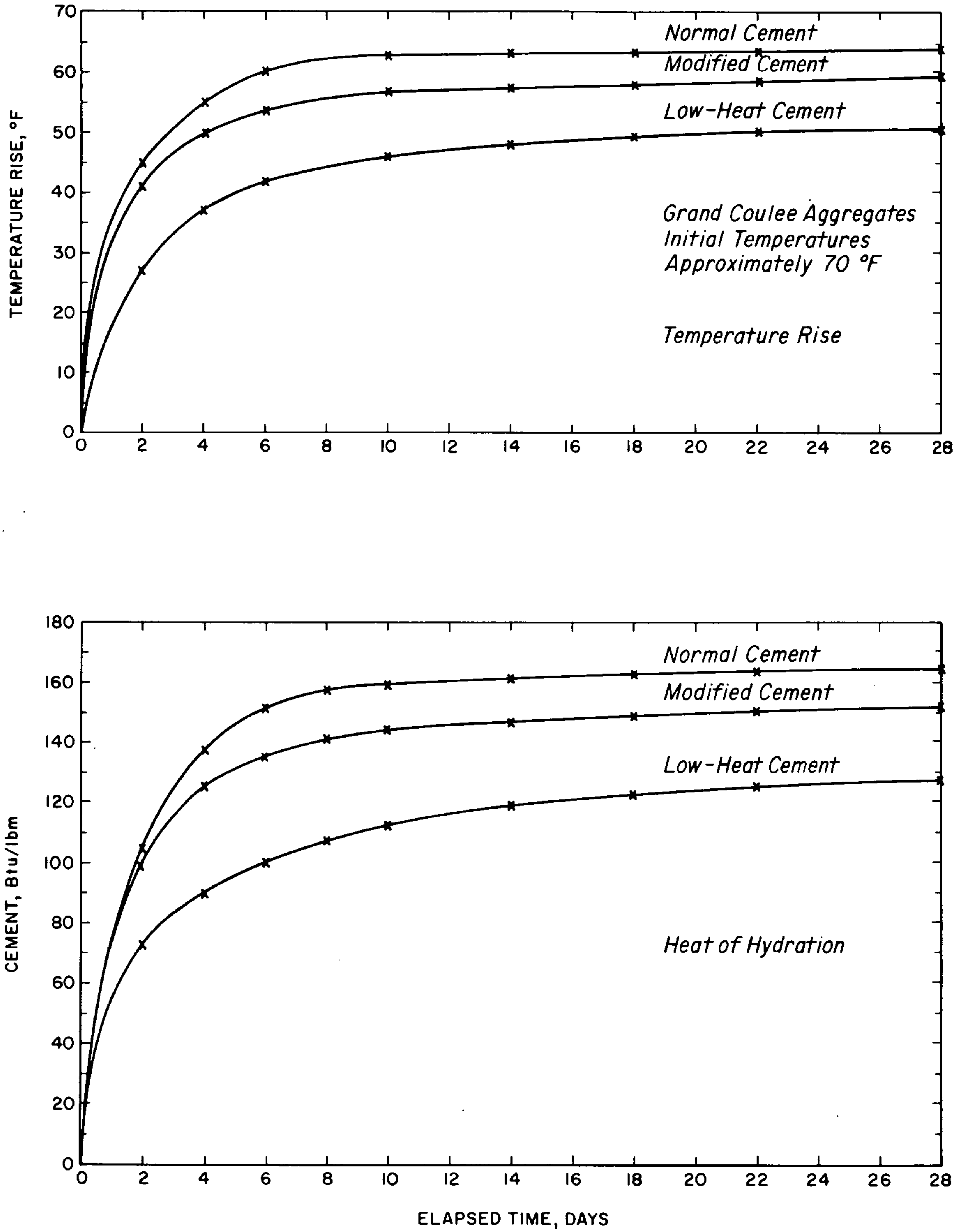


Figure 4a. – Temperature rise and heat of hydration versus time (English units).

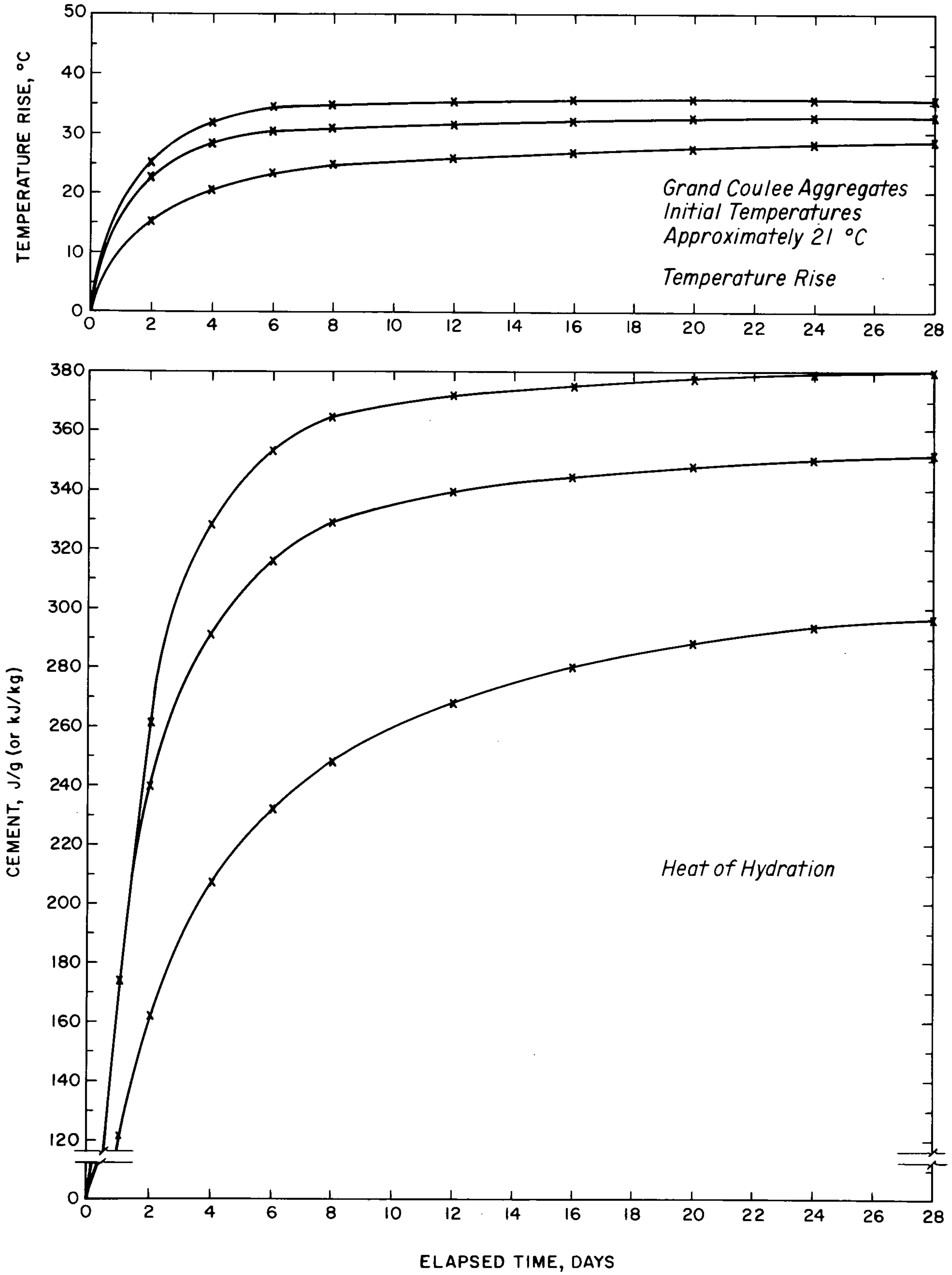


Figure 4b. - Temperature rise and heat of hydration versus time (metric units).

Spec. or Solic. No. DESIGN STAGE	Structure DAM	Tested by E. M. HARBOE 4-24-46 5-15-46 Date
Project MISSOURI RIVER BASIN	Item TEMPERATURE RISE STUDIES Location DENVER LAB	Computed by E. M. HARBOE 4-24-46 5-15-46 Date
Feature KORTES DAM	Station ~ Offset ~ Depth ~ to ~	Checked by J. J. SHIDELER 5-16-46 Date

TEMPERATURE RISE IN CONCRETE

Specimen Number: K4 H Date Cast: 4-24-46 Test Number: 4 Room Number: 2

Initial Temperature: 71.8 °F ~~(°C)~~ *Constant: 702.2 ÷ 56.0 = 12.54

Age			Age	Temperature Rise		Average Specific Heat		Heat of Hydration	
day	h	min	day	°F	°C	Btu/(lbm · °F)	J/(kg · °C)	Btu/lbm	kJ/kg
0	0	53	0.04	0.45	0.25	0.2140	895.9	1.21	2.8
0	5	23	0.22	7.40	4.11	.2149	899.7	19.94	46.4
0	10	43	0.45	16.05	8.92	.2160	904.3	43.48	101.2
1	0	0	1.00	24.47	13.59	.2170	908.5	66.59	154.8
2	0	08	2.01	35.25	19.58	.2184	914.3	96.55	224.5
3	0	0	3.00	41.25	22.92	.2192	917.7	113.39	263.8
5	0	0	5.00	47.10	26.17	.2199	920.6	129.89	302.1
6	0	0	6.00	48.47	26.93	.2201	921.5	133.79	311.2
7	0	0	7.00	49.85	27.69	.2203	922.3	137.72	320.3
8	0	0	8.00	50.75	28.19	.2204	922.7	140.27	326.2
9	0	18	9.01	51.79	28.77	.2205	923.1	143.21	333.0
10	0	0	10.00	52.75	29.31	.2206	923.6	145.93	339.5
12	0	13	12.01	53.33	29.63	.2207	924.0	147.60	343.3
13	0	43	13.03	53.76	29.83	.2207	924.0	148.63	345.6
14	0	08	14.01	53.99	29.99	.2208	924.4	149.50	347.6
15	0	08	15.01	54.31	30.17	.2208	924.4	150.38	349.7
16	0	0	16.00	54.39	30.22	.2208	924.4	150.60	350.3
19	0	0	19.00	55.01	30.56	.2209	924.8	152.39	354.4
20	0	0	20.00	55.10	30.61	.2209	924.8	152.64	355.0
21	0	0	21.00	55.25	30.69	.2210	925.2	153.12	356.1
22	0	08	22.01	55.35	30.75	.2210	925.2	153.40	356.8
23	4	38	23.19	55.40	30.78	.2210	925.2	153.54	357.1
26	0	33	26.02	55.80	31.00	.2210	925.2	154.65	359.7
27	0	23	27.02	55.89	31.05	.2210	925.2	154.90	360.2
27	22	13	27.93	56.00	31.11	.2210	925.2	155.20	360.9

$$*C = \frac{\text{Total Mass of Specimen}}{\text{Total Mass of Cementitious Material}}$$

Heat of Hydration = Temperature Rise × Average Specific Heat × C

Figure 5. - Adiabatic heat of hydration.

Btu/(lbm· °F) [955.0 J/(kg·°C)]. The average specific heat over this interval of temperature rise would be:

$$0.5\,(0.2139 + 0.2281) = 0.221\ \text{Btu/(lbm}\cdot{}^\circ\text{F), or}$$
$$0.5\,(895.5 + 955.0) = 925.3\ \text{J/(kg}\cdot{}^\circ\text{C)}$$

This average value of specific heat should be used to calculate the 28-day heat of hydration. The heat of hydration at 28 days is equal to temperature rise times average specific heat times mass of concrete divided by mass of cement, which would be:

$$\frac{(56.0)(0.221)(702.2)}{(56.0)} = 155.2\ \text{Btu/lbm, or}$$

$$\frac{(31.1)(925.3)(318.5)}{(25.4)} = 360.9\ \text{kJ/kg}$$

NOTE 2.–Normal practice in cement industry testing has been to use the CGS system of metric units. In that system of units, heat of hydration is reported as calories per gram of cement. To convert British thermal units per pound mass to calories per gram, divide by 1.8.

10.2 A data acquisition system has been assembled which takes measurements of temperature at predetermined intervals during the temperature rise test and stores the data. These data can then be printed or plotted. A computer program has also been developed for calculating heat of hydration. A complete description of this system and the computer program are given in appendix X1.

11. Report

11.1 Figure 12, of USBR 4909, includes relevant data on the cement, pozzolan, aggregate, mixture proportions, and initial temperature; it may be used as a reporting form. A table prepared similar to table 1 provides calculations of average specific heat through given temperature rise. Figure 4 shows a plot of temperature rise and heat of hydration. Figure 5 shows calculations of average specific heat and heat of hydration.

12. Precision and Bias

12.1 The precision and bias statements for this procedure have not been determined at this time.

Table 1a. – Sample calculation of average specific heat through given temperature rise for calculation of heat of hydration.†

Temp. °F	Temp. Rise, °F	Spec. Heat	Av. Spec. Heat
		Btu/(lbm·°F)	
71.8	0	0.2139	0.2139
72.8	1	.2142	.2141
73.8	2	.2144	.2142
74.8	3	.2147	.2143
75.8	4	.2149	.2144
76.8	5	.2152	.2146
77.8	6	.2154	.2147
78.8	7	.2157	.2148
79.8	8	.2160	.2150
80.8	9	.2162	.2151
81.8	10	.2165	.2152
82.8	11	.2167	.2153
83.8	12	.2170	.2155
84.8	13	.2172	.2156
85.8	14	.2175	.2157
86.8	15	.2177	.2158
87.8	16	.2180	.2160
88.8	17	.2182	.2161
89.8	18	.2185	.2162
90.8	19	.2187	.2163
91.8	20	.2190	.2165
92.8	21	.2193	.2166
93.8	22	.2195	.2167
94.8	23	.2198	.2169
95.8	24	.2200	.2170
96.8	25	.2203	.2171
97.8	26	.2205	.2172
98.8	27	.2208	.2174
99.8	28	.2210	.2175
100.8	29	.2213	.2176
101.8	30	.2215	.2177
102.8	31	.2218	.2179
103.8	32	.2220	.2180
104.8	33	.2223	.2181
105.8	34	.2226	.2183
106.8	35	.2228	.2184
107.8	36	.2231	.2185
108.8	37	.2233	.2186
109.8	38	.2236	.2188
110.8	39	.2238	.2189
111.8	40	.2241	.2190
112.8	41	.2243	.2191
113.8	42	.2246	.2193
114.8	43	.2248	.2194
115.8	44	.2251	.2195
116.8	45	.2253	.2196
117.8	46	.2256	.2198
118.8	47	.2259	.2199
119.8	48	.2261	.2200
120.8	49	.2264	.2202
121.8	50	.2266	.2203
122.8	51	.2269	.2204
123.8	52	.2271	.2205
124.8	53	.2274	.2207
125.8	54	.2276	.2208
126.8	55	.2279	.2209
127.8	56	.2281	.2210
128.8	57	.2284	.2212
129.8	58	.2286	.2213
130.8	59	.2289	.2214
131.8	60	.2292	.2216
132.8	61	.2294	.2217
133.8	62	.2297	.2218
134.8	63	.2299	.2219
135.8	64	.2302	.2221
136.8	65	.2304	.2222
137.8	66	.2307	.2223
138.8	67	.2309	.2224

Table 1b. – Sample calculation of average specific heat through given temperature rise for calculation of heat of hydration.

Temp. °C	Temp. Rise, °C	Spec. Heat	Av. Spec. Heat
		J/kg · °C)	
22.1	0	895.5	895.5
23.1	1	897.4	896.5
24.1	2	899.3	897.4
25.1	3	901.3	898.4
26.1	4	903.2	899.4
27.1	5	905.1	900.3
28.1	6	907.0	901.3
29.1	7	909.0	902.3
30.1	8	910.9	903.2
31.1	9	912.9	904.2
32.1	10	914.8	905.2
33.1	11	916.7	906.1
34.1	12	918.6	907.1
35.1	13	920.6	908.1
36.1	14	922.5	909.0
37.1	15	924.4	910.0
38.1	16	926.3	910.9
39.1	17	928.2	911.9
40.1	18	930.2	912.9
41.1	19	932.1	913.8
42.1	20	934.0	914.8
43.1	21	935.8	915.7
44.1	22	937.7	916.6
45.1	23	939.5	917.5
46.1	24	941.4	918.5
47.1	25	943.2	919.4
48.1	26	945.1	920.3
49.1	27	947.1	921.3
50.1	28	949.0	922.3
51.1	29	951.0	923.3
52.1	30	952.9	924.2
53.1	31	954.8	925.2
54.1	32	956.7	926.1
55.1	33	958.7	927.1
56.1	34	960.6	928.1
57.1	35	962.5	929.0
58.1	36	964.4	930.0
59.1	37	966.3	930.9
	38	968.2	931.9

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†An equation for specific heat of this particular concrete, as determined by specific heat tests and calculated by the method of least squares, is $0.1957 + 0.000\,2537\,T$ in English units.

APPENDIX

X1. COMPUTER PROGRAM DESCRIPTION AND OPERATION FOR ADIABATIC TEMPERATURE RISE TESTING OF CONCRETE

(Nonmandatory Information)

X1.1 Scope

X1.1.1 The program for the adiabatic temperature rise testing of concrete has two main functions: (1) to acquire temperature rise data, and (2) present these data in graphical and printed forms. The first function of acquiring the data is accomplished using the following equipment:

HP-85A Desktop Computer with I/O ROM, Printer/Plotter ROM, Advanced Programming ROM, Mass Storage ROM, IEEE-488 interface, and 16K memory module.

HP-3497A Data Acquisition and Control Unit with a 20-channel multiplexer card in slot 0 configured for four-wire resistance measurement.

HP-82901M Dual Flexible Disk Drive

The second function of printing and plotting the data uses the following equipment:

HP-7225B Plotter, and HP-82905A Printer

Other equipment could be used with this program, but would require modification of the software. The program was written to allow for a maximum of two tests to be performed simultaneously. The program takes temperature measurements at predetermined intervals, and stores these measurements and total elapsed time on a disk. Program will print or plot the stored data either during the test or after its completion.

X1.1.2 A temperature rise test usually is run for 28 days. Because of this extended length of time, it is important that the data be protected from loss and that the program can restart automatically in the event of a power failure. To guard against loss of data, the data is stored on a flexible disk immediately after data is acquired. To guard against a defective disk, all data are put on two flexible disks, one on each side of the dual drive. In the event of a power failure, the Auto-Start feature on the HP-85A is used. When power is restored, program is read from tape cassette in tape drive of HP-85A, and execution begins. When main program begins execution in this manner, it initially loads data file from tape that has reading intervals stored on it and then checks time and date to see if any readings were missed. The time and date are read from the HP-3497A, which has a battery-backed clock that was set at start of test. If any readings were missed or if it is time for another reading, program takes a reading and fills any missed readings with this reading.

X1.1.3 The temperature rise test uses nickel bulb resistance thermometers for sensing temperature. The resistance of these thermometers is measured by the HP-3497A using the four-wire ohms method for the most accuracy. A third-order polynomial is used to convert these resistance readings to temperature. Four thermometers are used in the test, two are placed in specimen and two are suspended in room to measure room temperature. One of the specimen thermometers and one of the room thermometers are conncected to the HP-3497A for data acquisition. The other two thermometers are used by the room temperature control equipment for control and recording.

X1.2 Procedure

X1.2.1 Operation of the program was designed to be self explanatory; however, a step-by-step procedure is as follows:

Step 1. Load main program from tape by typing: LOAD "Autost," followed by using END LINE key. (Hereafter, all typed commands are followed by pressing END LINE key).

Step 2. Press RUN key.

Step 3. You now have 10 seconds to push function key INIT to start initialization sequence. This key is marked k7 and for proper operation, the shift key must be held down while this key is pressed.

Step 4. Then, you will be asked for the following:

a. Room A Test Title
b. Room A Specimen ID
c. Room B Test Title
d. Room B Specimen ID

Type in titles and ID's when asked, and follow each answer by pressing END LINE key. Answers to these questions must be 18 characters or less.

Step 5. You will then be asked to enter data file names. These are the names used for the files that the test data will be stored on. Enter these names, 7 characters or less, and press END LINE key.

Step 6. The reading intervals are now entered. You will be asked for reading frequency and number of readings at that frequency. A maximum of 300 readings can be stored, so plan your work carefully. The following example illustrates this step:

To read every hour for first week, every 3 hours for second week, and every 6 hours for third and fourth weeks, make the following entries:

1,168	1-hour intervals for 168 readings (7 days times 24 readings per day = 168)
3,56	3-hour intervals for 56 readings (7 days times 8 readings per day = 56)
6,56	6-hour intervals for 56 readings (14 days times 4 readings per day = 56)
0,0	Terminates entries

Step 7. At this point, data files are created on disks and a special file named BASDAT is created on tape. This file contains the data file names and the reading interval information entered in step 6. When the statement "DATA FILE CREATION COMPLETE" is displayed, this process is complete.

Step 8. You will then be asked to enter the current time and date in the sequence MMDDHHMMSS. A "zero-fill" and military time must be used for proper entry; e.g., July 9 and 1:32 p.m., the proper entry is 0709133200. The date and time entry sets the clock and calendar in the HP-3497A.

Step 9. The preliminary setup is now complete. The program has now stopped and the next step is to press the RUN key. This time however, when the statement 10 SECONDS TO INITIALIZE is displayed, do NOT press the INIT key.

Step 10. The specimen should now be prepared. During the preparation process, note the exact time that mix is completed and the temperature of the mix at that time. The computer screen will display a list of options after step 9 is executed. The option of interest at this time is the START option, which corresponds to function key k8. Hold shift key down and press k8. You will then be asked to enter the starting time of the specimen. Enter this date and time in the same manner as date and time were entered in step 8. The starting mix temperature and room temperature should also be entered when asked for.

Step 11. The program is now off and running. If a second specimen is to be tested, start it in the same manner as described in step 10.

Step 12. The other options mentioned in step 10 that are displayed on the screen can be used during the test to perform several data display functions:

PRINDAT.–Pressing k5 (SHIFT and k5) causes all data taken to this point in the test to be printed on an external HP-82905A printer. This can be done at any time during a test, but should be done when it will not interfere with a regularly scheduled temperature reading.

T-PRINT.–This function provides an independent reading of specimen and room temperatures and the elapsed time, and prints these values on the computer's internal printer. Press k1 and you will be asked how many minutes you want between printings. If you enter 10, then every 10 minutes a reading of these values will be made and printed out. This will continue until k1 is pressed again and a new time is entered. If a zero is entered, the process is terminated. This is a nice feature to use for providing additional backup of the data. Please note that none of the data printed using this function will be stored on the floppy disks.

PLOT.–Pressing k2 will make a plot of the data to this point in the test on an external HP-7225B plotter. This should be done at a time that will not conflict with a regularly scheduled temperature reading.

RESIS.–Pressing k3 causes immediate temperature and resistance readings on all four thermometers, and these values are then printed on the computer's internal printer. This function is useful for finding a problem within the system.

X1.2.2 After test is completed, the data can be printed and plotted as desired, and is available on disk for future manipulations if required.

X1.3 Connection of Thermometers

X1.3.1 Connection of the thermometers to the data acquisition unit should be done as follows:

Channels 0 and 10.–Room A thermometer
Channels 1 and 11.–Specimen A thermometer
Channels 2 and 12.–Room B thermometer
Channels 3 and 13.–Specimen B thermometer

Channels 0, 1, 2, and 3 are used as voltage reading inputs, and channels 10, 11, 12, and 13 are used as current source outputs. The inputs and outputs are connected in parallel at the thermometer leads. It is important to note that if two tests are to be run simultaneously, the specimen initially used to start test must be placed in the room designated as Room A.

X1.4 Example of Computer Output

X1.4.1 Figure X1.1 is an example of adiabatic temperature rise.

X1.4.2 Figure X1.2 is a plot of adiabatic temperature rise.

X1.4.3 Figure X1.3 is a computation of specific heat.

X1.4.4 Figure X1.4 shows computer generated specific heat curves.

X1.4.5 Figure X1.5 consists of average specific heat and heat of hydration. The computer generated data had been established in English units; metric data were added.

Test: BUFFALO BILL DAM
Specimen: SAMPLE 1
Test Started: 6 FEB 1989

Day	Specimen Temp., °F	Temperature Rise, °F
0	48.0	0.0
1	66.6	18.6
2	78.3	30.3
3	82.8	34.8
4	86.5	38.5
5	89.7	41.7
6	92.2	44.2
7	94.3	46.3
8	96.0	48.0
9	97.4	49.4
10	98.6	50.6
11	99.6	51.6
12	100.4	52.4
13	101.1	53.1
14	101.6	53.6
15	102.0	54.0
16	102.4	54.4
17	102.6	54.6
18	102.7	54.7
19	102.9	54.9
20	102.9	54.9
21	102.9	54.9
22	102.9	54.9
23	102.9	54.9
24	102.9	54.9
25	102.9	54.9
26	102.9	54.9
27	102.8	54.8
27.85	102.8	54.8

Figure X1.1. - Computer generated adiabatic temperature rise.

Buffalo Bill Dam — High sand mix — Measured specific heat data.

Specimen No.	Average Temperature (°F)	Measured Specific Heat Btu/(lbm · °F)
1	47.44	0.250
2	47.24	.244
3	47.07	.247
1	65.48	.256
2	65.66	.252
3	64.96	.253
1	82.11	.261
2	82.43	.257
3	81.38	.259
1	97.31	.269
2	97.70	.266
3	96.23	.265
1	111.36	.276
2	111.70	.278
3	109.80	.270
1	124.62	.274
2	124.95	.265
3	122.36	.272
1	136.70	.271
2	136.91	.278
3	133.82	.280
3	144.04	.286

Points used in regression analysis and specific regression heat equations.

Specific heat equations:

$S = 0.231 + (0.348 \times 10^{-3})\,T$ or

$S = 0.224 + (0.516 \times 10^{-3})\,T - (893 \times 10^{-9})\,T^2$ or

$S = 0.226 + (0.436 \times 10^{-3})\,T - (66.3 \times 10^{-12})\,T^2 - (3.13 \times 10^{-9})\,T^3$

where:

T = concrete temperature in °F

S = specific heat in Btu/(lbm · °F)

Figure X1.3. - Computer generated specific heat.

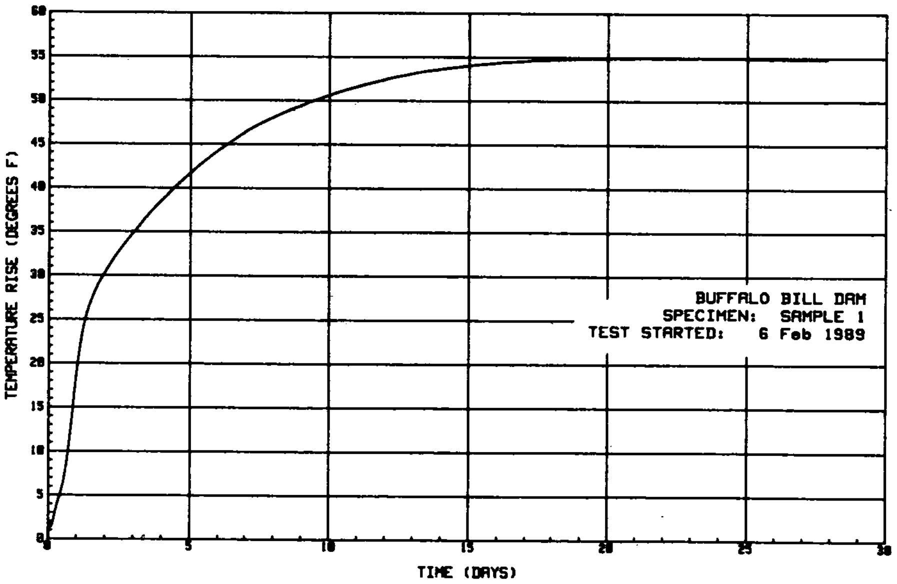

Figure X1.2. - Computer generated adiabatic temperature rise curve.

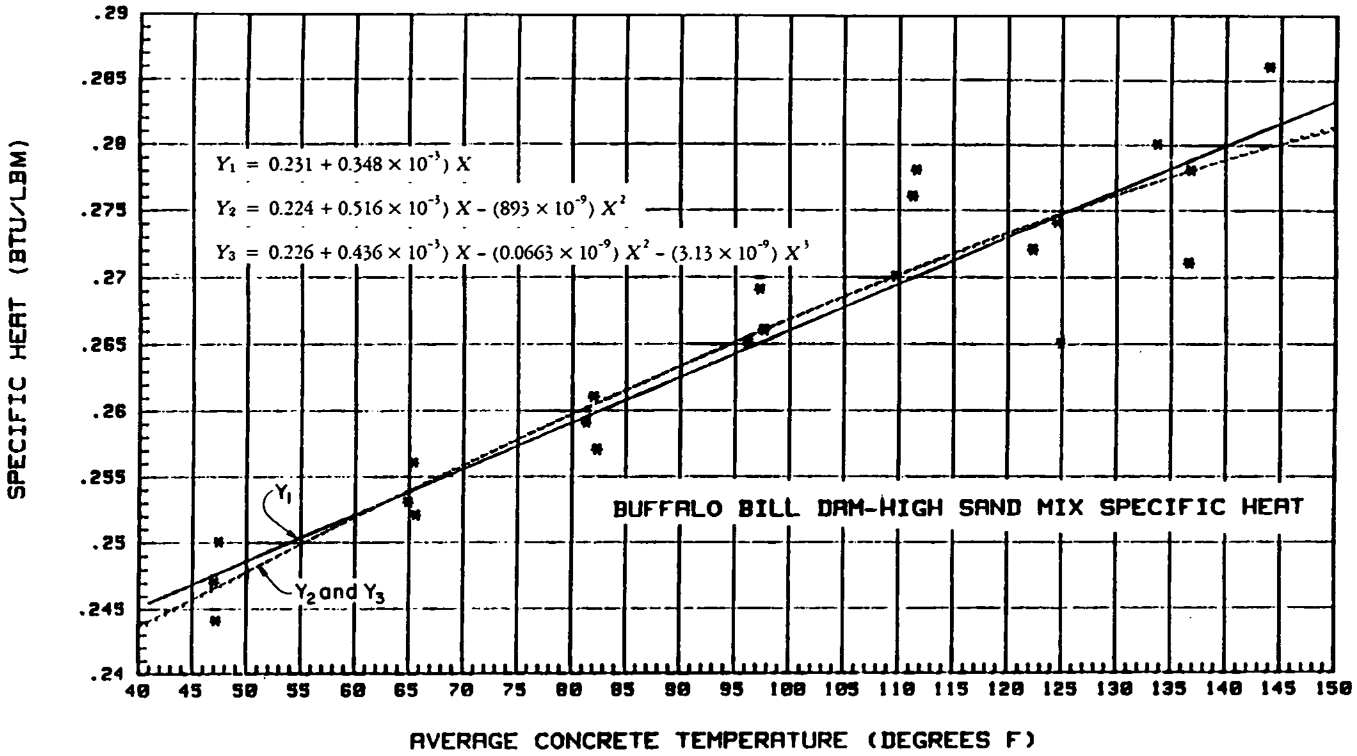

Figure X1.4. - Computer generated specific heat curves.

Buffalo Bill Dam — High Sand Mix

Age	Concrete Temperature, *T*		Specific Heat, *S*		Temperature Rise, *Tr*		Average Specific Heat, *Sa*		Heat of Hydration, *H*	
(days)	(°F)	(°C)	Btu/(lbm · °F)	J/(kg · °C)	(°F)	(°C)	Btu/(lbm · °F)	J/(kg · °C)	(Btu/lbm)	(kJ/kg)
0	48	8.9	0.2480	1038	0	0	0.2480	1038	0	0
1	66.6	19.2	.2544	1065	18.6	10.3	.2512	1052	54.31	125.90
3	82.8	28.2	.2601	1089	34.8	19.3	.2540	1064	102.74	238.58
7	94.3	34.6	.2641	1106	46.3	25.7	.2560	1072	137.77	320.20
14	101.6	38.7	.2666	1116	53.6	29.8	.2573	1077	160.29	373.09
21	102.9	39.4	.2670	1118	54.9	30.5	.2575	1078	164.32	382.15
28	102.8	39.3	.2670	1118	54.8	30.4	.2575	1078	164.02	380.90

Notes: Total batch mass = 649.04 lbm, (294.40 kg)
Cement and fly ash batch mass = 55.84 lbm, (25.33 kg)
$S = 0.231\ 2608 + 0.000\ 347\ 80\ T$
$Sa = 1/2\ (S + 0.2480)$, English units $Sa = 1/2\ (S + 1038)$, metric units
$H,\ \text{Btu/lbm} = \dfrac{Tr \times Sa \times 649.04}{55.84}$ $H,\ \text{kJ/kg} = \dfrac{Tr \times Sa \times 294.40}{25.33}$

Figure X1.5. - Calculations of average specific heat and heat of hydration.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4913-92

PROCEDURE FOR

WATER PERMEABILITY OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4913; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers the procedure for determining the permeability of concrete when subjected to water at a pressure of 400 lbf/in^2 (2758 kPa). The calculations are based upon an application of Darcy's law for unidirectional flow at constant head.

2. Applicable Documents

2.1 *USBR Procedures*:
4192 Making and Curing Concrete Test Specimens in Laboratory
2.2 *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
D 5 Standard Test Method for Penetration of Bituminous Materials[2]

3. Summary of Procedure

3.1 A 6-inch (152-mm) section of a 6- by 12-inch (152- by 305-mm) cylinder is placed in a frame that allows the water to enter one face under a head of 400 lbf/in^2 (2758 kPa) and exit at opposite face. When inflow reaches a constant rate, the permeability is calculated as the rate of flow through the specimen. The procedure also describes larger test cylinders which can be used for concretes containing aggregate up to 6-inch (150-mm) maximum size.

4. Significance and Use

4.1 Permeability test data are useful for estimating rate of leakage through concrete, rate of solution and constituents removed from cement in a concrete structure by percolating water, and basic information on the internal structure of concrete. Tests at a standard age provide a comparison of the internal structures of various concretes.

4.2 There are three methods by which water may pass through concrete or other semiporous materials: (1) by percolation under sufficient pressure to force liquid from exposed surface through the more or less continuous void spaces to the free surface, (2) by diffusion through the capillaries as a vapor due to difference in vapor pressure on opposite faces of the concrete, and (3) by capillarity and evaporation at the free surface. As most experimental work of this nature is confined to the first method, the pressure-type permeability test is usually used.

4.3 Wide variations may occur in permeability test results even between specimens cast from the same mix. This variation may be explained by assuming that the size and number of voids and capillaries differ in specimens of presumably the same composition; however, the amount of water percolating through concrete is generally very small. The flow is a function of pressure and the condition of the concrete, and depends on such factors as method of casting, length and type of curing, cement content, water-cement ratio, and aggregate grading. The permeability of concrete is usually decreased by a reduction in water-cement ratio, an increase in cement content, or a decrease in the maximum size aggregate.

5. Terminology

5.1 Terms used in this procedure, with the exception of permeability, are as defined in ASTM C 125.

5.2 *Permeability*.–The volume of water, in cubic feet (cubic meters), passing through a 1-ft^2 or 1-m^2 cross section of the material in 1 year under the action of a unit hydraulic gradient. The value so derived is based on a standard temperature of 68 °F (20 °C), a factor generally not considered in field determinations.

6. Apparatus

6.1 The purpose of the permeability test apparatus is to force water through a specimen and to measure the rate of percolation at a selected pressure that can be easily controlled and regulated. The apparatus consists basically of a pressure source, a water reservoir calibrated to measure water input, specimen containers, frames and connecting pipes, and test units (figs. 1 and 2).

6.1.1 *Pressure System*.–The test pressure is supplied by a cylinder of compressed air or nitrogen at about 2,200 lbf/in^2 (15 168 kPa) from which the main line pressure is reduced to about 600 lbf/in^2 (4137 kPa) using a master

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[1] *Annual Book of ASTM Standards*, vol. 04.02

[2] *Annual Book of ASTM Standards*, vol. 04.03

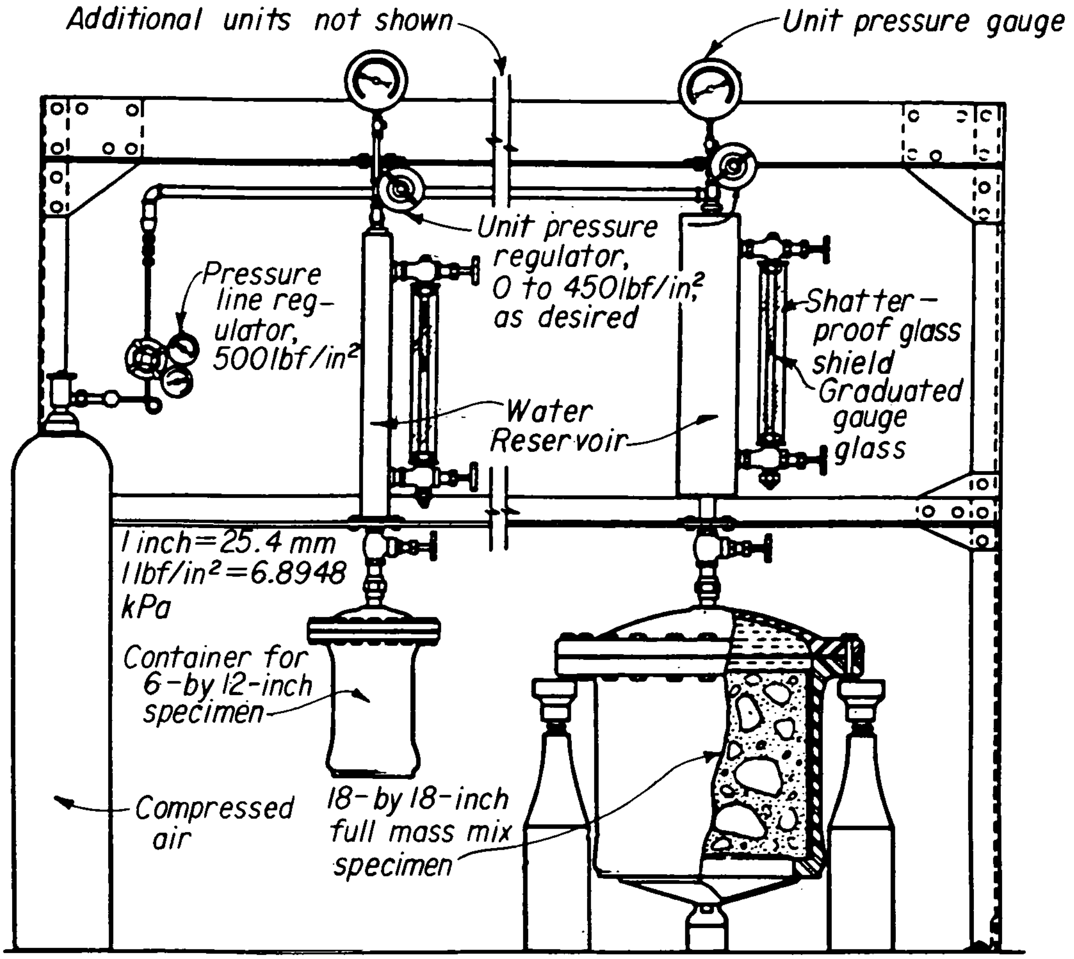


Figure 1. – Schematic layout of permeability apparatus.

regulator. The main line is connected to the reservoir through individual regulators of the heavy oxygen-cutting type that are capable of transmitting pressures from 0 to 500 lbf/in^2 (0 to 3447 kPa). This arrangement lends itself to flexible operation because the pressure on the units may be varied individually to supply any desired pressure up to a maximum of 450 lbf/in^2 (3103 kPa). This apparatus is provided with double extra-heavy brass pipe, fittings, and valves; and all joints are made with a Teflon base pipe compound.

6.1.2 *Water Reservoir*.–Each test unit includes a water reservoir that consists of a 30-inch (762-mm) length of 4-inch (100-mm) brass tubing that is attached to a side arm gauge glass provided with a graduated scale. Each reservoir shall be connected with suitable fittings and valves for filling reservoir with water, for admitting air pressure up to 450 lbf/in^2 (3103 kPa), and for connecting to specimen container. Reservoir should be made of a noncorrosive material such as brass or stainless steel and be able to withstand an internal pressure of 500 lbf/in^2 (3447 kPa).

6.1.3 *Specimen Container*.–The specimen container (fig. 3) is designed so that water entering the top covers upper surface of specimen and passes through the concrete and out the bottom without any lateral flow. This cast nickel steel container is also designed to withstand a pressure of 500 lbf/in^2 (3447 kPa). The inside diameter of the container is sufficient to provide a 1/2-inch (12.7-mm) clearance on all sides of the specimen for a sealing compound. A machined ledge is provided at the bottom to ensure a seat for the test cylinder and to prevent extrusion of sealing compound when under pressure. The top is secured against a neoprene gasket. Water passing through specimen is caught in a collecting container.

6.1.4 *Distilled Water or Sand Filter and Cotton Batting*.–If distilled water is not available or if steel test units must be used, a 1/2- to 2-inch (13- to 51-mm) deep sand filter shall be placed over a thin layer of cotton batting covering the specimen to remove rust or other impurities.

6.1.4.1 The sand filter should be composed of Ottawa sand, graded to contain about 70 percent of No. 30 to No. 50 (600- to 300-μm) and 30 percent of No. 50 to No. 100 (300- to 150-μm) sand particles.

6.1.5 *Supplementary Equipment*.–A portable electric retort with double pot to heat stearin pitch sealing compound, a vacu-blaster for cleaning surfaces, air-operated wrenches for tightening flange bolts, and miscellaneous trucks and dollies are required.

Figure 2. - View of permeability apparatus showing compressed-air cylinder (right) and testing units.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsiblity of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

8. Test Specimens

8.1 Unless another size is specified, mix and place concrete in 6- by 12-inch (152- by 305-mm) cylinder molds in accordance with the applicable provisions of USBR 4192, except that cylinder molds shall have 1/4-inch (6.4-mm) wide by 1/2-inch (12.7-mm) deep collars that are 3 inches (76 mm) from each end to provide grooves in the conctete, see figure 4.

8.2 Concrete for the 18- by 18-inch (457- by 457-mm) permeability cylinder specimens is also mass mixed and may contain aggregate up to 6-inch (150-mm) maximum size.

NOTE 1.–Figure 3 shows the dimensions of the containers for the 8- and 12-inch (203- and 305-mm) diameter test specimens. The test procedure for testing these specimen sizes is the same as for testing the 18- by 18-inch (457- by 457-mm) specimens.

8.3 The 6- by 6-inch (152- by 152-mm) concrete permeability specimens shall be broken from cylinders cast in 6- by 12-inch (152- by 305-mm) metal cylinder molds. The grooves formed in the concrete cylinders by the collars cause planes of reduced cross section which permit cylinders to be broken so that test specimens that are about 6 inches (152 mm) deep with freshly broken surfaces at both ends may be produced. Figure 5 illustrates one of these cylinders. To facilitate breaking the cylinders at the reduced sections, supports should be placed under the ends and center of grooved cylinder and a compressive load applied on the groove, as shown on figure 6. The sealing surface of the upper end of the specimen that is in position for testing and formed by rim on circumference of specimen by the collars shall be chipped or vacu-blasted before sample is placed in permeability container, as shown on figure 7. This method of preparation provides the most representative portion of the cylinder for permeability tests and eliminates the necessity of adjusting for "end effect" or "surface skin condition."

8.4 Because specimens 8 inches (203 mm) in diameter by 8 inches long, and larger, are considered too large to break because of the roughness presented by the large aggregate, the mortar from both the top and bottom of these cylinders shall be chipped or roughened by vacu-blasting until the aggregate is completely exposed, except for a 3/4-inch (19-mm) wide ring around the bottom edge, which is necessary to obtain a good seat on the supporting flange.

9. Preparation of Apparatus

9.1 The appropriate specimen container shall be carefully cleaned to remove any loose sealing compound before a sample is centered in it for testing in a down position or same position as cylinder was cast. Apply a 1/4-inch (6-mm) layer of plaster of Paris (note 2) to container flange. Seat specimen on flange so that specimen is centered in container (fig. 8). Fill annular space between specimen and container with a stearin pitch (a by-product of soap manufacture) compounded to yield a penetration of 20 to 25 when tested by ASTM D 5. The pitch should be heated using the electric retort to about 450 °F (232 °C), and poured around and between specimen and container (fig. 9). Several pours are usually necessary to ensure space is completely filled.

NOTE 2.–"Hydrostone," manufactured by the U.S. Gypsum Co., is recommended.

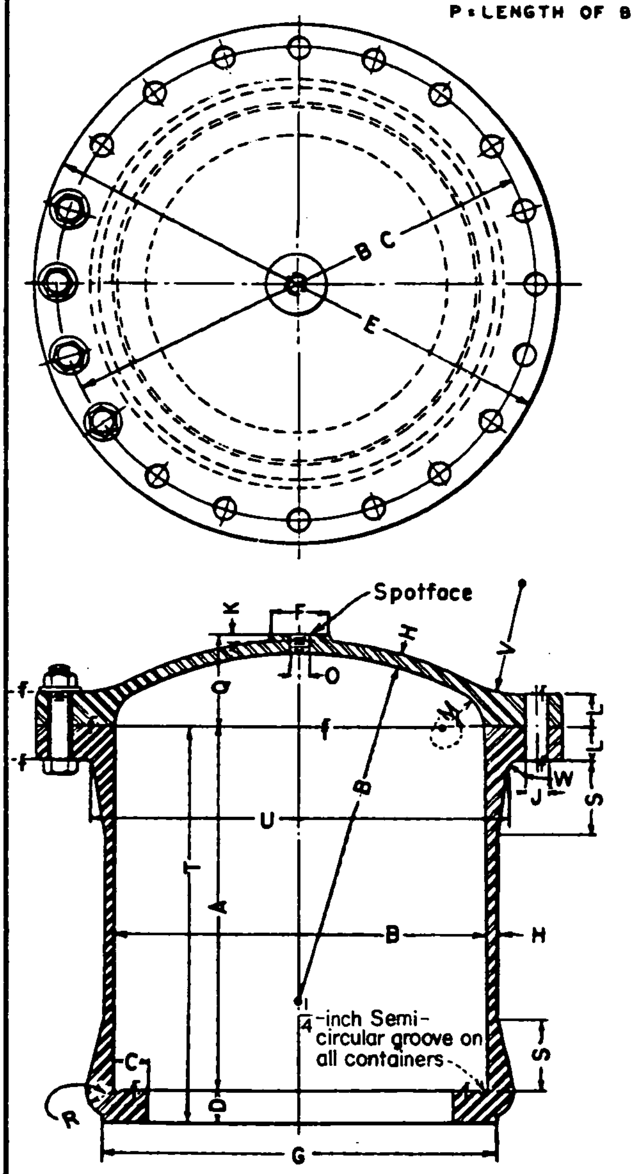
9.2 Place cap on the specimen container, tighten securely, and connect container to water reservoir.

10. Calibration and Standardization

10.1 Each water reservoir must be calibrated under operating pressure to determine the "tank factor," which is the relationship between gauge reading and water volume leaving the reservoir. Fill reservoir to above the zero

Specimen Size, inches	DIMENSIONS IN INCHES																						
	A	B	C	D	E	F	G	H	J	K	L	BC	M	N	O	P	Q	R	S	T	U	V	W
18	$19\frac{1}{4}$	19	$1\frac{3}{4}$	$1\frac{3}{4}$	27	3	$20\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{16}$ inch drill for 1-inch bolt	$\frac{1}{4}$	$1\frac{3}{4}$	$24\frac{1}{4}$	$2\frac{1}{4}$	20	$\frac{3}{4}$-inch pipe tap	$4\frac{3}{4}$	$4\frac{3}{4}$	$1\frac{1}{2}$	$3\frac{3}{4}$	21	$21\frac{1}{4}$	$5\frac{3}{4}$	$\frac{1}{2}$
12	$13\frac{1}{4}$	13	$1\frac{1}{2}$	$1\frac{1}{2}$	19	3	14	$\frac{1}{2}$	$\frac{25}{32}$ inch drill for $\frac{3}{4}$ inch bolt	$\frac{1}{4}$	$1\frac{1}{4}$	$17\frac{1}{4}$	2	20		$3\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{3}{4}$	$14\frac{3}{4}$	$14\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$
8	$9\frac{1}{4}$	9	1	$1\frac{1}{8}$	$14\frac{1}{4}$	$2\frac{1}{2}$	10	$\frac{1}{2}$	$\frac{21}{32}$ inch drill for $\frac{5}{8}$ inch bolt	$\frac{1}{4}$	$\frac{7}{8}$	$12\frac{3}{4}$	$1\frac{3}{8}$	16		$2\frac{5}{8}$	$2\frac{3}{4}$	$1\frac{3}{16}$	$2\frac{3}{8}$	$10\frac{3}{8}$	$10\frac{1}{2}$	$2\frac{1}{4}$	$\frac{3}{8}$
6	13	7	1	1	12	$2\frac{1}{4}$	8	$\frac{1}{2}$	$\frac{21}{32}$ inch drill for $\frac{5}{8}$ inch bolt	$\frac{1}{4}$	$\frac{7}{8}$	$10\frac{1}{2}$	$\frac{7}{8}$	16		$2\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$2\frac{1}{8}$	14	$8\frac{1}{2}$	2	$\frac{3}{8}$

N = NUMBER OF BOLTS
P = LENGTH OF BOLT



$\frac{1}{4}$-inch Semi-circular groove on all containers

GENERAL NOTES

Cap and shell to be of chrome nickel cast steel.

Bolts to be S.A.E. cap screws, hex. head and hex. nut complete with washers.

Steel castings of a density sufficient to withstand a hydrostatic pressure of 500 lbf/in^2.

Castings must be annealed before machining.

1 in = 25.4 mm
1 lbf/in^2 = 6.8948 kPa

Figure 3. – Design drawing of specimen container.

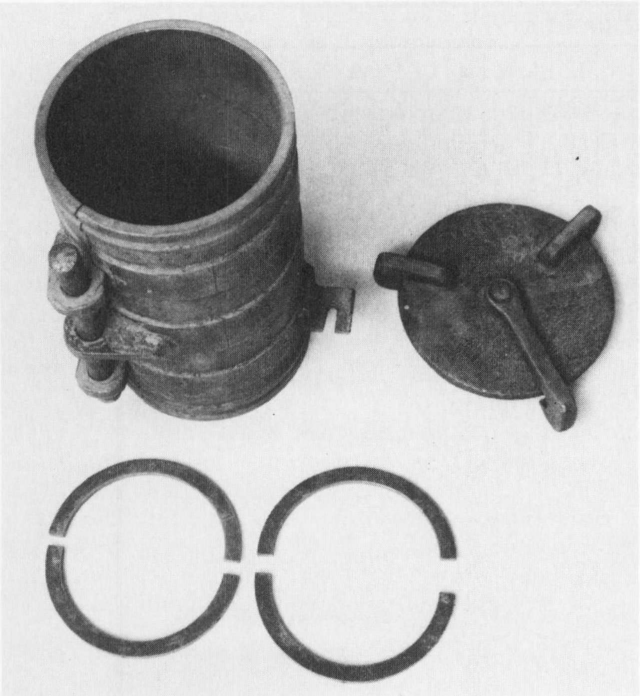


Figure 4. – A 6- by 12-inch (152- by 305-mm) cylinder mold with collars (rings) that provide grooves in the concrete.

reading on reservoir scale. Apply air pressure to 400 lbf/in^2 (2758 kPa) on the reservoir. Bleed water from system until water in reservoir is at zero mark on scale. Remove water from system through the outlet valve in 500-cm^3 increments into a graduated cylinder. After each increment has been removed, level of water in gauge glass shall be read on the scale and recorded. The calibration constant or tank factor shall be calculated from these readings as cubic centimeters per centimeter.

11. Procedure

11.1 After all connections have been secured, fill system with water at 73.4±2 °F (23.0±1.1 °C). Apply air pressure of 400 lbf/in^2 (2758 kPa) to the water reservoir. Read water level on gauge glass. Inflow measurements should be taken frequently during first day and twice a day for remainder of test period. Readings shall be recorded on worksheet (fig. 10). A careful inspection of the bottom surface of test specimen should be made to determine exact time of outflow. In some cases, outflow may not occur.

11.2 Testing shall continue for about 500 hours. At completion of test, container shall be detached from test unit and heated with hot water to soften pitch so that specimen may be removed.

12. Calculation and Interpretation of Results

12.1 Plot inflow data as shown on figure 11. Select a 100-hour period for which flow rate was essentially constant. Record the test age as the age of the concrete at midpoint of 100-hour period.

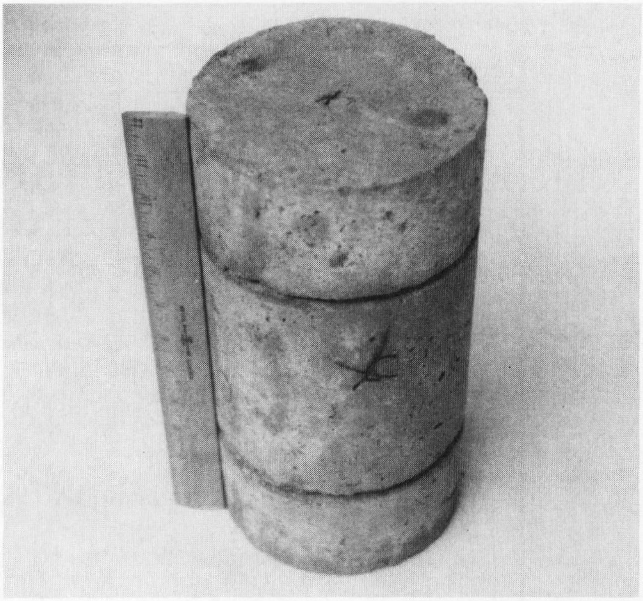


Figure 5. – A cast concrete permeability cylinder showing grooves formed by the collars shown on figure 4.

12.2 Calculate coefficient of permeability (fig. 12) as follows:

$$K = \frac{QL}{AH} \qquad [1, 2, 3, 4, 5]^{3} \qquad (1)$$

where:

K = coefficient of permeability in feet per second (meters per second),
Q = increment of flow in cubic feet per second (cubic meters per second),
L = length of specimen in feet (meters),
A = cross-sectional area of specimen in square feet (square meters), and
H = applied pressure per foot (meter) of water (note 3).

If

Q' = flow in cubic feet per year (cubic meters per year), and
Q_1 = increment of flow in cubic centimeters per hour,

Then,

$$Q' = Q_1\left(\frac{\text{cm}^3}{\text{h}}\right)\left(\frac{24\text{h}}{\text{d}}\right)\left(\frac{365\text{d}}{\text{yr}}\right)\left(\frac{\text{ft}^3}{28\ 317\ \text{cm}^3}\right)$$

$$= 0.309355\ Q_1\ \text{ft}^3/\text{yr, or}$$

$$= Q_1\left(\frac{\text{cm}^3}{\text{h}}\right)\left(\frac{24\text{h}}{\text{d}}\right)\left(\frac{365\text{d}}{\text{yr}}\right)\left(\frac{\text{m}^3}{1 \times 10^6\ \text{cm}^3}\right)$$

$$= 0.008760\ Q_1\ \text{m}^3/\text{yr}$$

NOTE 3.–A pressure of 400 lbf/in^2 (2758 kPa) equals a head of 924 feet (281.6 m) of water.

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[3] Numbers in brackets refer to entries in References, section 15.

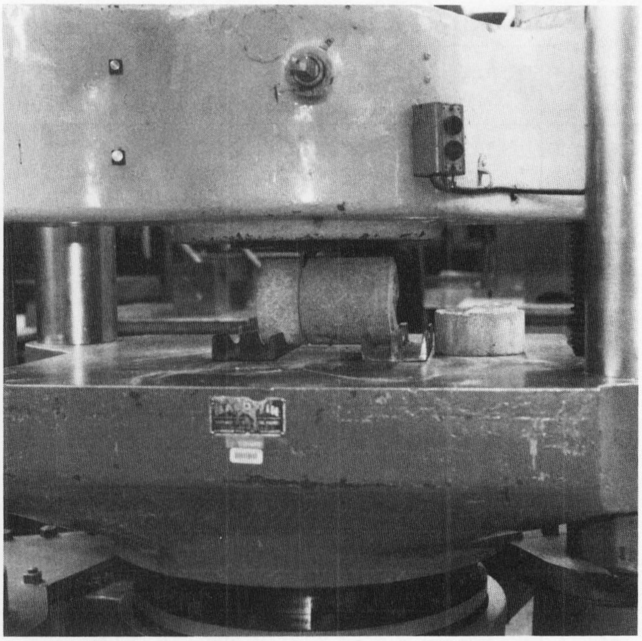

Figure 6. - Method of breaking permeability specimen. Note that one end has already broken off along the grooved plane.

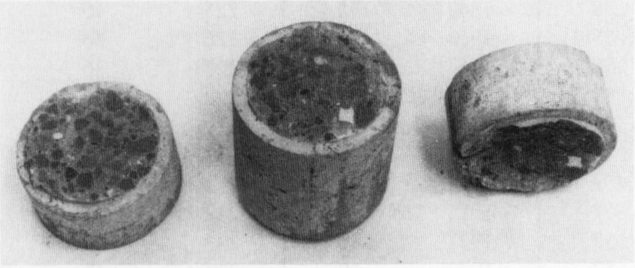

Figure 7. - Broken permeability cylinder. Note that center section, which is to be used for test, has not yet been chipped to remove smooth surfaces formed by collars.

Figure 8. - View of bottom of specimen container showing method of applying plaster of Paris to container flange.

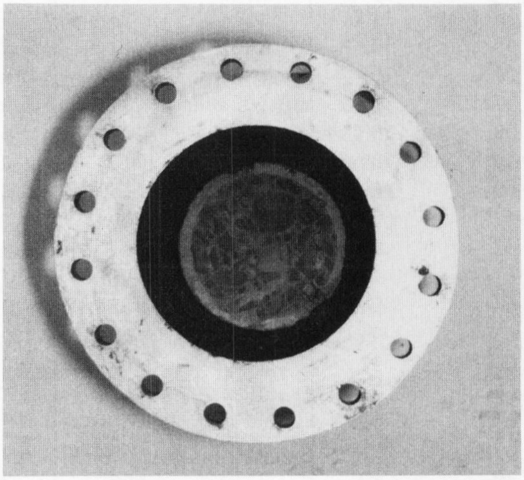

Figure 9. - View of top of specimen container showing specimen sealed into position with stearin pitch.

12.3 For the usual laboratory tests, a correction for temperature from 73.4±2 °F (23.0±1.1 °C) to the standard temperature of 68 °F (20 °C) need not be made because the small resulting value difference is not considered of practical importance.

12.4 The test age of a specimen is the number of days from casting date to the time used on the inflow-time curve to determine value of rate of inflow. When a series of concrete mixes are to be compared for permeability at early ages, the hydration of the cement alters the permeability with age, and the results should be converted to a comparable test age. Table 1 and figure 13 show factors taken from average values that can be used for adjusting permeability values to 60-days age. Because cements and pozzolans hydrate at different rates, more comparable results can be obtained when time permits delaying permeability test until specimens are in excess of 240-days age, when hydration is essentially complete.

12.5 The adjustment for end effect (table 2 and fig. 14) depends on specimen length if the length is less than 30 inches (762 mm). This adjustment is not required if the specimens tested have freshly broken surfaces on the top and bottom as opposed to chipped or vacu-blasted surfaces. The chipping of the formed surface created by the collar on top of specimen is not considered to be a chipped or vacu-blasted surface.

12.6 The amount of outflow is determined by measuring the mass or volume of water in collecting jar or container at regular intervals. This value is entered on the worksheet (fig. 10); it is not used in the calculation of permeability but sometimes provides useful information.

13. Report

13.1 A report on this procedure is best accomplished by a letter submitting the properites of the mix design investigations. The report shall include:

Table 1. – Age factors for adjusting permeability values to 60-days age (from fig. 13).

Age, days	Factor	Age, days	Factor	Age, days	Factor	Age, days	Factor	Age, days	Factor
39	150	80	81	121	64	162	55	203	49
40	147	81	80	122	64	163	55	204	48
41	143	82	80	123	64	164	55	205	48
42	140	83	79	124	63	165	55	206	48
43	137	84	78	125	63	166	55	207	48
44	135	85	77	126	63	167	55	208	48
45	133	86	77	127	62	168	55	209	48
46	131	87	76	128	62	169	55	210	48
47	128	88	76	129	62	170	54	211	47
48	125	89	75	130	61	171	54	212	47
49	122	90	75	131	61	172	54	213	47
50	119	91	75	132	61	173	54	214	47
51	116	92	74	133	60	174	54	215	47
52	114	93	74	134	60	175	54	216	47
53	112	94	73	135	60	176	53	217	47
54	110	95	73	136	60	177	53	218	46
55	108	96	72	137	59	178	53	219	46
56	107	97	72	138	59	179	53	220	46
57	105	98	71	139	59	180	53	221	46
58	103	99	70	140	59	181	52	222	46
59	101	100	70	141	59	182	52	223	46
60	100	101	69	142	58	183	52	224	46
61	98	102	69	143	58	184	52	225	46
62	96	103	69	144	58	185	51	226	46
63	94	104	68	145	58	186	51	227	46
64	94	105	68	146	57	187	51	228	46
65	93	106	68	147	57	188	51	229	45
66	92	107	67	148	57	189	50	230	45
67	91	108	67	149	57	190	50	231	45
68	90	109	66	150	57	191	50	232	45
69	90	110	66	151	57	192	50	233	45
70	89	111	66	152	57	193	50	234	45
71	88	112	66	153	57	194	50	235	45
72	87	113	66	154	56	195	50	236	45
73	86	114	65	155	56	196	50	237	45
74	85	115	65	156	56	197	49	238	45
75	84	116	65	157	56	198	49	239	45
76	84	117	65	158	56	199	49	240	45
77	83	118	65	159	56	200	49		
78	82	119	65	160	56	201	49		
79	82	120	65	161	56	202	49		

- Source of concrete materials.
- Mixture proportions.
- Curing conditions, if other than continuously moist.
- Age at test.
- Coefficient of permeability.
- Plot of inflow.

14. Precision and Bias

14.1 The precision of this test procedure has not been determined.

14.2 There is no known bias.

15. References

[1] "Progress Report–Boulder Dam–Concrete Research Permeability Tests on Concrete," Technical Memo. No. 377, Bureau of Reclamation, Denver, CO, April 25, 1934.

[2] Ruettgers, A., E. N. Vidal, and S. P. Wing, "An Investigation of the Permeability of Mass Concrete With Particular Reference to Boulder Dam," *ACI Proceedings*, vol. 31, 1935.

[3] Vidal, E. N., and G. A. Sampson, "Apparatus and Technique for the Bureau of Reclamation Concrete Permeability Tests," *ASTM Proceedings*, vol. 36, part I, 1936.

[4] *Calculations of Permeability Test Results*, Bureau of Reclamation Concrete Laboratory Report No. C-80, Jan. 4, 1940.

[5] *Apparatus and Tentative Test Procedure for Permeability Tests of Concrete*, Bureau of Reclamation Materials Laboratories Report No. C-426 (Unpublished).

Table 2. -Adjustment factors for end effect (from fig. 14).

Lenth of specimen, inches (mm)	Factor[1], percent	Length of specimen, inches (mm)	Factor[1], percent
1 (25)	21	18 (457)	112
2 (51)	38	24 (610)	119
3 (76)	50	28 (711)	124
4 (102)	60	36 (914)	127
6 (152)	75	48 (1219)	134
8 (203)	86	60 (1524)	136
9 (229)	90	120 (3048)	143
12 (305)	100	240 (6096)	147
15 (381)	106	480 (12 192)	149

[1] The value of this factor approaches 150 percent as the length approaches infinity: Ratio of specimen length to its length plus 6 inches for the end effect is $\infty/(\infty + 6) = 100$. For the standard 12-inch specimen, the ratio of specimen length to its length plus 6 inches for end effect would be $12/(12 + 6) = 0.667$. Since the end effect factor for this standard 12-inch specimen is 100 percent, the factor at infinity must be the ratio for an infinitely long specimen divided by the ratio for the 12-inch specimen, or $100/0.667 = 150$.

NOTE: The permeability computed from the test data for the length of specimen at any age, divided by the appropriate factor, should be equal to the permeability for the same concrete at the same age when tested in a 12-inch-long specimen when the end effect equals 6 inches of additional representative concrete.

Spec. or Solic. No. DESIGN STAGE	Structure DAM	Tested by T. DOLEN & K. MITCHELL Date 11-9 to 12-3-82
Project CENTRAL UTAH	Item RCC MIX DESIGN INVEST. Location DENVER LAB	Computed by K. MITCHELL Date 12-3-82
Feature UPPER STILLWATER DAM	Station ~ Offset ~ Depth ~ to ~	Checked by T. DOLEN Date 12-3-82

WATER PERMEABILITY OF CONCRETE

Mix No. RCC No. L-4 MSA 1½ inches ~~(mm)~~ Source: CRUSHED SANDSTONE-UPPER STILLWATER

Cement No. M-7120 Type II LA Brand/Source LAB STD./DEVILS SLIDE, UT Mass 132.0 lbm ~~(kg)~~

Pozzolan No. M-6498 Class F Source/Supplier LAB STD./CHICAGO, IL Mass 295.0 lbm ~~(kg)~~ 69 %

Mix Proportions: — % — to — inch (mm), 55 % 1½ to 3/4 inch ~~(mm)~~, 39 % 3/4 to 3/8 inch ~~(mm)~~, 6 % 3/8 to 4 inch ~~(mm)~~, __ % __ to __ inch (mm) Sand 34.5 %

Mix Properties: W/(C+P) 0.44, Density 148.41 lbm/ft³ ~~(kg/m³)~~, Slump 0 inches ~~(mm)~~

Air Content: Press. — % Grav. 1.0 %

Curing: CONTINUOUS FOG CURE AT 100% RELATIVE HUMIDITY AT 73.4 °F

Specimen No. 1, Size 6x6.0 inches ~~(mm)~~, Date Cast 4-1-82, Test Age 239 days Unit No. 3, Tank Factor 119.43 cm³/cm

Test Press. 400 lbf/in² ~~(kPa)~~ × 2.31 or ~~0.102~~ = 924 feet ~~(m)~~ of Head, Purpose INVESTIGATIONS

Date	Time	Test Hours Individual (I) Cumulative (C)		Inflow				Outflow		Remarks
				Gauge Reading,	Diff. in Gauge Reading,	Tank Factor 119.43 Times Diff. in Gauge Reading, cm³		Direct Mass or Volume Measure, cm³		
		I	C	cm	cm	I	C	I	C	
11-9-82	3:00pm	0	0	7.30	0	0	0			Age at start
11-9	5:00pm	2	2	7.40	0.10	11.9	11.9			of test was
11-10	7:00am	14	16	7.70	0.30	35.8	47.7			222 days
11-12	8:00am	49	65	8.15	0.45	53.7	101.4			
11-15	8:00am	72	137	8.50	0.35	41.8	143.2	Not Measured		Outflow Noted
11-16	8:00am	24	161	8.60	0.10	11.9	155.1			
11-17	8:00am	24	185	8.70	0.10	11.9	167.0			
11-18	8:00am	24	209	8.75	0.05	6.0	173.0			
11-19	8:00am	24	233	8.80	0.05	6.0	179.0			
11-22	8:00am	72	305	9.15	0.35	41.8	220.8			
11-23	8:00am	24	329	9.20	0.05	6.0	226.8			
11-24	8:00am	24	353	9.20	0	0	226.8			
11-26	7:45am	48	401	9.40	0.20	23.9	250.7			
11-29	8:00am	72	473	9.60	0.20	23.9	274.6			
11-30	8:00am	24	497	9.70	0.10	11.9	286.5			
12-1	8:00am	24	521	9.75	0.05	6.0	292.5			
12-2	8:00am	24	545	9.80	0.05	6.0	298.5			
12-3	8:00am	24	569	9.85	0.05	6.0	304.5			

Figure 10. – Sample data and calculation form for water permeability of concrete.

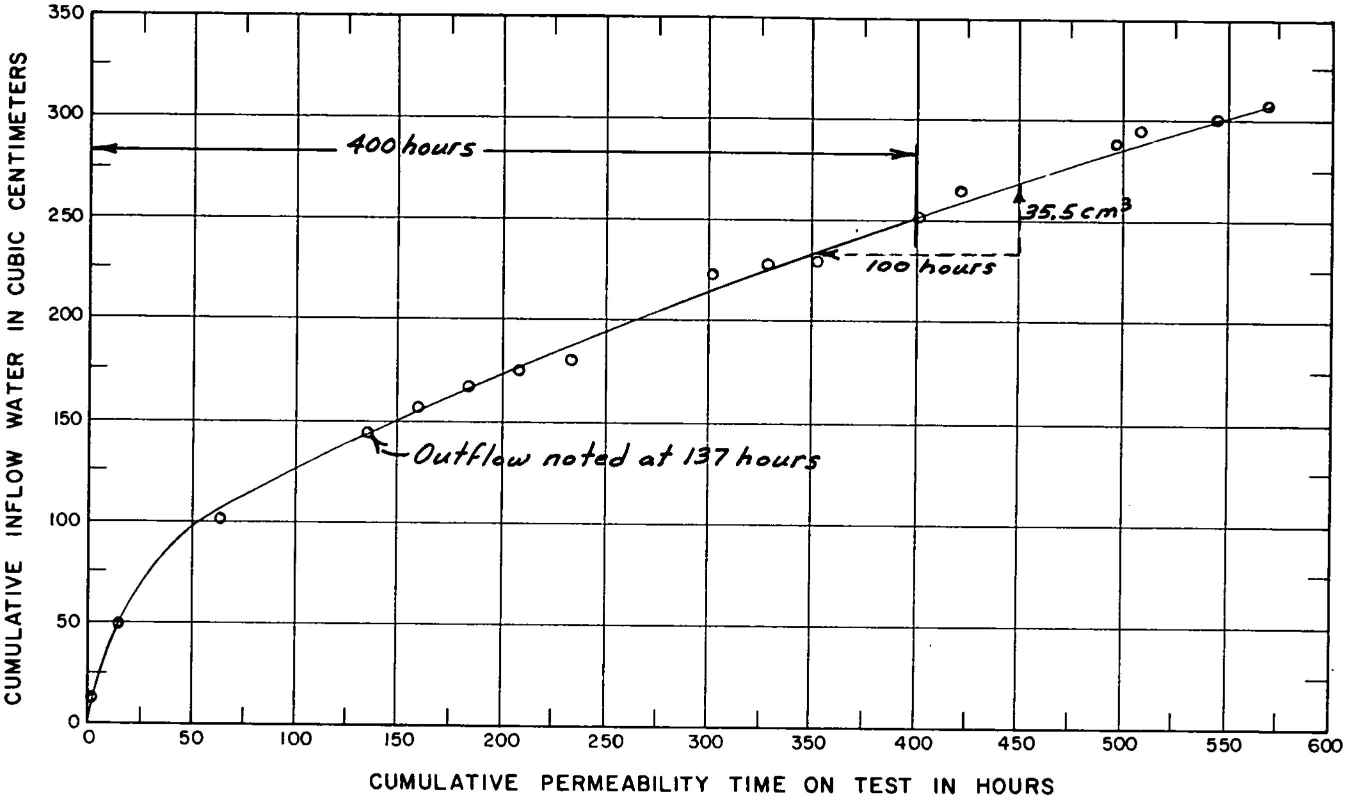

Figure 11. - Inflow data curve.

Spec. or Solic. No. DESIGN STAGE	Structure DAM	Tested by T. DOLEN & K. MITCHELL Date 11-9 TO 12-3-82
Project CENTRAL UTAH	Item RCC MIX DESIGN INVEST. Location DENVER LAB	Computed by K. MITCHELL Date 12-3-82
Feature UPPER STILLWATER DAM	Station ~ Offset ~ Depth ~ to ~	Checked by T. DOLEN Date 12-3-82

WATER PERMEABILITY OF CONCRETE

Basic Equation: $K = \dfrac{QL}{AH}$ or $Q = \dfrac{KAH}{L}$

where:

K = coefficient of permeability in ft/s (m/s),
Q = increment of flow in ft³/s (m³s),
L = length of specimen in feet (m),
A = cross-sectional area of specimen in ft² (m²), and
H = head of water in feet (m).

TEST DATA REPORTED

L = 6.06 /12 = 0.505 ft ~~(mm)~~
$A = \pi d^2/4 = \pi$ (0.5) $^2/4$ = 0.196 ft² ~~(m²)~~
H = 400 lbf/in² ~~(kPa)~~ × 2.31 ~~(0.102)~~ = 924 ft ~~(m)~~
Q_1 (fig. 11) = 0.355 cm³/h
Age of specimen at time flow is obtained: 239 days
End Condition: BROKEN ENDS

STEP 1:

Let Q' = flow in ft³/yr (m³/yr). If flow rate Q_1 is reported in cm³/h,
$Q' = 0.309355\ Q_1$ ft³/yr, or
$= 0.008760\ Q_1$ m³/yr (from section 12.2)
$= (0.309355)(0.355) = 0.1098$ ft³/yr ~~(m³/yr)~~

STEP 2:

Let $K_1 = \dfrac{Q'L}{AH}$ in (ft³/ft²)/yr or (m³/m²)/yr, K_1 is unit hydraulic gradient

$$K_1 = \frac{(0.1098)(0.505)}{(0.196)(924)} = \frac{0.055449}{181.1} = 3.06 \times 10^{-4}$$ (ft³/ft²)/yr or ~~(m³/m²)/yr~~

STEP 3:

Adjust K_1 value to 60-day age using table 1:

$$K_1 = \frac{100K_1}{\text{Factor from table 1}} = \frac{(100)(0.000306)}{(45)} = 6.8 \times 10^{-4}$$ (ft³/ft²)/yr or ~~(m³/m²)/yr~~

This calculation is shown only for illustration purposes. This step was not used because the procedure assumes a higher degree of hydration of cementitious materials at 60 days' age than is achieved with RCC.

STEP 4:

For specimens with broken ends, $K_2 = K_q$, and this step is not required.
Adjust K_2 value:

$$K_q = \frac{100\,K_2}{\text{Factor from table 2}} = \frac{(100)(0.00068)}{(75)} = 9.1 \times 10^{-4}$$ (ft³/ft²)/yr or ~~(m³/m²)/yr~~

This calculation is shown only for illustration purposes. This step was not necessary because ends of specimen were broken and not chipped.

Figure 12. - Sample worksheeet for determining coefficient of permeability.

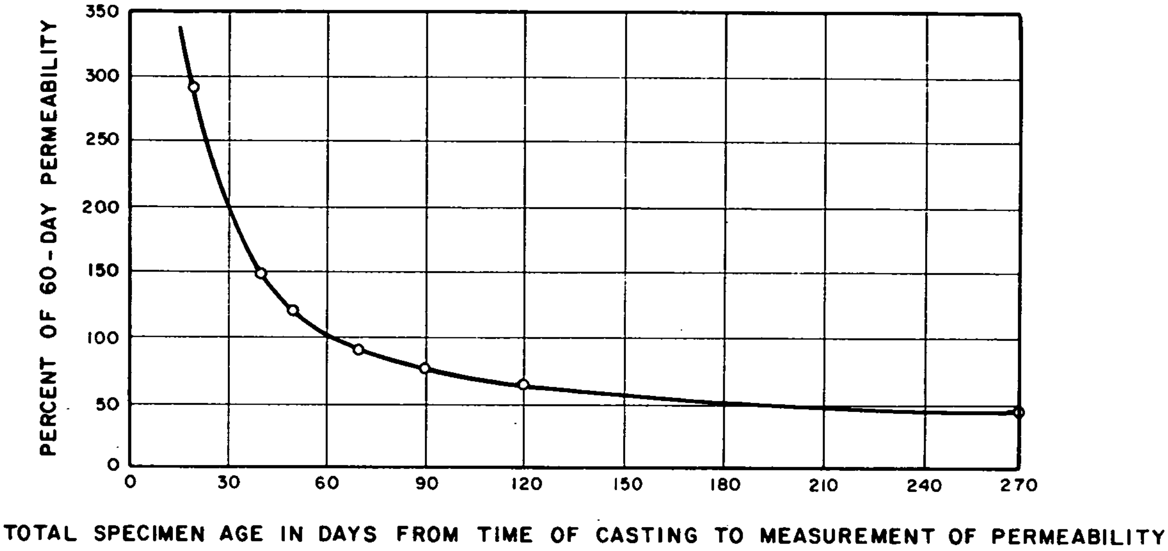

Figure 13. – Effect of specimen age on permeability.

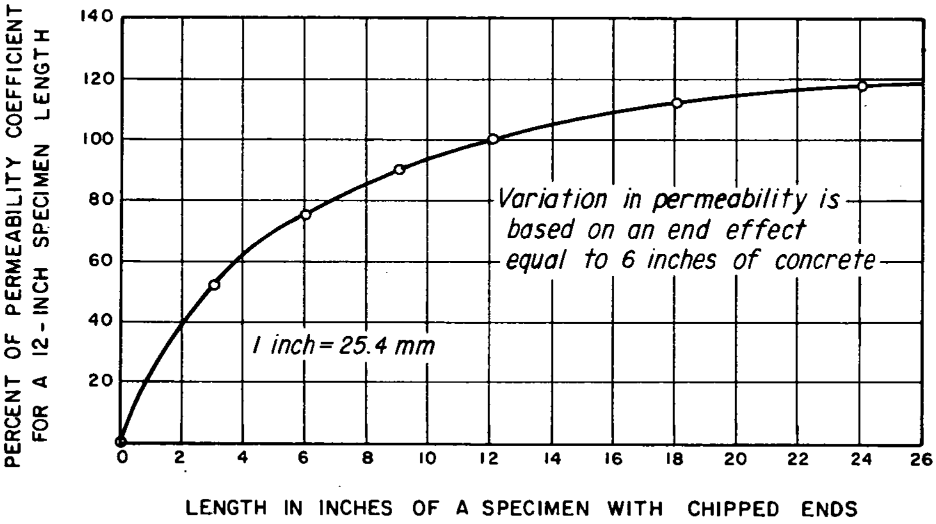

Figure 14. – Variation of permeability coefficient with specimen length.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4914-92

PROCEDURE FOR

DIRECT TENSILE STRENGTH, STATIC MODULUS OF ELASTICITY, AND POISSON'S RATIO OF CYLINDRICAL CONCRETE SPECIMENS IN TENSION

INTRODUCTION

This test procedure is under the jurisdiction of the Materials Engineering Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4914; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers the procedures for determining the chord modulus of elasticity (Young's static modulus), Poisson's ratio, and the direct tensile strength of molded concrete cylinders and diamond-drilled concrete cores under longitudinal tensile stress.

2. Applicable Documents

2.1 *USBR Procedures*:

1104 Load Verification of Testing Machines
4031 Making and Curing Concrete Test Specimens in Field
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4192 Making and Curing Concrete Test Specimens in Laboratory

2.2 *ASTM Standards*:

C 174 Standard Method of Measuring Length of Drilled Concrete Cores[1]
E 6 Standard Definitions of Terms Relating to Methods of Mechanical Testing[2]

3. Significance

3.1 This procedure is of primary significance in determining the direct tensile properties of various concrete materials.

4. Terminology

4.1 *Tensile Strength.*–As defined in ASTM E 6.
4.2 *Modulus of Elasticity.*–As defined in ASTM E 6.
4.3 *Poisson's Ratio.*–As defined in ASTM E 6.

5. Apparatus

5.1 *Testing Machine.*–The testing machine shall conform to the requirements of USBR 1104, and may be of any type capable of imposing a load at the rate and magnitude prescribed in this test procedure. A self-aligning, spherically seated, alignment assembly shall be mounted on the testing machine. This assembly provides precise alignment through an adaptor plate that bolts into the crosshead, and holds a spherical brace and bearing to seat the alignment rod.

5.2 *Longitudinal Strain Gauges.*–A bonded sensing device for measuring strain to the nearest 5 microunits per unit shall be used for determining the modulus of elasticity. The deformation shall be calculated from the average of measurements made by diametrically opposite gauge lines, each parallel to the longitudinal axis, centered at midheight of the specimen. The effective length of each gauge line shall be greater than two times the maximum concrete aggregate size but less than two-thirds the height of the specimen.

5.3 *Transverse Strain Gauges.*–For Poisson's ratio, the transverse strain shall be the average value determined by two bonded gauges mounted circumferentially, at diametrically opposite points, at midheight of the specimen. The strain gauges shall have the capability of measuring the circumferential strain to the nearest 5 microunits per unit.

5.4 *End Plates and Connecting Assembly.*–End plates, to be bonded to ends of cast or cored specimens, shall be made of high-quality steel with diameters not larger than 1.4 times the diameter of the cylindrical test specimen. The plates shall be of such thickness and strength to minimize flexing under the ultimate tensile load. A double end plate design, as shown on figures 1 and 2, has been found to give the best performance. In this design, stress from the testing machine is distributed by a ring of bolts to an end plate that is bonded to the specimen. Threaded connectors attach the end plates to an alignment rod of the testing machine. With this type of end plate, a specimen with a length-to-diameter ratio as low as 1.5 may be tested. With a single-plate, center-pull, end plate, the length-to-diameter ratio should exceed 2.0 because of the greater length of end effect on the specimen.

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[1] *Annual Book of ASTM Standards*, vol. 04.02.

[2] *Annual Book of ASTM Standards*, vols. 03.01, 08.03.

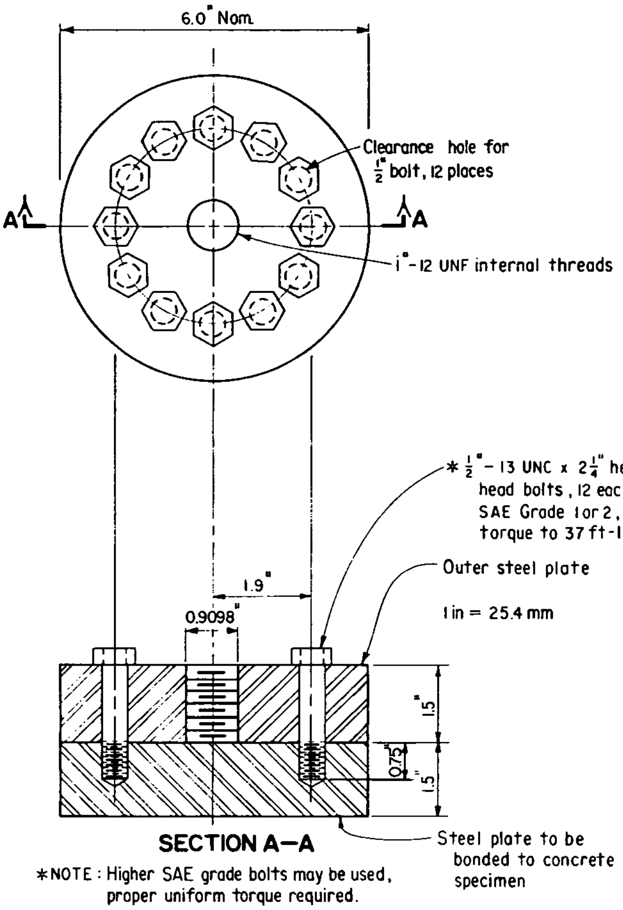


Figure 1. - Steel end plate assembly for testing 6-inch (150-mm) concrete cylinders in tension (2 required).

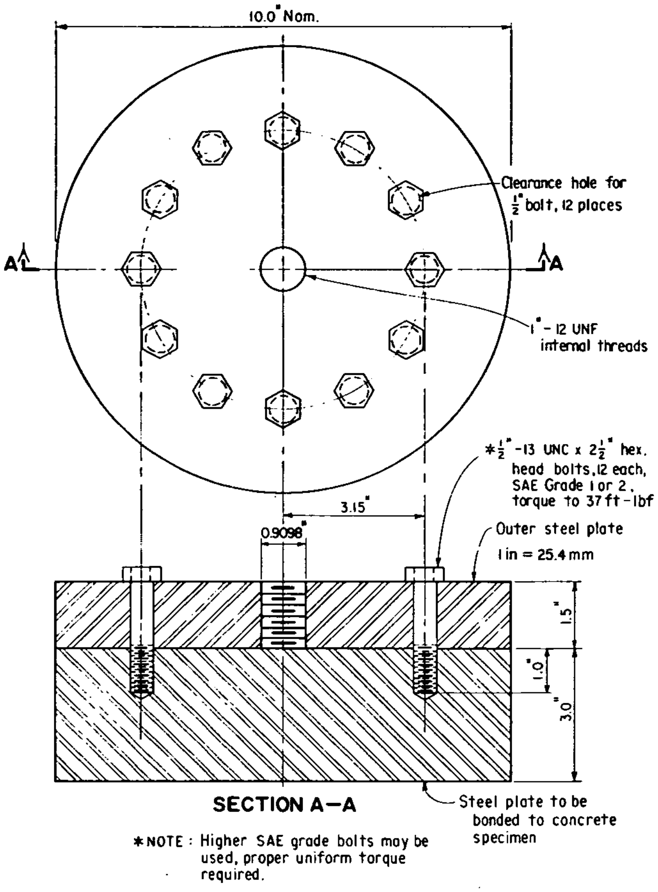


Figure 2. - Steel end plate assembly for testing 10-inch (250-mm) concrete cylinders in tension (2 required).

6. Precautions

6.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 *Caution*: Exposure to epoxy adhesives can cause skin irritations and other health problems. Personnel applying these adhesives are cautioned to avoid contact with skin, avoid prolonged or repeated breathing of vapors, and use with adequate ventilation.

7. Test Specimens

7.1 *Molded Cylindrical Specimens.*-Test cylinders shall conform to the size, molding, and curing requirements set forth in USBR 4192 (laboratory specimens) or USBR 4031 (field specimens). Moist cured specimens, during the period between their removal from the curing environment and testing, shall be kept moist by a wet cloth cover.

7.2 *Drilled Core Specimens.*-Cores shall comply with the requirements for drilling, end preparation, and moisture condition as applied to compressive strength specimens in USBR 4042, except that only diamond-drilled cores having a length-to-diameter ratio greater than 1.5 shall be used. Requirements relative to storage and ambient conditions immediately prior to testing shall be the same as those for molded cylindrical specimens in USBR 4192.

7.3 *Measurement of Test Specimens.*-The diameter of each test specimen shall be determined by averaging two diameter measurements taken at right angles to each other near the center of the specimen length. These diameters shall be measured to the nearest 0.01 inch (0.25 mm) with a caliper. The average diameter shall be used for calculating cross-sectional area. The length of the specimen shall be reported to the nearest 0.10 inch (2.5 mm), with the drilled specimens measured in accordance with ASTM C 174.

8. Conditioning

8.1 *Bonding End Plates.*-Sandblast the face of the end plate to remove all foreign matter and to provide a good bonding surface. Lightly sandblast or lap the ends of the specimens to remove laitance and to provide a good surface for bonding to the end plate. Surface dry the ends of the specimen and bond end plates to the specimen using a high-modulus, high-bond-strength epoxy. End plates shall be bonded perpendicular to the longitudinal axis of the specimen.

8.2 *Attaching Bonded Strain Gauges.*-Smooth the areas to receive gauges by wire brushing or sanding. Remove loose dust from the surface by air jet or brushing. Dry surface of concrete to receive gauge. Apply a leveling and sealing precoat of epoxy adhesive to the concrete. After sealing coat has hardened, abraid the surface with silicon-carbide paper. Bond gauge to specimen using a high-strength epoxy adhesive. Other adhesives recommended by the strain gauge manufacturer may be used in place of the epoxy.

8.3 *Moisture Condition.*-Strength and elasticity of concrete are affected by the moisture condition at time of test. For comparable results, standard conditions are to test the specimen with the concrete in a saturated condition. Epoxy adhesive does not adhere well to wet surfaces; therefore, the surfaces to which end plates and gauges must be bonded need to be surface dried with a minimum of drying occurring to the test specimen as a whole. On removing specimen from moist room preparatory to applying end plates and gauges, wrap the specimen in plastic. Cut windows into the plastic where the strain gauges are to be applied. Seal the plastic around windows to the specimen. If significant drying occurs, waterproof the gauges and return specimen to moist room before testing.

9. Calibration and Standardization

9.1 The calibration and standardization of the miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

10. Procedure

10.1 An ambient temperature and humidity, as constant as possible, shall be maintained throughout the test. All unusual fluctuations in temperature or humidity shall be noted in the report.

10.2 If comparison specimens are available, the ultimate tensile strength shall be determined prior to testing for modulus of elasticity.

10.3 Attach a threaded connector into the bonded end plate at each end of the test specimen. Ensure that rods of the alignment assemblies move freely in the spherical heads. Thread specimen connectors to rods of the top and bottom alignment assemblies. Attach strain gauge leads to indicating or recording instrument.

10.4 Apply load continuously and without shock at a constant rate between 100 and 200 (lbf/in^2)/min (689 to 1378 kPa/min) to what is anticipated to be about 40 percent of ultimate load. If instruments are not of the continuously recording type, record strain at every 20-lbf/in^2 (138-kPa) increment of stress. Reduce load to zero at about the same rate that load was applied. Repeat the loading and the readings. If the two test runs appear compatible, make a final continuous loading to failure. If modulus of elasticity and Poisson's ratio are not to be measured, continue loading to failure on first loading. Record maximum applied load at failure and note type of failure.

11. Calculations

11.1 Calculate the modulus of elasticity to the nearest 50,000 lbf/in^2 or 0.350 GPa as follows:

$$E = \frac{S_2 - S_1}{\epsilon_2 - \epsilon_1} \tag{1}$$

where:

E = chord modulus of elasticity, in pound force per square inch (gigapascals);
S_2 = stress corresponding to 40 percent of ultimate load or at a stress corresponding to a selected strain, in pound force per square inch (megapascals);
S_1 = stress selected to be near the start of the straight portion of the stress-strain curve, in pound force per square inch (megapascals);
ϵ_2 = longitudinal strain produced by stress S_2, to nearest 5 microunits per unit; and
ϵ_1 = longitudinal strain produced by stress S_1, to nearest 5 microunits per unit.

11.2 Calculate Poisson's ratio to the nearest 0.01 as follows:

$$r = \frac{t_2 - t_1}{\epsilon_2 - \epsilon_1} \tag{2}$$

where:

r = Poisson's ratio,
t_2 = transverse strain at midheight of specimen produced by stress S_2 (sec. 11.1), to nearest 5 microunits per unit;
t_1 = transverse strain at midheight of specimen produced by stress S_1 (sec. 11.1), to nearest 5 microunits per unit; and
ϵ_2 and ϵ_1 = as previously defined in equation (1).

11.3 Calculate direct tensile strength to nearest 10 lbf/in^2 (0.069 MPa) as follows:

$$T = \frac{L}{A} \text{ (inch-pound units)}$$

$$T = \frac{L}{1000A} \quad \text{(metric units)} \tag{3}$$

where:

T = direct tensile strength in pound force per square inch (megapascals),
L = ultimate total load in pound force (kilonewtons), and
A = cross-sectional area in square inches (square meters).

11.4 Figure 3 shows a typical calculation form and figure 4 shows a typical plot of the data. Data acquisition and calculations may be performed automatically by computer and are represented by figures 5 and 6.

Spec. or Solic. No. Research	Structure NA	Tested by Neil Johnson Date 1-17-91
Project NA	Item Elastic Properties Location Denver Lab	Computed by Neil Johnson Date 1-17-91
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by Todd Rutenbeck Date 1-17-91

DIRECT TENSILE STRENGTH, STATIC MODULUS OF ELASTICITY,
AND POISSON'S RATIO OF CYLINDRICAL CONCRETE SPECIMENS IN TENSION

Date: 1-17-91 Time: 9:40 a.m., ~~p.m.~~ Cylinder: Ident. No. A1 ; Dimensions 6.00 by 12.05 in ~~(mm)~~

Area: 28.27 in² ~~(m²)~~ Type of Curing: Fog Cure

Stress S_1 or S_2		Longitudinal Strain ϵ_1 or ϵ_2 $\times 10^{-6}$		Transverse Strain t_1 or t_2 $\times 10^{-6}$	
lbf/in²	MPa	lbf/in²	MPa	µin/in	µm/m
20 20		6 6		0 0	
46 71		17 21		3 4	
104 130		30 38		5 7	
156 183		46 55		8 10	
209 235		63 72		11 13	
261 287		81 90		14 15	
313 339		100 109		17 18	
365 392		120 130		19 21	
418 444		141 151		23 24	
469 494		163 174		26 28	
520 546		186 198		29 31	
571 597		211 224		32 34	
622 647		239 254		35 37	
672 698		270 287		39 40	
704 707		291 294		41 41	
710 713		296 298		41 41	
716 719		300 302		42 42	

$E = (S_2 - S_1) \div (\epsilon_2 - \epsilon_1) = (\underline{288} - \underline{104}) \div (\underline{90} - \underline{30}) \times 10^{-6} = \underline{184} \div \underline{60} \times 10^{-6} = \underline{3.05} \times 10^{-6}$ lbf/in² ~~(MPa)~~

$r = (t_2 - t_1) \div (\epsilon_2 - \epsilon_1) = (\underline{15} - \underline{5}) \times 10^{-6} \div (\underline{90} - \underline{30}) \times 10^{-6} = \underline{10} \times 10^{-6} \div \underline{60} \times 10^{-6} = \underline{0.17}$

Ultimate Total Load = 20,326 lbf ~~(kN)~~

Direct Tensile Strength = 720 lbf/in² ~~(MPa)~~

Figure 3: – Elastic properties data and computation form.

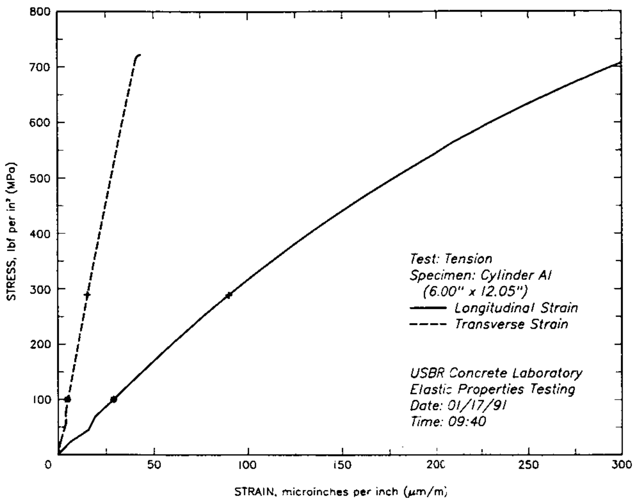


Figure 4. - Graphical plot of data from figure 3.

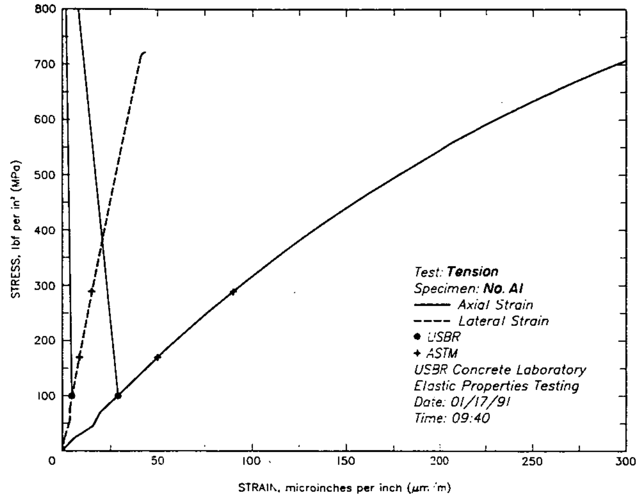
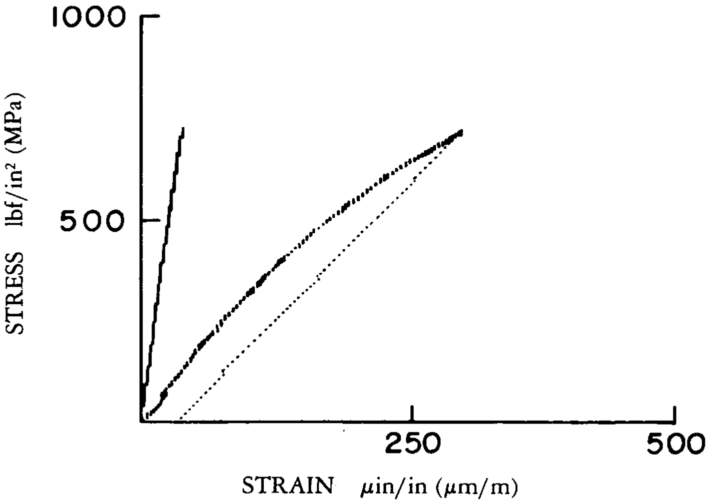


Figure 6. - Computer generated graph.



- - - - - - - - - - - TERMINATE - - - - - - - - - - -

Figure 5. - Computer generated data.

USBR Concrete Laboratory Elastic Properties Testing

Test: Tension
Spec: No. A1
Date and time: 01/17/91 09:40

Stress lbf/in² (MPa)	Longitudinal Strain $\epsilon \times 10^{-6}$	Transverse Strain $t \times 10^{-6}$
20	6	0
20	6	0
46	17	3
71	21	4
104	30	5
130	38	7
156	46	8
183	55	10
209	63	11
235	72	13
261	81	14
287	90	15
313	100	17
339	109	18
365	120	19
392	130	21
418	141	23
444	151	24
469	163	26
494	174	28
520	186	29
546	198	31
571	211	32
597	224	34
622	239	35
647	254	37
672	270	39
698	287	40
704	291	41
707	294	41
710	296	41
713	298	41
716	300	42
719	302	42

Maximum Load = 719 lbf/in²

Figure 5. - Computer generated data. — Continued.

12. Report

12.1 The report may include the data from figures 3 through 6 as appropriate along with a cover letter. The final report shall include:

- Specimen identification number.
- Dimensions of specimen in inches (millimeters).
- Curing and environmental history of concrete.
- Tensile strength of concrete.
- Modulus of elasticity, if determined.
- Poisson's ratio, if determined.

13. Precision and Bias

13.1 The precision and bias of this procedure have not been determined.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4915-92

PROCEDURE FOR

DIRECT SHEAR OF CYLINDRICAL CONCRETE SPECIMENS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4915; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation outlines a procedure for measuring peak and residual shear strength as a function of stress normal to the shear plane. The procedure is to be used for measuring shear strength of intact or open concrete joints, concrete/rock interfaces, homogeneous concrete, and other planar, possibly weak features. Results are employed in stability analyses of concrete structures.

1.2 Intact specimens are tested to failure by the shearing process at predetermined normal stresses. The shear stress at failure for at least three "like" specimens at different normal stresses are used to compute a failure envelope. Specimens with open features as well as sheared homogeneous specimens are subjected to sliding forces in a series of at least three normal stresses; a peak failure envelope is obtained for each specimen. Normal and shear stresses for similar features may be statistically analyzed to determine a combined failure envelope.

1.3 Test results obtained by this procedure do not take into consideration pore pressure, specimen size, progressive failure, nonuniform stress, or displacement distribution.

2. Applicable Documents

2.1 *USBR Procedures*:

1007 Calibrating Dial Indicators
1008 Calibrating Linear Variable Differential Transformers
4192 Making and Curing Concrete Test Specimens in Laboratory
4823 Examination and Sampling of Hardened Concrete in Construction

3. Significance and Use

3.1 The test is used to complement other concrete property tests which provide data relating to the strength properties of concrete.

4. Terminology

Cohesion.–Shear strength or resistance at zero normal stress.

Dilatancy.–The change in the value of normal displacements as a result of applied shear force.

Direct Shear Test.–A shear test in which a specimen under an applied normal force is stressed to failure by moving one section of the specimen container (holding ring) relative to other section.

Failure Envelope.–An envelope defined by a locus of points that represents the combinations of shear and normal stresses that will cause a material to fail.

Friction Angle or Angle of Internal Friction.–Angle between axis of normal stress and the tangent to failure envelope at a point representing a given failure stress condition for material.

Intact Shear Test.–A direct shear test in which failure is induced along a particular zone of weakness such as a joint or lift line.

Intact Specimen.–A bonded specimen, with no broken joint, for which an intact shear test can be performed.

Normal Displacement.–Displacement in inches (millimeters) measured perpendicular to the shear zone.

Normal Force or Load.–The pounds force (newtons) applied to test specimen perpendicular to test feature.

Normal Stress.–Normal force divided by area of shear surface, pounds force per square inch (megapascals).

Open Specimen.–Specimen with an open or unbonded joint, on which only a sliding friction test can be performed.

Shear Direction.–Direction that shearing takes place across the shear surface.

Shear Displacement.–Displacement in inches (millimeters) measured parallel to direction of shear force.

Shear Force or Load.–The pounds force (newtons) applied parallel to shear surface which ultimately causes failure or displacement across this surface.

Shear Plane.–Plane along which failure of material occurs by shearing.

Shear Stress.–Shear force divided by area of shear surface, pounds force per square inch (megapascals).

Shear Surface.–Similar to shear plane except that this is actual sliding surface where displacement occurs.

Shear Zone.–Zone of material located within test gap.

Sliding Friction Test.–A direct shear test of an open or nonjointed plane.

Surface Roughness.–Irregularity of shear surface.

Test Apparatus.–Machine used to perform a direct shear test.

Test Feature.-Specific zone of material on or in a specimen to be tested such as an open joint, lift line, or rock-concrete contact.

Test Gap.-Distance between the two holding rings where shear and normal forces are applied.

5. Apparatus and Materials

5.1 Equipment for sampling specimens is outlined in USBR 4823. Preparation of specimens for testing is outlined in USBR 4192.

5.2 The test apparatus consists of a pair of specimen "holding" rings to support the two halves of the specimen, which may or may not be intact. Specimens are encapsulated in the rings with cement, epoxy, or a similar strong adhesive. Specimen is positioned in shear device so that resultant of an applied normal force acts perpendicular to shear plane, where a force is applied along the plane of test feature. The apparatus should have low friction rollers, cables, or other devices to ensure that frictional resistance of equipment to shear force is less than 1 percent of the maximum shear force applied in the test. The apparatus should also be capable of applying the specified normal force and maintaining it within 2 percent throughout the test, and be capable of shearing the specimen at a uniform rate of load or displacement with 10 percent deviation.

5.3 Indicators to measure displacement normal to test feature should have a sensitivity of 0.001 inch (0.025 mm).

5.4 Indicators to measure shear displacement should have a sensitivity of 0.001 inch (0.025 mm), and a capacity in excess of expected total shear displacement.

5.5 Normal and shear forces and displacements should be recorded or plotted continuously, or at a minimum of 10 regular increments, before reaching peak value.

6. Precautions

6.1 *Safety.*-This procedure may include the use of hazardous materials, operations, and equipment. Therefore, personal safety devices such as glasses, shoes, and gloves are required. It is the responsibility of the user to establish appropriate safety practices and to determine applicability of regulatory limitations prior to use.

6.2 *Technical.*-Specimens must be protected against mechanical damage during casting and insertion into test apparatus. Specimens with open features must be cast with care so that foreign material is not introduced onto test surfaces.

7. Test Samples, Testing Units, and Test Specimens

7.1 The number of specimens tested is determined by practical considerations. It is considered good practice to test, within each sample group, nine similar specimens at three different normal stresses. The minimum recommended sample group size is three specimens.

7.2 The specimen can be cylindrical or irregular shaped. The test feature must be at about midheight of specimen. The specimen length on either side of shear zone must be long enough to ensure that a firm grip is achieved by encapsulating material. Specimen size and corresponding shear surface area should be maximized within limits of sampling, shear box dimensions, and test apparatus load capabilities.

7.2.1 The area of shear surface, or expected shear surface, must be measured. Cylindrical specimen diameters should be determined within 0.01 inch (0.25 mm) by averaging two diameter measurements taken at right angles to each other near test feature. The inclination of test feature (inclination at which test feature is oriented with respect to axis of specimen) must be measured to nearest degree. The average diameter and inclination are used to calculate cross-sectional area.

7.2.2 The area of irregular-shaped specimens is determined by planimetric measurement of a peripheral trace of specimens. If preferred, area of cylindrical-shaped specimens may also be determined using this method.

7.3 The moisture condition of specimen at time of testing shall be noted.

7.4 If a specific shear direction is selected prior to testing, specimen must be marked accordingly and care must be taken during casting process to maintain marking.

7.5 For concrete specimens with open test features, joint roughness should be described prior to testing.

8. Calibration and Standardization

8.1 The calibration and standardization of equipment used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or by reference to another.

8.2 Regular calibration of all load-indicating devices, such as load cells and hydraulic pressure gauges, should be maintained for the testing range.

8.3 Regular calibration of all displacement measuring devices, such as the LVDT (linear variable differential transformer), must be in accordance with USBR 1008, and dial gauges in accordance with USBR 1007. These devices should be maintained for the anticipated testing range.

8.4 If an automatic recording system is used, regular calibration should be maintained for the testing range.

9. Conditioning

9.1 No specific conditioning atmosphere is required to perform the test; however, temperature and humidity observations should be included with results of each test.

10. Procedure

10.1 *Photographs*:

10.1.1 *Intact Specimens.*-Photograph two side views, 90° apart, of specimen. One photograph should be oriented such that test feature is shown perpendicular to direction of shearing.

10.1.2 *Open Specimens.*-Photograph specimen as stated in section 10.1.1, and also a view of open test surfaces.

10.2 The specimen holding rings should be cleaned and greased before use to aid in removal of specimens after testing.

10.3 *Casting Intact Specimens in Holding Rings*:

10.3.1 Specimen is centered in one holding ring and test feature is aligned parallel to line of shearing action of test apparatus.

10.3.2 Encapsulate lower half of specimen in holding ring, and fill to top of ring. If test feature is irregular and extends beyond test gap provided by test apparatus, then only fill holding ring to within 1/8 inch (3.2 mm) of test feature.

10.3.3 Spacer blocks should be placed around test feature, and all possible avenues for encapsulating material to escape should be plugged with clay. The second holding ring is then positioned over specimen and aligned parallel to first ring.

10.3.4 Encapsulate specimen in second ring as described in 10.3.2 for first ring.

10.3.5 After curing encapsulate material, remove spacer blocks, clay, etc., from between holding rings.

10.4 *Casting Specimens With Open Features in Holding Rings*:

10.4.1 One-half of specimen is positioned in a ring so that test feature is centered and aligned with line of shearing action of test machine. The two halves of the specimen are then mated.

10.4.2 Encapsulate first specimen half as described in 10.3.2.

10.4.3 Spacer blocks are placed around test feature, and all possible channels for encapsulating material to escape should be plugged to ensure that no material will flow onto test surface. The second ring is then positioned over specimen and aligned with first ring.

10.4.4 Encapsulate remaining specimen half in second ring as described in 10.3.2.

10.4.5 After encapsulating material has cured, rings can be separated and spacer blocks, clay, etc., removed.

10.5 Specimen holding rings should be bolted, clamped, or wired together while being transported or assembled in test apparatus to minimize mechanical damage of test feature.

10.6 Specimen holding rings are positioned in test apparatus, and bolts, clamps, or wires removed.

10.7 Load and displacement measurement devices are checked, activated, and zeroed.

10.8 The required normal force (computed from the specified stress multiplied by cross-sectional area) is applied and the corresponding normal displacement recorded.

10.9 Shear force and shear displacement are "zeroed" along with recording device.

10.10 Specimen is sheared at a "controlled" rate of stress or displacement until a peak shear stress is reached. Continuous readings or a minimum of 10 data points including shear, normal stress, and displacement should be recorded before reaching peak value.

NOTE 1.–For an intact specimen, break value is determined from peak shear stress of initial run for that specimen. The open feature created by shear failure of original intact specimen can subsequently be tested for shearing resistance under a sequence of normal stresses; i.e., return to procedure of section 10.8.

10.11 Once peak shear stress is determined, shear load is released, normal force is changed to next value, and procedures of sections 10.8 through 10.10 repeated. Shearing resistance tests for open features are performed by applying a minimum of three normal forces in order of increasing magnitude.

10.12 If excessive shear displacement occurs during testing, normal force may be removed, specimen realigned to original position, and test sequence continued. The correlation of results may vary, depending upon nature of test feature and position of specimen at each normal stress. Alternatively, specimen can be remated for every normal stress, and procedures of 10.8 through 10.10 repeated.

10.13 Specimens are again photographed as described in section 10.1.

11. Calculations

11.1 *Formulas*:

$$\tau = \frac{S}{A} \tag{1}$$

$$\sigma_n = \frac{N}{A} \tag{2}$$

where:

τ = shear stress, in pound force per square inch (megapascals);
S = shear force, in pound force (Newtons);
A = initial cross-sectional area, in square inches (square millimeters);
σ_n = normal stress, in pound force per square inch (megapascals); and
N = normal force, in pound force (Newtons).

$$d = \arctan\left(\frac{d_n}{d_s}\right) \tag{3}$$

where:

d = effective dilatancy of slides,
d_n = normal component of tangent line drawn to rising leg of normal displacement versus shear displacement graph, and
d_s = shear component of tangent line drawn to rising leg of normal displacement versus shear displacement graph.

NOTE 2.–Conditions of dilatancy prompting the need for equation (3) occur so infrequently that no typical data are included in this procedure.

NOTE 3.–For each specimen, plot graphs of shear stress versus normal and horizontal displacement and peak shear stress versus normal stress. Failure envelopes are computed for the following three types of combined data using least-squares linear regression:

(1) peak sliding resistance data for individual specimens
(2) peak (breaking strength) data for similar, intact specimens

(3) peak sliding resistance data for specimens with similar open features

Better results may be obtained by using curvilinear failure envelopes. The friction angle and cohesion are computed to represent each failure envelope.

11.2 Figures 1 and 2 show typical graphs, and figure 3 shows a typical data and calculation form.

12. Report

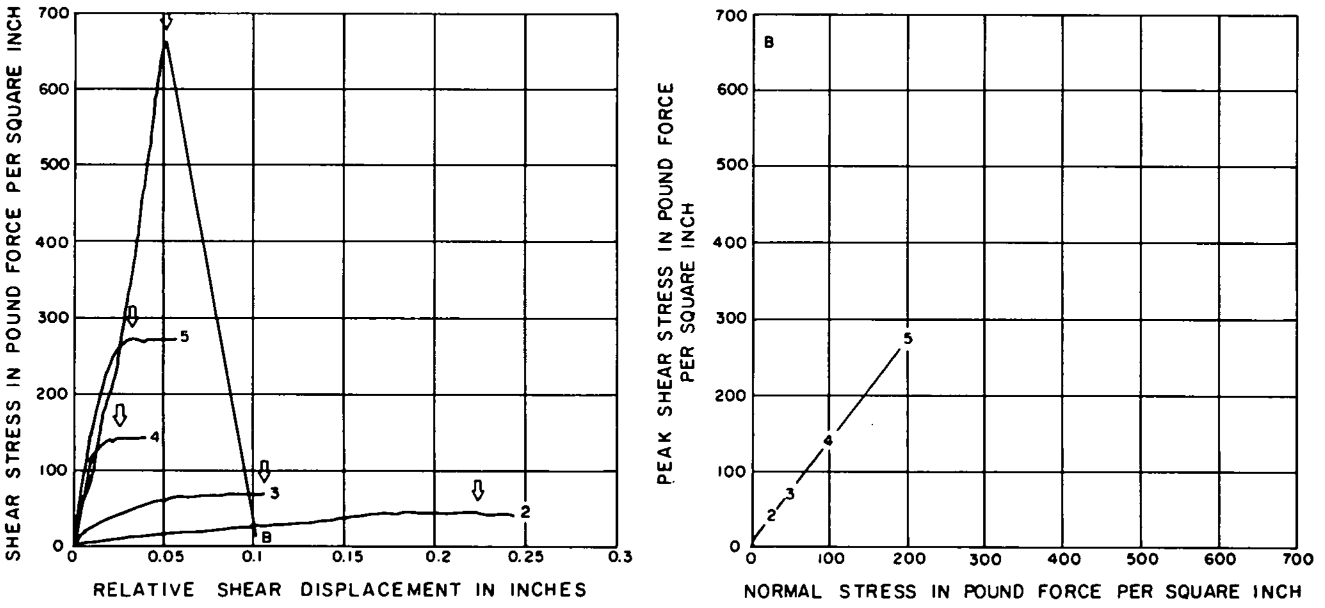
12.1 The report should include the following information:

- Identification of specimen–type, history.
- Description of test feature before testing. An open surface feature should describe roughness with respect to orientation; include photographs.
- Description of sheared surfaces after testing. Type of failure. If originally intact, percent of aggregate along or across feature and amount of crushing, shearing, etc. Include photographs and other notes, description of possible interference with casting material, and roughness (with respect to direction of shearing).
- Moisture condition at time of testing.
- Test information–data, type, rate, etc.
- Tabulation of all recorded data–normal and shear stresses and displacements.
- Tabulation of all computed results–break values, dilatancy, friction angle, cohesion.
- Graphs as described in note 3 of section 11.
- Calibration data.

12.2 A cover letter accompanied with figures 1, 2, and 3 will serve as a reporting form.

13. Precision and Bias

13.1 The precision and bias statements for this procedure have not been established.



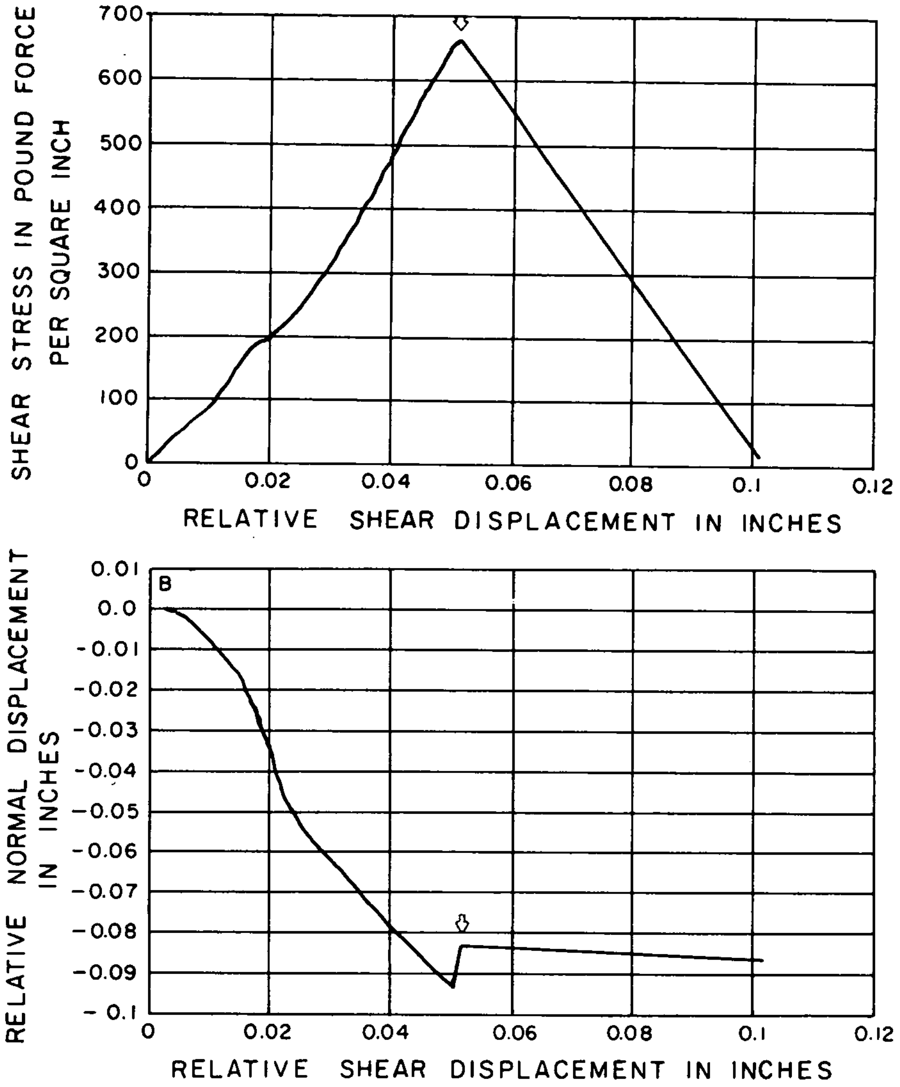
Project: Central Utah
Feature: Upper Stillwater Dam
Type: RCC - Solid Core (JT-PM)
Specifications No.: DH22-117.2
Index No.:
Tested By: JM
Date Tested: 8-10-87
Nominal Area: 26.61 in^2

Cycle No.	Normal Stress, lbf/in^2	Peak Shear Stress, lbf/in^2	Relative Displacement, inches
B	25	664	0.0514
2	26	46	0.2231
3	50	70	0.1056
4	100	143	0.0259
5	200	273	0.0324

Sliding Friction Results:
$\tau = 9 + 1.324\ \sigma_n$
Cohesion = 9 lbf/in^2
phi = 53°
Correction Coefficient = 0.9994

NOTES: B = Intact Shear Strength; 2, 3, 4, and 5 = Sliding Friction Tests
All values shown in inch-pound units, 1 inch = 25.4 mm, 1 lbf/in^2 = 0.00689 MPa, and 1 in^2 = 645 mm^2

Figure 1. – Typical plots of direct shear data for an intact specimen followed by multistage sliding friction tests along the shear surface. Arrows show locations of peak shear stress. The peak shear stress versus normal stress plot shows the least squares fit to the sliding friction peak shear strength data using a Coulomb-Navier failure criterion.



SHEAR PARAMETERS AT FAILURE

Relative Displacement in inches		Stresses in pound force per square inch	
Normal	Shear	Normal	Shear
-0.0829	0.0514	25	664

Project: Central Utah
Feature: Upper Stillwater Dam
Type: RCC-Solid Core (JT-PM)
Specifications No.: DH22-117.2
Index No.:
Tested By: JM
Date Tested: 8-10-87
Nominal Area: 26.61 in^2

NOTE: Values shown in inch-pound units, 1 inch = 25.4 mm, 1 lbf/in^2 = 0.00689 MPa, and 1 in^2 = 645 mm^2

Figure 2. – Typical plots of direct shear data for one increment of normal stress. Plots shown are for an intact specimen, and the arrows show where failure occurred.

Spec. or Solic. No. DC-7558	Structure DAM-ROLLER COMPACTED CONCRETE	Tested by J. MONTGOMERY Date 3-7-87
Project CENTRAL UTAH	Item DRILL CORE, 6-inch Nom. SIZE, DIA = 5.82 inches Location DH-22	Coupted by J. MONTGOMERY Date 3-7-87
Feature UPPER STILLWATER DAM	Station SEE DRAWINGS Offset Depth 117.2 FEET to	Checked by J. TOUSEULL Date 3-7-87

DIRECT SHEAR OF CYLINDRICAL CONCRETE SPECIMENS

Normal Force, N = 665 lbf ~~(N)~~, Contact Area, A = 26.61 in² ~~(mm²)~~, Normal Stress, σ_n = 25 lbf/in² ~~(MPa)~~

Elapsed Time, seconds	Relative Normal Displacement Readings in inches ~~(mm)~~					S Shear Force, lbf ~~(N)~~	Relative Shear Displacement, inches ~~(mm)~~		τ Shear Stress, lbf/in² ~~(MPa)~~	Remarks
	1	2	3	4	Average		Reading	Difference		
0	0.0000	0.0000	0.0000	0.0000	0.0000	0	-0.5113	0.0000	0	INITIAL LOADING INTACT SPECIMEN
4	0.0000	0.0000	0.0000	0.0001	0.0000	85	-0.5106	0.0007	3	
8	-0.0071	-0.0085	0.0045	0.0036	-0.0019	1,483	-0.5056	0.0057	56	
13	-0.0209	-0.0237	-0.0094	-0.0115	-0.0164	4,075	-0.4963	0.0150	153	
16	-0.0327	-0.0369	-0.0467	-0.0516	-0.0420	5,502	-0.4899	0.0214	207	
20	-0.0468	-0.0531	-0.0634	-0.0673	-0.0577	7,443	-0.4836	0.0277	280	
24	-0.0571	-0.0643	-0.0693	-0.0737	-0.0661	9,445	-0.4785	0.0328	355	
28	-0.0644	-0.0725	-0.0769	-0.0816	-0.0739	11,516	-0.4740	0.0373	433	
32	-0.0689	-0.0774	-0.0821	-0.0868	-0.0788	13,037	-0.4708	0.0405	490	
36	-0.0734	-0.0822	-0.0878	-0.0924	-0.0840	14,673	-0.4674	0.0439	551	
40	-0.0778	-0.0864	-0.0930	-0.0969	-0.0885	16,207	-0.4640	0.0473	609	
44	-0.0821	-0.0891	-0.0978	-0.0996	-0.0922	17,325	-0.4613	0.0500	651	
46	-0.1599	-0.1360	-0.0365	+0.0009	-0.0829	17,666	-0.4599	0.0514	664	SPECIMEN RUPTURED
46	-0.1716	-0.1383	-0.0379	+0.0018	-0.0865	413	-0.4102	0.1011	16	

Figure 3.-Typical data form for direct shear analysis.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4916-92

PROCEDURE FOR

LOSS OF ENTRAINED AIR WITH VARIOUS FLY ASHES (FOAM INDEX)

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4916; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure was established from a report of February 1981 on "The Use of Fly Ash in Air-Entrained Concrete-Report of Recent NSGA-NRMCA Research Laboratory Studies" by Richard C. Meininger, Director of Engineering Research, National Sand and Gravel Association and National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, Maryland 20910. Credit was extended to Vance Dodson of the W. R. Grace Co. on a report given at the January 1980 meeting of the Transportation Research Board in Washington, DC, on the introduction of this test.

1. Scope

1.1 This designation covers a procedure for determining the tendency of a given fly ash to increase the air-entraining admixture requirement of a concrete.

2. Applicable Documents

2.1 *ASTM Standards*:

C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1,2]
C 150 Standard Specification for Portland Cement[1,3]
C 260 Standard Specification for Air-Entraining Admixtures for Concrete[1]
C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[1]

3. Summary of Procedure

3.1 A mixture of fly ash, cement, air-entraining admixture, and water is shaken in a glass bottle to produce a foam. The foam is considered stable if it completely covers the water surface after a 45-second waiting period following 15 seconds of vigorous shaking. The minimum amount of admixture required to produce a stable foam when fly ash is present is compared with amount required when only cement is used.

4. Significance and Use

4.1 One of the potential disadvantages in the use of fly ash in air-entrained concrete is an abnormally high demand for air-entraining admixture with some ashes, usually attributed to the quantity and form of carbon in the ash. This test procedure identifies such ashes and provides an estimate of the amount of admixture required in concrete.

5. Terminology

5.1 Terms used in this procedure, with the exception of "foam index," are as defined in ASTM C 125.

5.2 Foam index is defined as the minimum amount of air-entraining admixture necessary to produce a stable foam under a prescribed set of conditions.

6. Apparatus

6.1 *Jar.*–A tightly stoppered, wide-mouth jar with a capacity of 16 fluid ounces (473 mL), and a length-to-diameter ratio of 1.0.

6.2 *Scales.*–Scales for determining mass of ingredients shall have an accuracy of 0.3 percent of mass being determined.

7. Materials

7.1 Cement shall comply with requirements of ASTM C 150; fly ash shall comply with requirements of ASTM C 618, class F or C; and air-entraining admixture shall comply with requirements of ASTM C 260.

8. Calibration and Standardization

8.1 No special calibration is required.

9. Conditioning

9.1 No conditioning of materials is required.

10. Procedure

10.1 Place 16 grams of cement, 4 grams of fly ash, and 50 mL of water in jar. Cap jar and shake for 15 seconds.

10.2 Add a small-measured amount of diluted (1 in 20 solution) air-entraining admixture, cap jar, and shake

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[1] *Annual Book of ASTM Standards*, vol. 04.02.
[2] *Annual Book of ASTM Standards*, vol. 04.03.
[3] *Annual Book of ASTM Standards*, vol. 04.01.

vigorously for 15 seconds. Allow jar to stand for 45 seconds.

10.3 Observe the foam. If foam completely covers surface, it is considered stable; if it does not, it is unstable.

10.4 If first trial produces unstable foam, add another increment of air-entraining admixture and repeat procedure. If first trial produces stable foam, discard sample and repeat procedure with a smaller quantity of air-entraining admixture. Continue repetitions until it is possible to estimate amount of admixture necessary to produce a stable foam.

10.5 Repeat the entire procedure using a mixture of 20 grams of cement and 50 mL of water.

10.6 This procedure is considered to be a 5-minute test. After a successful 5-minute test, let specimen stand for 45 minutes, shake vigorously for 15 seconds, allow to stand for 45 seconds, and then observe the foam. If now considered unstable, measure and add additional admixture to stabilize the foam. This is called the 45-minute test.

11. Interpretation of Results

11.1 The minimum quantity of admixture, expressed in concentrated form, required in each mixture to produce a stable foam is recorded as the foam index for that mixture for both the 5- and 45-minute test.

12. Report

12.1 A report on this procedure would probably be done by letter. Figure 1 shows a typical form for recording test results, this form should include:

- Identification of cement, fly ash, and air-entraining admixture.
- Foam index for cement-fly ash mixture for both the 5- and 45-minute test.
- Foam index for cement mixture without fly ash for both the 5- and 45-minute test.

13. Precision and Bias

13.1 The precision values for this procedure have not been determined.

13.2 There is no known bias.

Spec. or Solic. No. NA	Structure	Tested by J. OWENS Date 12-8-81
Project NA	Item RESEARCH Location DENVER LAB	Recorded by J. OWENS Date 12-8-81
Feature NA	Station ~ Offset ~ Depth ~ to ~	Checked by K. MITCHELL Date 12-8-81

LOSS OF ENTRAINED AIR WITH VARIOUS FLY ASHES (FOAM INDEX)

Fly Ash Sample No.	Brand Name	Plant ID	Class	Cement Sample No.	Brand Name	Plant ID	Type	Admixture Sample No.	Brand Name	Supplier	Foam Index, ounces or mL of AEA			
											Cement		Cement-Fly Ash	
											5 min	45 min	5 min	45 min
M-7430	PANHANDLE FLY ASH	CARLSBAD, NM	F	M-7120	IDEAL CEMENT	DEVIL'S SLIDE, UT	II LA	M-5553	SOL-AIR	SWIFT Co.	0.5 0.5	0.5 0.7	0.7 0.9	1.0 1.2

NOTES:

Figure 1. - Foam index determination at 5 and 45 minutes.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

March 3, 1849

USBR 4917-92

PROCEDURE FOR

WATER CONTENT OF FRESHLY MIXED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4917; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of an ASTM draft proposal for a new designation entitled "Standard Test Method for Determining Water Content of Freshly Mixed Concrete," and "Technical Report M-85/06 (revised) July 1985, Operations Guide and Modification Analysis for Use of the Corps of Engineers Concrete Quality Monitor on Roller-Compacted Concrete and Soil Cement" as presented by the Department of the Army Construction Engineering Research Laboratory, Champaign, Illinois.

1. Scope

1.1 This designation covers the procedures for three chemical methods for determining the free water content of a sample of freshly mixed concrete. These three methods are applicable to either laboratory or field conditions. The choice of which method to use is up to the discretion of the user; the existing environmental conditions may have some bearing on the choice.

2. Applicable Documents

2.1 *USBR Procedures*:
4094 Specifications for Ready-Mixed Concrete
4127 Specific Gravity and Absorption of Coarse Aggregate
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4172 Sampling Freshly Mixed Concrete
4918 Cement Content of Freshly Mixed Concrete

2.2 *ASTM Standard*:
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Materials[1]

2.3 *American Chemical Society Reagent Chemicals Specifications*[2]

3. Summary of Procedure

3.1 A given mass of freshly mixed concrete is intermixed with a chloride solution of given strength and volume. The chloride ion concentration of intermixed solution is directly related to water content of concrete sample, and is determined by volumetric titration or coulometric reference technique. A blank test is required that intermixes a given volume of distilled water with a concrete sample of given mass, and determines chloride ion concentration of intermixed blank solution by volumetric titration or coulometric reference technique. In method A [3,4], the chloride ion concentration is determined by adding an excess of a standard silver nitrate solution to a fixed volume of each intermixed solution. Chloride ions are thereby precipitated as silver chloride. The residual silver is determined by titrating with a standard thiocyanate solution in the presence of a ferric alum end-point indicator. In method B [5] and method C [6], the chloride ion concentration is determined by adding a fixed volume of intermixed solution to the acid buffer. The concentration is then determined using an instrumental coulometric reference technique. If blank test indicates no chlorides are present in concrete, the blank test may be waived in subsequent testing.

4. Significance and Use

4.1 Test results can be used to determine variability of water content within a single batch of concrete, and also the variability of water content between different batches of nominally identical concrete. If test is used to indicate concrete uniformity, correct and appropriate sampling procedures must be followed. Sampling procedures are referenced in section 8.

4.2 The water-cement ratio of a concrete sample can be estimated when test is used in conjunction with USBR 4918.

4.3 This procedure is not applicable to concretes containing certain materials that yield significant and varying amounts of chloride ions in solution under conditions of the tests.

METHOD A (KELLY-VAIL) — WATER CONTENT TEST BY VOLUMETRIC TITRATION

5. Apparatus

5.1 The apparatus components listed in sections 5.1.1 through 5.1.19 are recommended minimum selections necessary to conduct required analysis; other components

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[2] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on testing reagents not listed by the American Chemical Society, see references [1,2], section 31.

can be used. An acceptable selection of apparatus components is shown in table 1.

5.1.1 *Balance*.–The balance shall have a capacity of not less than 5.75 lbm (2600 grams), and a sensitivity to at least 0.00022 lbm (0.1 gram).

5.1.2 *Handtools*.–Shovel, hand scoops, and rubber gloves as required.

5.1.3 *Sample Tub*.–Polyethylene, 5-quart (4.7-L) capacity.

5.1.4 *Wide-Mouth Jar*.–Polyethylene, 1/2-gallon (1.9-L) capacity jar, with screw closure and lid (two required).

5.1.5 *Universal Mixer*.–End-over-end mixer (fig. 1), driven at 40 to 60 r/min, with the capacity to hold and turn end-over-end a 1/2-gallon (1.9-L) wide-mouth jar containing 5.5 lbm (2.5 kg) of material.

5.1.6 *Timer*.–A 0- to 15-minute industrial timer switch with automatic reset for use with mixer.

5.1.7 *Conical Beaker*.–Narrow mouth, with a 16.9-fluid ounce (500-mL) capacity (two required).

5.1.8 *Pipet*.–Volumetric pipet, glass, class A or B, with a 1.69-fluid ounce (50-mL) capacity.

5.1.9 *Automatic Pipet*.–Glass pipet (two required) with Teflon plug, with capacities of 0.85 and 0.34 fluid ounces (25 and 10 mL).

5.1.10 *Amber Reagent Bottles*.–Narrow-mouth, Boston rounds-from-amber, polypropylene bottles; 32-fluid ounce (950- to 1000-mL) capacity; two required.

5.1.11 *Rubber Stopper*.– No. 6 (two required), one with two holes and one with three holes for use with amber reagent bottles.

5.1.12 *Buret*.–Buret shall have an acrylic body with Teflon plug, class A or B accuracy, and of 3.38-fluid ounce (100-mL) capacity.

5.1.13 *Volumetric Flask*.–Polypropylene, 16.9-fluid ounce (500-mL) capacity, two required.

5.1.14 *Fixed Volume Dispensers*.–Polyethylene with polypropylene measuring chambers; two 0.07-fluid ounce (2-mL) and two 0.17-fluid ounce (5-mL) dispensers required.

5.1.15 *Carboy*.–Rectangular, aspirator-type with spigot; 2-gallon (7.6-L) capacity; made of linear polyethylene.

5.1.16 *Double Buret Clamp*.–Double buret holder clamp, nonferric alloy die casting, and nickel plated.

5.1.17 *Utility Clamp*.–Three-pronged grip and vinylized jaws.

5.1.18 *Rubber Tubing*.–Rubber latex tubing, 1/4-inch (6.4-mm) inside diameter and 10 feet (3 m) long, for connecting glass tubing siphon lines to 1.69-fluid ounce (50-mL) automatic pipets.

5.1.19 *Glass Tubing*.–Standard wall, 0.276-inch (7-mm), glass tubing siphon lines; two required for one rubber stopper and one required for other stopper.

NOTE 1.–Any volumetric dispenser that has an accuracy equal to or greater than ±0.0017 fluid ounce (±0.05 mL) and a reproducibility equal to or greater than ±0.0007 fluid ounce (±0.02 mL) is acceptable.

6. Reagents

6.1 *Purity of Reagents*.–Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available (see sec. 2.3). Other grades may be used provided it is first ascertained that reagent is of sufficiently high purity to permit its use without lessening accuracy of determination. A comparison of results obtained using the proposed grades with results obtained using reagent grade chemicals should be made to ensure that proposed grades are sufficiently pure, unless previous records confirm they are satisfactory.

6.2 *Purity of Water*.–Unless otherwise indicated, all references to water shall be understood to mean distilled water or water of equal purity.

6.3 *Ferric Alum Indicator Solution*.–Dissolve 0.11 lbm (50 g) of $FeNH_4(SO_4)_2 \cdot 12H_2O$ (ferric ammonium sulphate) in 3.4 fluid ounces (100 mL) of water, and add 5 drops of nitric acid solution (1 + 1).

6.4 *Nitric Acid Solution* (1 + 1).–Carefully add one volume of HNO_3 (concentrated nitric acid, sp. gr. 1.42) to one volume of tap water.

6.5 *Nitrobenzene* (sp. gr. 1.20).–*Caution*:$C_6H_5NO_2$ (nitrobenzene) is extremely toxic and is rapidly absorbed through the skin. Contact with skin or clothing and inhalation of fumes and vapors should be avoided. Precaution should be observed when using this chemical.

6.6 *Potassium Thiocyanate Solution* (0.05 *N*).–Dissolve 24.3±0.2 grams of dry KSCN (potassium thiocyanate) in water and dilute to 1.3 gallons (5 L).

6.7 *Silver Nitrate Solution* (0.5 *N*).–Dissolve 255±2 grams of dry $AgNO_3$ (silver nitrate) in distilled water and dilute to 0.79 gallon (3 L).

6.8 *Sodium Chloride Solution* (0.5 *N*).–Dissolve 292±3 grams of dry NaCl (sodium chloride) in tap water and dilute to 2.6 gallons (10 L).

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7.2 Specific precautions are addressed in section 6.5 on toxicity of nitrobenzene.

8. Sampling

8.1 The sample of concrete from which water content test specimens are made shall be representative of entire batch, and shall be not less than 44.1 lbm (20 kg). The sample shall be obtained in accordance with USBR 4172 and/or 4094; the latter designation outlines procedures for sampling for uniformity of concrete produced in truck mixers. If wet sieving of aggregates larger than 1-1/2 inches (37.5 mm) is not permitted, the wide-mouth jar (sec. 5.1.4) should be of adequate size to accommodate larger aggregate concrete.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 *Blank Equivalent Constant.*-Using an automatic pipet, place 0.34 fluid ounce (10 mL) of the 0.5 *N* $AgNO_3$ solution into a beaker. Using fixed volume dispensers, add 0.34 fluid ounce of HNO_3 (1 + 1), 0.17 fluid ounce (5 mL) of ferric alum indicator solution, and 0.07 fluid ounce (2 mL) of nitrobenzene. Shake well for a few seconds, and then titrate solution using a 3.38-fluid ounce (100-mL) buret of 0.05 *N* KSCN solution. Swirl contents of beaker during titration. Stop titration when an initial, permanent, reddish-brown color appears. Record volume of KSCN required to reach endpoint; this volume is the blank equivalent constant.

9.3 *Water Content Versus Potassium Thiocyanate Endpoint.*-Determine a mass of 100.0±0.1 grams for 3.38 fluid ounces (100 mL) of water. Place water in a clean, wide-mouth jar. Using a volumetric flask, add 16.9 fluid ounces (500 mL) of 0.5 *N* NaCl solution. Secure lid and mix in a universal mixer for 3 minutes. Remove jar from mixer and withdraw a 0.84-fluid ounce (25-mL) sample of intermixed solution using a volumetric pipet. Place this sample in a conical beaker. Using an automatic pipet, add 0.84 fluid ounce of 0.5 *N* $AgNO_3$ to beaker and, with fixed volume dispensers, add 0.34 fluid ounce (10 mL) of HNO_3 (1 + 1), 0.17 fluid ounce (5 mL) of ferric alum indicator solution, and 0.07 fluid ounce (2 mL) of nitrobenzene. Shake well. Titrate using a 3.38-fluid ounce (100-mL) buret of 0.05 *N* KSCN solution. Swirl contents of beaker during titration. Titrate to a permanent, reddish-brown color endpoint. Record volume of KSCN; this is KSCN volume required for a chloride-free concrete specimen containing 100 grams of water.

9.4 *Water Content Versus Total Potassium Thiocyanate Calibration Curve.*-Repeat procedure outlined in section 9.3 for 140.0±0.1 and 180.0±0.1 grams of water. Plot water content in grams versus KSCN in milliliters, and draw a smooth curve through calibration data.

9.5 *Calibration Requirements.*-The calibration procedures outlined in sections 9.2, 9.3, and 9.4 are required each time new reagents are used. A single-point calibration check, in accordance with procedure outlined in 9.3, is required on a weekly basis before testing concrete specimens. If single-point calibration check differs from established value by more than 0.02 fluid ounce (±0.50 mL) of KSCN, a complete recalibration is required.

9.6 The Bureau has never performed this test; therefore, no typical worksheets, calculations, etc., are included for method A.

10. Conditioning

10.1 The only conditioning required is the wet sieving of aggregates larger than 1-1/2 inches (37.5 mm) (if allowed), as discussed in section 8.1.

11. Procedure

11.1 Obtain two equal masses of 4.41±0.44 lbm (2000±200 g) each for test specimens from sample obtained in accordance with 8.1. Record exact mass of each test specimen to nearest 0.002 lbm (1 g).

NOTE 2.-The reason for the wide range of sample mass is to prevent mortar-aggregate ratio from being biased through adjustment of sample size.

11.2 Place each specimen into individual wide-mouth jars. Using a volumetric flask, add 16.9 fluid ounces (500 mL) of 0.5 *N* NaCl solution to one specimen (sample) and 16.9 fluid ounces of distilled water to other specimen (blank). Secure lids on jars.

11.3 Turn the two jars end-over-end, either by hand or in an end-over-end mixer. At least 75 complete revolutions are recommended if jars are turned by hand; if turned by a 40- to 60-r/min mixer, at least 2 minutes of mixing are recommended. Under no circumstances should jars be turned at a speed exceeding 80 r/min because any higher speed would prevent salt solution and distilled water from completely mixing with concrete samples.

11.4 Remove jars from mixer, loosen lids, allow contents to settle for 3 to 5 minutes; then withdraw 0.84 fluid ounce (25 mL) from each jar. Using a volumetric pipet, place the two withdrawals in separate conical beakers. Using an automatic pipet, add 0.84 fluid ounce (25 mL) of 0.5 *N* $AgNO_3$ solution to sample specimen and 0.34 fluid ounce (10 mL) of 0.5 *N* $AgNO_3$ solution to blank specimen. Using fixed volume dispensers, add 0.34 fluid ounce (10 mL) of HNO_3 (1 + 1), 0.17 fluid ounce (5 mL) of ferric alum indicator solution, and 0.07 fluid ounce (2 mL) nitrobenzene to each beaker. Shake well.

11.5 The chloride strength of the sample and blank solutions in the beakers are determined by titration using the 0.05 *N* KSCN solution that is in a 3.38-fluid ounce (100-mL) buret. Titration may be accelerated by initially adding 0.84 fluid ounce (25 mL) of 0.05 *N* KSCN with an automatic pipet, and then completing titration with the KSCN. Swirl contents of sample and blank beakers during titration. Stop titrations when first, permanent, reddish-brown color appears. Record volumes of KSCN solution required to reach endpoints. These volumes are represented by x in equation (1) and s in section 12.2. If concrete being tested does not contain chlorides, use of blank specimen may be discontinued after initial determination.

12. Calculations

12.1 Calculate KSCN equivalent of blank specimen as follows:

$$y = a - x \quad (1)$$

where:

y = KSCN equivalent of blank specimen, in milliliters;
a = blank equivalent constant, in milliliters, as determined in accordance with section 9.2; and
x = volume of KSCN, in milliliters, required to reach endpoint of blank specimen, as determined in accordance with section 11.5.

12.2 Water content is determined using calibration curve described in section 9.4. The KSCN value to be used with calibration curve is $s + y$, which is the volume of potassium thiocyanate solution required for sample plus volume of potassium thiocyanate equivalent of blank specimen. The computed water content shall be shown in pound mass (grams).

NOTE 3.–Computed water content is often stated as a percent of total specimen mass by dividing computed water content by recorded mass of test sample and multiplying by 100:

$$\text{Water content (percent)} = \frac{\text{Water content in pound mass (kilograms)}}{\text{Mass of sample in pound mass (kilograms)}} (100)$$

NOTE 4.–Computed water content may also be expressed:

$$\text{Water content in pound mass per cubic yard (kilograms per cubic meter)} = \frac{c}{M_s}(d) \quad (2)$$

where:

c = water in test sample, in pound mass (kilograms);
M_s = mass of test sample, in pound mass (kilograms); and
d = density of concrete, in pound mass per cubic yard (kilograms per cubic meter), as determined in accordance with USBR 4138.

12.3 Refer to section 9.6 for statement concerning calculations.

13. Precision

13.1 The single operator standard deviation has been found to be 0.55 percent; therefore, results of two properly conducted tests by same operator on same material should not differ by more than 1.56 percent.[3] Multilaboratory precision data have not been obtained.

METHOD B (USA-CERL/KELLY-VAIL) — WATER CONTENT TEST BY COULOMETRIC REFERENCE TECHNIQUE

14. Apparatus

14.1 *Balance.*–Refer to section 5.1.1.

14.2 *Hand Scoop.*–The hand scoop shall have a square mouth, be made of cast aluminum, and have a bowl size about 3 inches wide by 8 inches long (76 by 203 mm).

14.3 *Sample Tub.*–Refer to section 5.1.3.

14.4 *Wide-Mouth Jar.*–Refer to section 5.1.4.

14.5 *Centrifuge.*–Variable speed, four-place centrifuge for 0.51-fluid ounce (15-mL) tubes.

14.6 *Centrifuge Tubes.*–Disposable, polystyrene centrifuge tubes, 0.51-fluid ounce (15-mL) capacity (two required per test).

14.7 *Eppendorf Pipet.*–Tip ejector, fixed volume, 0.0034-fluid ounce (100-μL) capacity pipet.

14.8 *Disposable Pipet Tips.*–Disposable tips for 0.0034-fluid ounce (100-μL) Eppendorf pipet.

14.9 *Chloride Meter.*–The chloride meter accepts samples of either 0.0007-fluid ounce (20-μL) or 0.0034-fluid ounce (100-μL) capacity, and makes a coulometric determination of chloride with precision of duplicate chloride determinations having a coefficient of variation of 1.0 percent.

NOTE 5.–One known device meeting these requirements is the Corning Model 920M Chloride Meter.

14.10 *Volumetric Flask.*–Polypropylene volumetric flask with a 8.4-fluid ounce (250-mL) capacity.

14.11 *Carboy.*–Refer to section 5.1.15.

15. Reagents

15.1 *Purity of Reagents.*–Refer to section 6.1.

15.2 *Purity of Water.*–Distilled water or water of equal purity is required to run the blank test described in section 19.2. Unless otherwise indicated, tap water may be used.

15.3 *Sodium Chloride Solution* (0.5 *N*).–Refer to section 6.8.

NOTE 6.–Dry NaCl crystals dissolve slowly, and mechanical agitation is recommended to ensure that crystals completely dissolve.

15.4 *Acid Buffer Solution.*–A prepared reagent consisting of 0.075 lbm/gal (0.9 g/100 mL) of polyvinyl alcohol, 0.40 lbm/gal (4.8 g/100 mL) glacial acetic acid, 0.013 lbm/gal (0.16 g/100 mL) nitric acid, and 0.0003 lbm/gal (4 mg/100 mL) NaCl in deionized water.

NOTE 7.–One known source is Corning; this is a reagent for the Corning Model 920M Chloride Meter.

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[3] These percentage values represent, respectively, the 1S and D2S limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

16. Precautions

16.1 Refer to section 7.1.

17. Sampling

17.1 The sample of concrete from which water content test specimens are made shall be representative of entire batch, and shall be not less than 4.41 lbm (20 kg). The sample shall be obtained in accordance with USBR 4172 and/or 4094; the latter designation outlines procedures for sampling for uniformity of concrete produced in truck mixers.

18. Calibration and Standardization

18.1 Refer to sections 9.1 and 19.6.

19. Procedure

19.1 Obtain two equal masses of 4.41±0.44 lbm (2000±200 g) each for test specimens (note 2) from sample obtained in accordance with 17.1. Record exact mass of each test specimen to nearest 0.002 lbm (1 g).

19.2 Place each specimen into individual wide-mouth jars. Using a volumetric flask, add 8.4 fluid ounces (250 mL) of 0.5 *N* NaCl solution to one specimen (sample) and 8.4 fluid ounces of distilled water to other specimen (blank). Secure lids on jars.

19.3 Turn the two jars end-over-end, either by hand or in an end-over-end mixer. At least 75 complete revolutions are recommended if jars are turned by hand; if turned by a 40- to 60-r/min mixer, at least 2 minutes of mixing are recommended. Under no circumstances should jars be turned at a speed exceeding 80 r/min because any higher speed would prevent salt solution and distilled water from completely mixing with concrete samples.

19.4 After mixing, remove lids and pour solutions from each jar into two separate, centrifuge, tubes. Place tubes into the centrifuge, and centrifuge at 2,000 to 3,000 r/min for 3 to 4 minutes.

19.5 To prepare chloride meter for analysis, place sample selector toggle switch on 0.0034 fluid ounce (100 μL), place ON/OFF switch in ON position, pour 0.51 to 0.57 fluid ounce (15 to 17 mL) of acid buffer solution into meter's 0.68-fluid ounce (20-mL) beaker, place beaker onto stand, lower silver electrodes into beaker, and press conditioning switch to start conditioning cycle.

NOTE 8.–These steps are for use with the Corning Model 920M Chloride Meter; if another device is used, steps should be modified to meet manufacturer's calibration and operation procedures.

19.6 To determine chloride strength of blank sample, use, an Eppendorf pipet to transfer a 0.0034-fluid ounce (100-μL) specimen from blank sample centrifuge tube into meter's 0.68-fluid ounce (20-mL) beaker. Press titration switch. Record result and repeat test to ensure reproducibility. If meter's blank light is on, no chlorides are present. If concrete being tested does not contain chlorides, use of blank specimen may be discontinued after initial determination. When an air entrainer or a component which causes foam when centrifuged is present, an extra step is necessary. After centrifuging sample, wipe foam layer out of centrifuge tube with a cotton swab, and recentrifuge sample before obtaining the 0.0034-fluid ounce (100-μL) specimen.

19.7 To determine chloride strength of actual sample, use an Eppendorf pipet to transfer a 0.0034-fluid ounce (100-μL) specimen from actual sample centrifuge tube into meter's 0.68-fluid ounce (20-mL) beaker. Press titration switch. Record result and repeat test to ensure reproducibility to ±1 percent.

19.8 To determine chloride strength of the 0.5 *N* NaCl solution, use an Eppendorf pipet to transfer 0.0034 fluid ounce (100 μL) of 0.5 *N* NaCl solution into meter's 0.68-fluid ounce (20-mL) beaker. Press titration switch. Record result and repeat test to ensure reproducibility to ±1 percent.

20. Calculations

20.1 Calculate water content by using chloride strengths determined in accordance with procedure described in section 19:

Water content in fluid ounces (mL)

$$= (250)\ \frac{Std}{Sa - Bl\left(\frac{SaM}{BlM}\right)}\ -1 \qquad (3)$$

where:

Std = relative chloride strength of 0.5 *N* NaCl solution, in milliequivalents per liter (sec. 19.8);
Sa = relative chloride strength of sample solution, in milliequivalents per liter (sec. 19.7);
Bl = relative chloride strength of blank solution, in milliequivalents per liter (sec. 19.6);
SaM = mass of sample to nearest 0.0022 lbm (1 g); and
BlM = mass of blank to nearest 0.0022 lbm (1 g).

NOTE 9.–Computed water content is often stated as a percent of total specimen mass by dividing computed water content by recorded mass of test sample and multiplying by 100:

Water content (percent)

$$= \frac{\text{Water content in fluid ounces (milliliters)}}{\text{Mass of sample in pound mass (grams)}}\ (100)$$

NOTE 10.–Computed water content may also be expressed as shown in equation (2), note 4, section 12.2.

20.2 The Bureau has never performed this test; therefore, no typical worksheets or calculations are included for method B.

21. Precision

21.1 The single operator standard deviation has been found to be 0.53 percent; therefore, results of two properly conducted tests by same operator on same material should not differ by more than 1.50 percent[3]. Multilaboratory data have not been obtained.

22. Improved Accuracy: Correction for Sampling Errors

22.1 Small samples often do not contain representative amounts of coarse aggregate and, therefore, accuracy of water content determination may be improved by using the following procedure.

22.1.1 After water content is found, pour sample remaining in jar over a No. 4 (4.75-mm) sieve. Sieve the aggregate, and then rinse aggregate off to ensure that mass measured is not biased by residual cement and water slurry. Determine the SSD (saturated-surface-dry) mass of the damp coarse aggregate either by drying with a towel or by determining mass of sample immersed in water using procedures described in USBR 4127. For the latter method:

$$B = \frac{C}{1 - \left(\frac{1}{sg}\right)} \tag{4}$$

where:

B = SSD mass in air, in pound mass (kilograms);
C = immersed mass of aggregate, in pound mass (kilograms); and
sg = SSD specific gravity.

22.1.2 Determine coarse aggregate content of a larger sample of concrete, 0.5 ft^3 (0.014 m^3) for example, which is representative of the batch or load of concrete. Express the SSD mass of aggregate as a decimal fraction of mass of concrete (note 9).

22.1.3 Correct the determined water content (sec. 12.2) by multiplying it by the following fraction:

$$\frac{1 - A_t}{1 - A_s}$$

where:

$A_t = \frac{B}{M_s}$,
B = as defined in equation (4),
M_s = as defined in equation (2), and
A_s = decimal fraction of mass of concrete (sec. 22.1.2).

NOTE 11.–In some instances, it may be possible to use a theoretical A_s derived from the batch masses and coarse aggregate sieve analysis. Such values will be in error to the extent that the sieve analysis of the coarse aggregate passing the No. 4 (4.75-mm) sieve varies in individual batches.

22.2 Refer to section 20.2 for statement concerning calculations.

Method C — Corps of Engineers Concrete Quality Monitor Water Content of Soil Cement or Roller-Compacted Concrete

23. Apparatus

23.1 *Balance.*–Refer to section 5.1.1.
23.2 *Hand Scoop.*–Refer to section 14.2.
23.3 *Sample Tub.*–Refer to section 5.1.3.
23.4 *Wide-Mouth Jar.*–Refer to section 5.1.4.
23.5 *Centrifuge.*–Refer to section 14.5.
23.6 *Centrifuge Tubes.*–Refer to section 14.6.
23.7 *Eppendorf Pipet.*–Tip ejector, fixed volume, 0.0007-fluid ounce (20-µL) capacity pipet.
23.8 *Disposable Pipet Tips.*–Disposable tips for 0.0007-fluid ounce (20-µL) Eppendorf pipet.
23.9 *Chloride Meter.*–Refer to section 14.9 and note 5.
23.10 *Volumetric Flask.*–Refer to section 14.10.
23.11 *Carboy.*–Refer to section 5.1.15.
23.12 *Beakers.*–Polypropylene Griffin low-form, graduated, 8.45-fluid ounce (250-mL) capacity beakers.

24. Reagents

24.1 *Sodium Chloride Solution* (0.5 *N*).–Refer to section 6.8.

24.2 *Acid Buffer Solution.*–Refer to section 15.4 and note 7.

25. Precautions

25.1 Refer to section 7.1.

26. Sampling

26.1 The sample of concrete from which the water content test specimens are made shall be representative of the entire batch and shall not be less than 26.4 to 33 lbm (12 to 15 kg). The sample shall be obtained in accordance with USBR 4172 and/or 4094; the latter designation outlines procedures for sampling the uniformity of concrete prepared in truck mixers.

27. Calibration and Standardization

27.1 Refer to sections 9.1 and 28.

28. Procedure

NOTE 12.–The Corning 920M chloride meter provides readouts in metric units only; therefore, the following procedural steps address only metric quantities.

28.1 The CQM (Concrete Quality Monitor) water content test consists of adding 250 mL of a 0.5 *N* NaCl solution to a 2-kg concrete sample, intermixing the two, and determining the chloride concentration of the intermixed supernatant salt solution using the Corning 920M chloride meter. If the concrete contains chlorides from other sources, both an actual and a blank sample must be used. The blank sample should be 250 mL of distilled water added to a 2-kg concrete sample.

28.2 Obtain a 12- to 15-kg sample of fresh concrete, mix to ensure homogeneity, and prepare two subsamples of at least 2±0.2 kg each (note 13). Record exact mass of each subsample to nearest gram. Place one subsample in a wide-mouth jar and, using a volumetric flask, add 250 mL of distilled water. Secure lid on jar. This is the blank sample required for estimating chlorides in the concrete itself.

NOTE 13.–The reason for the wide range of sample mass is to prevent biasing the mortar/aggregate ratio of the sample by adjusting the sample size.

28.3 Place the second 2-kg sample in another wide-mouth jar, add 250 mL of 0.5 *N* NaCl solution, and secure lid.

28.4 Turn both jars end-over-end, either by hand or in an end-over-end mixer. A minimum of 75 complete revolutions is recommended if the jars are turned by hand; if turned by a 40- to 60-r/min mixer, a minimum of 2 minutes is recommended.

NOTE 14.–Under no condition should the jars be turned so rapidly that the centrifugal force would exceed the gravitational force because the excess speed would prevent the salt solution and distilled water from completely mixing with the concrete.

28.5 After mixing, remove jar lids and pour the water-cement slurry from the blank sample and the NaCl solution-cement slurry from the actual sample into the centrifuge tubes. Place these tubes into the centrifuge and run at 2000 to 3000 r/min for 3 to 4 minutes.

28.6 Prepare chloride meter for analysis by (1) placing sample selector toggle switch on 100 µL and placing ON/OFF switch to ON, (2) placing 15 to 17 mL of acid buffer solution into the 20-mL beaker of the meter, (3) placing beaker on stand, (4) lowering the silver electrodes, and (5) starting the conditioning cycle by pressing the conditioning switch. These five steps are required only at the beginning of each day or when buffer solution sign indicates that it needs changing (about every five to eight readings).

pipetting 20 µL of blank sample, using an Eppendorf pipet, into meter's 20-mL beaker (note 15). Press titration switch. Record result and repeat test to ensure reproducibility, *Bl* in equation (3). If meter's blank light is on, no chlorides are present.

NOTE 15.–The 20-µL sample will result in a reading of about 100 on the NaCl chloride meter; if desired, a 100-µL sample may be used.

28.8 Determine chloride strength of actual sample by pipetting 20 µL of actual sample, using an Eppendorf pipet, into meter's 20-mL beaker (note 15). Press titration switch. Record result and repeat test to ensure reproducibility to ±1 percent, *Sa* in equation (3).

28.9 Determine chloride strength of the 0.5 *N* NaCl solution by pipetting 20 µL of this solution, using an Eppendorf pipet, into the meter's 20-mL beaker. Press titration switch. Record result and repeat test to ensure reproducibility to ±1 percent, *Std* in equation (3). The water content can now be calculated using equation (3) in section 20.

28.10 If concrete being tested does not contain chlorides; that is, if chloride strength of blank sample equals zero, the blank sample tests may be terminated.

29. Comparison With Mix Design Values

29.1 The water contents determined using the CQM method should be compared with the batch proportion values. If this comparison varies by less than 10 percent, it may be assumed that the CQM method is working properly, the concrete batch is homogeneous, and that the batched proportion values are correct. If the compared results vary by more than 10 percent, a second complete CQM test should be run. The 2-kg test samples for this rerun should be taken from the original 12- to 15-kg sample collected for the initial runs. Use extreme care on the rerun to ensure that no procedural errors are made. If second test agrees closely with the batch proportion values, it may be assumed that initial test was in error. If second test is significantly different from both the batch values and initial test or if second test agrees closely with initial test, one of three possibilities has occurred:

(1) concrete sample is not representative of bulk, which indicates poor mixer efficiency and nonhomogeneity;
(2) batch is not the same as indicated by batch proportions; or
(3) CQM system is incorrectly calibrated.

29.2 Figure 2 shows a series of analytical steps for determining which of the three possible problems has occurred. It is recommended that an inquiry be made as to any possible changes or problems that may have occurred at the batch plant.

29.3 Figure 3 shows a sample worksheet with typical data and calculations.

30. Report

30.1 No sample reporting form is included for this test procedure.

31. References

[1] Rosen, Joseph, *Reagent Chemicals and Standards*, D. Van Nostrand Co., Inc., New York, NY.

[2] *United States Pharmacopeia and National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Streets, Easton, PA, 18042, 1980.

[3] Kelly, R. T. and J. W. Vail, "Rapid Analysis of Fresh Concrete," *Concrete*, April 1968, pp. 140-145, and May 1968, pp. 206-210.

[4] Howdyshell, P. A., *Operations Guide: Water and Cement Content of Fresh Concrete*, Technical Report M-177/ADA 022697, U.S. Army Construction Engineering Research Laboratory, USA-CERL, September 1975.

[5] Howdyshell, P. A., *Revised Operations Guide for a Chemical Technique to Determine Water and Cement Content of Fresh Concrete*, Construction Engineering Research Laboratory Technical Report M-212/ADA 039120 (USA-CERL), Interstate Research Park, P O Box 4005, Champaign, IL, 61820, April 1977.

[6] Howdyshell, P. A., *Corps of Engineers Concrete Quality Monitor: Operations Guide*, Technical Report M-293/ADA 102753, USA-CERL, May 1981.

Table 1. – Test equipment for determining water content.

Item No.	Equipment	Quantity[1]			Description	Source[2]
		Method A	Method B	Method C		
1	Balance	1	1	1	Triple beam, 2600-g min. capacity, 0.1-g sensitivity.	ES
2	Hand scoop	1	1	1	One piece, cast-aluminum, bowl size about 3 inches wide by 5 or 8 inches long (76 by 127 or 230 mm).	ES
3	Sample tub	1	1	1	Polyethylene, 5-qt. (4.7-L) capacity.	DS
4	Wide-mouth jar	2	2	2	Polyethylene, 0.5-gal (1.9-L) capacity, with screw closure and lid.	LGS
5	Universal mixer	1	–	–	End-over-end mixer, double-ended shaft, driven at 40 to 60 r/min by a 1/4-hp (0.19-kW) a-c motor. Capable of turning the wide-mouth jars containing 5.5 lbm (2.5 kg) of material.	LES
6	Timer	1	–	–	0- to 15-min industrial timer switch with automatic reset (115 V, 60 cycle); for use with item 5.	LES
7	Beaker	–	–	1	Polypropylene, Griffin low-form graduated, 250-mL capacity (sold in case lots of six).	LES
8	Conical beaker, 500 mL	2	–	–	Glass, narrow-mouth. To allow for breakage, a shelf-pack of 12 is normally ordered.	LGS
9	Amber bottles	2	–	–	Narrow-mouth, Boston rounds-from-amber, polypropylene bottles; 32-fl. oz. (950- to 1000-mL) capacity. Normally ordered in packages of six bottles.	LGS
10	Rubber stopper	2	–	–	No. 6 size, one with two holes and one with three holes.	LGS
11	Pipet, 25 mL	1	–	–	Volumetric pipet, glass, class A or B. To allow for breakage, a shelf-pack of 12 is normally ordered.	LGS
12	Automatic pipet,				Glass pipet with Teflon plug. To allow for breakage, two cases (two per case) are normally ordered.	LGS
	10 mL	1	–	–		
	25 mL	2	–	–		
13	Eppendorf pipet	–	1	1	Tip ejector, fixed volume, one of 0.0034-fl. oz. (100-µL) capacity, and one of 0.0007-fl. oz. (20-µL) capacity.	LGS
14	Disposable pipet tips	–	As req'd.	3	Disposable tips for the pipets listed in item 13.	LGS
15	Buret, 100 mL	1	–	–	Acrylic body with Teflon plug, class A or B accuracy.	LGS
16	Volumetric flask				Polypropylene.	LGS
	500 mL	2	–	–		
	250 mL	–	1	1		
17	Fixed volume dispensers					
	2 mL	1	–	–	Polyethylene with polypropylene measuring chambers.	LGS
	5 mL	2	–	–		
18	Carboy	1	1	1	Rectangular, aspirator-type with spigot and screw closure; 2-gal (7.6-L) capacity; linear polyethylene.	LGS

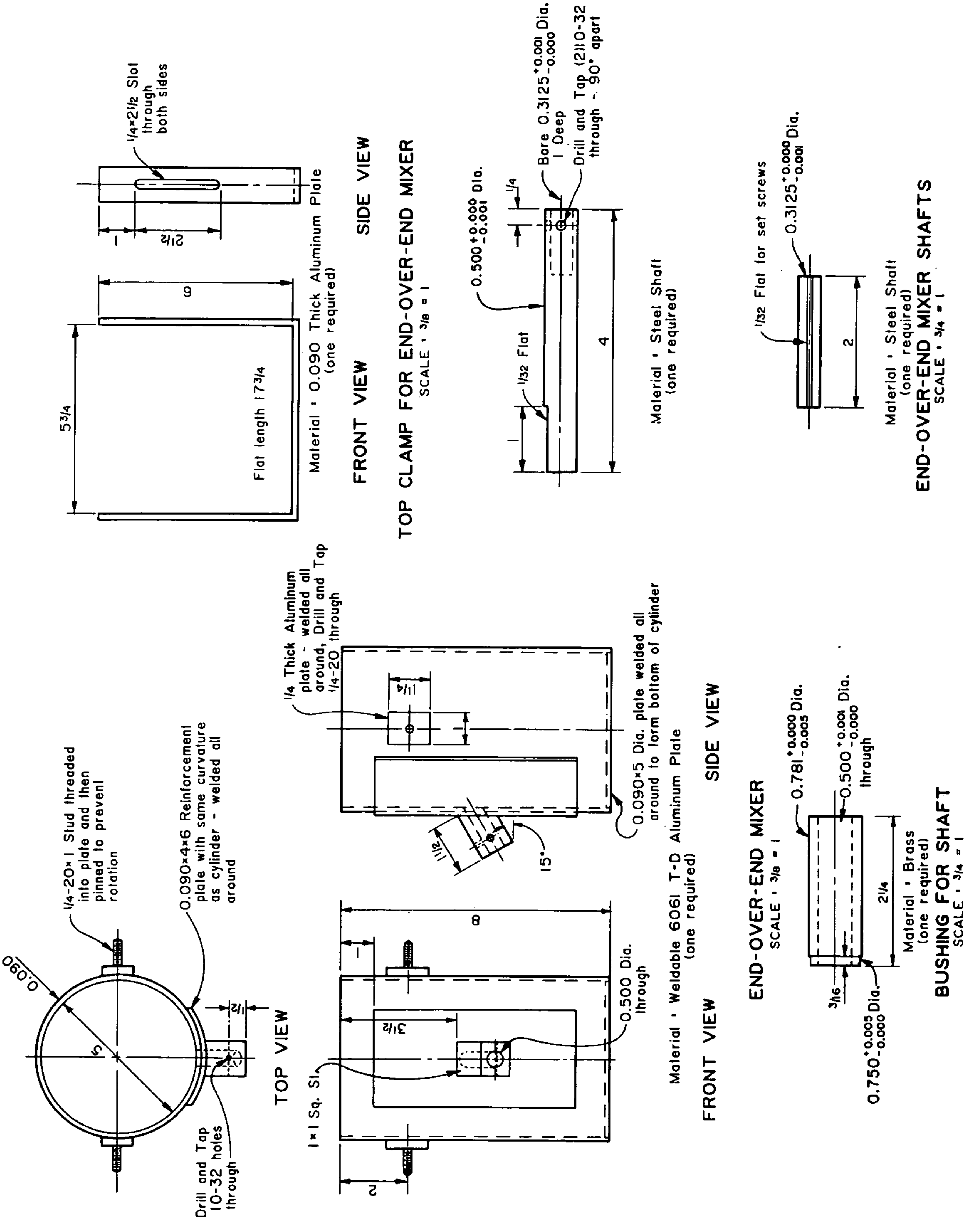
Table 1. – Test equipment for determining water content–Continued.

Item No.	Equipment	Quantity[1]			Description	Source[2]
		Method A	Method B	Method C		
19	Double buret clamp	1	–	–	Double buret holder clamp, nonferric alloy die casting, nickel-plated.	LGS
20	Utility clamp	1	–	–	Three-pronged grip and vinylized jaws.	LGS
21	Rubber tubing	10 ft (3.05 m)	–	–	Amber rubber latex tubing, 0.25-inch (6.4-mm) i.d., std. 1/16-inch (1.6-mm) wall thickness. Normally sold in 96-foot (29.3-m) lengths.	LGS
22	Glass tubing	3 lines	–	–	Glass tubing, 0.276-inch (7-mm) o.d. by 10 inches (254 mm) long, standard wall thickness.	LGS
23	Centrifuge	–	1	1	Variable speed, four-place centrifuge for 0.51-fl. oz. (15-mL) tubes.	LGS
24	Centrifuge tubes	–	(2 per test)	(2 per test)	Disposable polystyrene tubes of 0.51-fl. oz. (15-mL) capacity.	LGS
25	Chloride meter	–	1	–	A chloride meter that will accept a 0.0007- or 0.0034-fl. oz. (20- or 100-μL) sample of chloride for coulometric determination. The Corning Model 920M Chloride Meter is one known device that meets requirements.	LES or LGS

[1] Quantity required to conduct tests.

[2] Source:

ES indicates equipment suppliers for concrete and soils testing labs.
DS indicates domestic food freezer supplier.
LGS indicates laboratory glass supplier.
LES indicates laboratory equipment supplier.



Note : All dimensions shown in inches, 1 inch = 25.4 mm.

Figure 1. – Details of an end-over-end mixer.

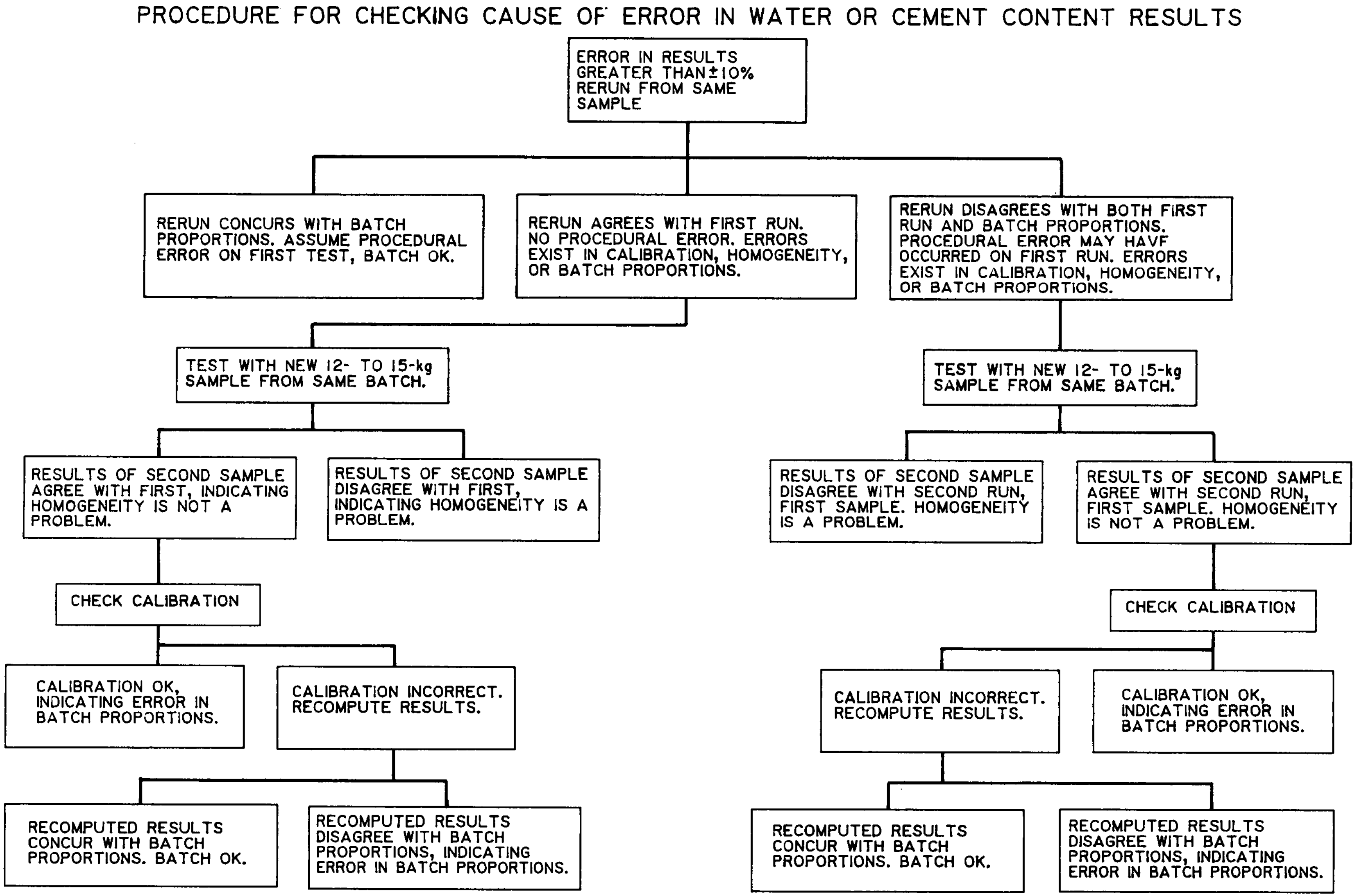


Figure 2. – Procedure for checking cause of error in water content results.

Spec. or Solic. No. NOT AVAILABLE	Structure ROLLER-COMPACTED CONCRETE	Tested by CORPS OF ENGINEERS Date 1982
Project WILLOW CREEK DAM HEPPNER, OR	Item RESEARCH Location TROUTDALE, OR	Computed by ~ Date
Feature WILLOW CREEK DAM	Station ~ Offset ~ Depth ~ to ~	Checked by ~ Date

WATER CONTENT OF FRESHLY MIXED CONCRETE

1	2	3	4	5	6	7	8
Sample No.	*Std* Chloride Strength of 0.5 *N* NaCl Solution, meq/L	*Sa* Chloride Strength of Sample Solution, meq/L	*Bl* Chloride Strength of Blank Solution, meq/L	*SaM* Mass of Sample Solution, grams	*BlM* Mass of Blank Solution, grams	Water Content in mL, Equation (3)	Water Content in Percent, $\frac{7}{5}$ (100)
1	94	57	0				
	93	58	0				
	95	59	0				
		56	0				
AVERAGE	94.0	57.5	0	3465	3465	158.7	4.58
2	94	73	0				
	94	73	0				
	94		0				
AVERAGE	94.0	73.0	0	2815	2815	85.6	3.04

Figure 3. - Sample calculation form for determining water content using method C.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4918–92

PROCEDURE FOR

CEMENT CONTENT OF FRESHLY MIXED CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4918; the number immediately following the designation indicates year of original adoption or year of last revision. This test procedure is a modified version of an ASTM draft proposal for a new designation entitled "Standard Test Method for Determining Cement Content of Freshly Mixed Concrete," and "Technical Report M-85/06 (revised) July 1985, Operations Guide and Modification Analysis for Use of the Corps of Engineers Concrete Quality Monitor on Roller-Compacted Concrete and Soil Cement" as presented by the Department of the Army Construction Engineering Research Laboratory, Champaign, Illinois.

1. Scope

1.1 This designation covers the procedures for three physical-chemical methods for determining cement content of a sample of freshly mixed concrete. These three methods are applicable to all freshly mixed portland cement concrete batches for which calibration can be obtained in advance, except for those containing certain aggregates, fly ash, or admixtures that, when washed over a No. 100 (150-µm) sieve, yield significant and varying amounts of calcium ions in solution under conditions of test. The choice of which method to use is up to the discretion of the user; existing environmental conditions may have some bearing on the choice.

2. Applicable Documents

2.1 *USBR Procedures*:
4094 Specifications for Ready-Mixed Concrete
4127 Specific Gravity and Absorption of Coarse Aggregate
4138 Density, Yield, Clean Separation, and Air Content (Gravimetric) of Concrete
4172 Sampling Freshly Mixed Concrete
4917 Water Content of Freshly Mixed Concrete

2.2 *ASTM Standards*:
C 670 Standard Practice for Preparing Precision Statements for Test Methods for Construction Material[1]
E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes[2]

2.3 *American Chemical Society Reagent Chemicals Specifications*;[3]

3. Summary of Procedure

3.1 A given mass of freshly mixed concrete is washed with a given volume of water over a nest of sieves. The water is agitated so as to uniformly suspend cement and other fine particles washed from concrete (those particles passing finest sieve). A constant-volume representative sample of the cement suspension is obtained and diluted with a known volume of nitric acid and water. The diluted sample is agitated without heat to dissolve calcium compounds in the cement. The calcium ion concentration of resulting solution is determined by manual volumetric titration in Method A [3,4] or by instrumental fluourometric determination in Method B [5], and is correlated to cement content of specimen by a previously developed calibration curve. Method C [6] uses somewhat different equipment to separate the aggregate and cement to obtain a representative sample of the cement suspension. This method includes the use of a commercially available calcium analyzer and chloride meter for determining the calcium and chloride solution strengths, respectively [4].

4. Significance and Use

4.1 Test results can be used to determine variability of cement content within a single batch of concrete, and also the variability of cement content between batches of nominally identical concrete. If test is used to indicate concrete uniformity, correct and appropriate sampling procedures must be followed. Sampling procedures are referenced in section 8.

4.2 The water-cement ratio of a concrete sample can be estimated when test is used in conjunction with USBR 4917.

4.3 This procedure is not applicable to concretes containing certain aggregates, fly ash, or admixtures that, when washed over a No. 100 (150-µm) sieve, yield significant and varying amounts of calcium ions in solution under conditions of the tests, see section 1.1.

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[1] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.03, 04.08.

[2] *Annual Book of ASTM Standards*, vols. 04.01, 04.02, 04.06, 05.05, 14.02.

[3] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington DC. For suggestions on testing reagents not listed by the American Chemical Society, see references [1,2], section 31.

METHOD A (KELLY-VAIL) — CEMENT CONTENT BY MANUAL VOLUMETRIC TITRATION

5. Apparatus

5.1 The apparatus components listed in sections 5.1.1 through 5.1.20 are recommended minimum selections necessary to conduct required analysis; other components can be used, see references [5,6]. An acceptable selection of apparatus components is shown in table 1.

5.1.1 *Balance.*-The balance shall have a capacity of not less than 5.75 lbm (2600 grams), and a sensitivity to at least 0.00022 lbm (0.1 gram).

5.1.2 *Handtools.*-Shovels, hand scoops, and rubber gloves as required.

5.1.3 *Sample Tub.*-Polyethylene, 5-quart (4.7-L) capacity.

5.1.4 *Specimen Tub.*-Polyethylene, 2-quart (1.9-L) capacity.

5.1.5 *Washing Machine.*-Domestic, portable, washing machine; must have a smooth interior, side-mounted impeller, and recirculating pump and hose. The recirculating hose shall be fitted with a T-piece and have 3 feet (0.91 m) of 1/4-inch (6.4-mm) inside-diameter, latex tubing for connecting to linked pipet. The inside dimensions of the washing machine tub shall be a minimum of 15-5/16 by 12-5/16 inches (389 by 313 mm), and capable of holding a 15-5/16- by 12-5/16-inch nest of sieves. Working capacity of the tub shall be 10 gallons (37.6 L).

NOTE 1.-The cement suspension tank described in section 14.5 may be fitted with the T-piece and substituted for the washing machine.

5.1.6 *Sieve Nest.*-Rectangular steel frame, 15-5/16 by 12-5/16 by 8 inches (389 by 313 by 203 mm), with a No. 50 (300-μm) sieve at bottom and a No. 4 (4.75-mm) sieve at midheight. The No. 4 sieve should be removable. A separate sieve frame, 4 inches (102 mm) deep, with a No. 100 (150-μm) sieve at the bottom, shall be nested below the No. 50 sieve of the top frame.

NOTE 2.-The No. 100 sieve should be used with the No. 50 and No. 4 sieves when a calcareous[4] fine aggregate is encountered. The combination of sieves used for calibration and cement content testing must be consistent.

NOTE 3.-If cement suspension tank listed in section 14.5 is used, the sieve nest listed in section 14.6 should be used.

5.1.7 *Wash Bottle.*-Polyethylene, 1.69-fluid ounce (50-mL) capacity.

5.1.8 *Linked Pipets.*-A 4.23±0.34-fluid ounce (125±10-mL) glass pipet with an automatic leveling and overflow device, and fitted with a three-way tap is required. To this pipet is attached a 3.38±0.34-fluid ounce (100±10-mL) automatic pipet with a three-way tap that can empty its contents through the larger pipet without draining the contents out of the overflow device. The reproducibility of the automatic pipet must be ±0.2 percent.

5.1.9 *Automatic Pipet.*-A 10.14±0.84-fluid ounce (300±25-mL) automatic glass pipet fitted with a three-way tap. Reproducibility of this pipet must be ±0.2 percent.

5.1.10 *Carboy.*-Rectangular, aspirator-type with spigot and screw closure, 2-gallon (7.6-L) capacity, made of linear polyethylene (two required).

5.1.11 *Magnetic Stirrer.*-Variable-speed magnetic stirrer (milkshake type) with Teflon-coated magnetic stirring rod.

5.1.12 *Buret.*-Buret shall have an acrylic body with Teflon plug, class A or B accuracy, and of 3.38-fluid ounce (100-mL) capacity. A three-pronged utility clamp and a support base and rod are required to hold buret.

5.1.13 *Fixed Volume Dispenser.*-Polyethylene dispenser with a polypropylene measuring chamber, 0.17-fluid ounce (5-mL) capacity.

5.1.14 *Rubber Tubing.*-Rubber latex tubing, 0.5-inch (13-mm) inside diameter and 20 feet (6.1 m) long.

5.1.15 *Timer.*-A 0- to 15-minute industrial timer switch with automatic reset.

5.1.16 *Dropping Bottle*-Polyethylene, 1.01-fluid ounce (30-mL), narrow-mouth bottle and dropping pipet.

5.1.17 *Conical Beakers or Erlenmeyer Flasks.*-Narrow-mouth, conical beakers or Erlenmeyer flasks; glass. One 16.9-fluid ounce (500-mL) capacity and one 27.05- or 33.81-fluid ounce (800- or 1000-mL) capacity required.

5.1.18 *Utility Clamp.*-Three-pronged grip and vinylized jaws.

5.1.19 *Pipet.*-Volumetric glass pipet, class A or B, with a 0.84-fluid ounce (25-mL) capacity.

5.1.20 *Suction Bulb.*-Rubber suction bulb, recommended when pipetting the 0.84-fluid ounce cement sample.

6. Reagents

6.1 *Purity of Reagents.*-Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[3] Other grades may be used, provided it is first ascertained that reagent is of sufficiently high purity to permit its use without lessening accuracy of determination. A comparison of results obtained using the proposed grades with results obtained using reagent grade chemicals should be made to ensure that proposed grades are sufficiently pure, unless previous records confirm they are satisfactory.

6.2 *Purity of Water.*-Unless otherwise indicated, all references to water shall be understood to mean distilled water or water of equal purity. The primary use of the distilled water is for reagent preparation.

6.3 *Ammonium Hydroxide* (ammonium chloride buffer solution, pH = 10).-Add 4.8 fluid ounces (142 mL)

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[4] A fine aggregate is regarded as "calcareous" when results of a chemical analysis show in excess of 20 percent calcium oxide.

of NH_4OH (ammonia hydroxide), assay as NH_3 (ammonia) (w/w) 28 to 30 percent, to 0.039 pound mass (17.5 g) of NH_4Cl (ammonia chloride), and dilute to 8.4 fluid ounces (250 mL) with water. The ammonium hydroxide in the buffer solution evaporates rapidly. The solution should be kept under cover except when dispensing reagents to minimize evaporation.

6.4 *Eriochrome Black T Indicator Solution*.-Dissolve 0.5 gram of Eriochrome Black T, color index No. 14645, in 0.84 fluid ounce (25 mL) of triethanolamine. The indicator solution has a storage life of about 2 months.

6.5 *Nitric Acid Solution* (1 + 19).-Add 1 volume of concentrated HNO_3 (nitric acid, sp. gr. 1.42) to 19 volumes of water.

6.6 *Di-Sodium Ethylenediaminetetracetate* (0.01*N*).-Dissolve 3.72±0.01 grams of EDTA (di-sodium ethylenediaminetetracetate) in water and dilute to 33.8 fluid ounces (1 L). Store EDTA solution in polyethylene bottles.

7. Precautions

7.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

7.2 A precaution is given in section 11.5 on color perception.

8. Sampling

8.1 The sample of concrete from which cement content test specimen is taken shall be representative of entire batch, and shall have a mass of not less than 44.1 lbm (20 kg). The sample shall be obtained in accordance with USBR 4172 and/or 4094, the latter designation outlines procedures for sampling for uniformity of concrete produced in truck mixers.

9. Calibration and Standardization

9.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard.

9.2 *Aggregate Blank*.-Prepare a representative 4.4-lbm (2-kg) sample of concrete using materials and mix proportions of the concrete to be tested minus the cement. The sample mass should be 4.4 lbm minus the mass of cement which would be contained in a 4.4-lbm sample of concrete. To determine the relative calcium ion content of these materials, follow the steps outlined in sections 11.2 through 11.5. Record the volume of EDTA solution required for "aggregate blank."

NOTE 4.-If 6.6-lbm (3-kg) specimens are tested, procedure should be followed for 6.6 lbm instead of 4.4 lbm.

9.3 *Cement*.-Using materials and mix proportions of the concrete to be tested, hand mix a 4.4-lbm (2-kg) sample of concrete. Determine mass of cement and water for this mix to nearest 0.022 lbm (1 g), and determine mass of aggregates to nearest 0.022 lbm (10 g). Ensure that all cement from tools, mixing bowl, etc., is washed into washing machine. Determine relative calcium ion content of this mix by following the steps outlined in sections 11.2 through 11.5. Record volume of EDTA solution required for cement calibration specimen (note 4).

9.4 *Calibration Curve*.-To construct the linear calibration curve of cement content versus volume of EDTA required, plot zero cement and volume of EDTA required for aggregate blank (sec. 9.2) as one point. Plot mass of cement in 4.4-lbm (2-kg) concrete calibration sample and volume of EDTA required (sec. 9.3) as a second point. Connect the two points by a straight line to complete calibration curve for these sources and types of cement and aggregate. All unknown cement contents are linearly proportional in terms of calcium ion content [5].

9.5 *Calibration Requirements*.-Both the cement calibration test (sec. 9.3) and aggregate blank test (sec. 9.2) must be repeated each time tap water sources, additives, aggregate sources, cement source, or cement type change; and each time a new EDTA reagent solution is used. A daily cement calibration test should be made. The results of the three most recent daily tests must agree within 5 percent; if they do not, three tests should be made each day. After 3 days of three-a-day test averages being within 5 percent of each other, one test per day may be resumed until deviation exceeds 5 percent.

9.6 The Bureau has never performed this test; therefore, no typical worksheets, calculations, etc., are included for Method A.

10. Conditioning

10.1 Conditioning of concrete for calibration is covered under section 9.

11. Procedure

11.1 Obtain a 4.41±0.44-lbm (2000±200-g) test specimen from concrete sample in accordance with section 8.1. The concrete shall contain aggregate sizes up to 1-1/2 inches (37.5 mm). Record exact mass of test specimen to nearest 0.0022 lbm (1 g). Also, obtain a 6.6±0.66-lbm (3000±300-g) test specimen of sample for concrete containing aggregate sizes greater than 1-1/2 inches. Correct for coarse aggregate variance as described in section 22.

NOTE 5.-The reason for the wide range of sample mass is to prevent the mortar-aggregate ratio from being biased through adjustment of sample size.

11.2 Fill washing machine with 10±0.1 gallons (37.9±0.4 L) of tap water. Transfer test specimen to sieves nested over washing machine, and turn on recirculating pump and agitator of machine. Wash the plus No. 4 (+4.75-mm) aggregates carefully on the sieve using the jet of water from recirculating pump hose. After all cement has been removed from aggregate retained on No. 4 sieve, remove sieve (note 6). Wash the plus No. 50 (+130-μm) aggregate on sieve for about 1-1/2 minutes or until all cement has been removed from aggregate. If both the No. 50 (300-μm) and the No. 100 (150-μm) sieves are used, remove the No. 50 sieve at this time and wash aggregate retained on No. 100 sieve for 1-1/2 minutes. Squeeze end of large-bore recirculating hose to force cement suspension to flow through T-piece and 1/4-inch (6.4-mm) inside diameter tubing. Rapidly release recirculating hose to allow cement suspension to flow through it. As soon as hose is released, connect end of the 1/4-inch tubing to 4.23-fluid ounce (125-mL) linked pipet. Squeeze recirculating hose again to direct cement suspension into pipet. When pipet is filled to overflow device, switch off lower pipet tap and release recirculating hose.

NOTE 6.–For greater accuracy, aggregate retained on No. 4 (4.75-mm) sieve may be used in procedure described in section 22.

11.3 Drain the 4.23-fluid ounce (125-mL) aliquot of cement suspension into 27.05-fluid ounce (800-mL) beaker. Wash out the 4.23-fluid ounce linked pipet using 3.38 fluid ounces (100 mL) of HNO_3 solution from automatic pipet positioned above the linked pipet. Leave tap on the lower 4.23-fluid ounce linked pipet open during this washing so that acid wash solution will flow into 27.05-fluid ounce beaker. Dilute the cement-HNO_3 solution in beaker with 10.14 fluid ounces (300 mL) of tap water from the 10.14-fluid ounce automatic pipet. Place a Teflon-coated magnetic stirring rod in beaker and stir contents on a magnetic stirrer for 3 minutes.

11.4 Pipet off 0.84 fluid ounce (25 mL) of resulting cement solution after stirring is completed, and place in a 16.9-fluid ounce (500-mL) conical beaker. Using a fixed-volume dispenser, add 0.34 ounce (10 mL) of ammonia-ammonium chloride buffer solution and 4 to 8 drops of the Eriochrome Black T indicator solution. The same number of drops should be used for both the calibration and test samples. To obtain a clear and distinct endpoint, buffer must be added before indicator solution.

11.5 The calcium ion concentration of the solution in the 16.9-fluid ounce beaker is determined by an EDTA endpoint titration using a 3.38-fluid ounce (100-mL) buret. Swirl contents of beaker during titration. Stop titration when solution turns from a red-wine color to a pronounced blue. Record volume of EDTA solution required to reach endpoint. Operators should not wear tinted glasses or sunglasses during calcium titration process because such glasses may alter the perception of the red-wine to blue endpoint.

12. Calculations

12.1 Determine cement content of sample by first correcting result from section 11.5 to an exact 4.41-lbm (2000-g) sample,[5] and then referring to calibration graph. Correct data by following formula:

$$R = [TW_1 + (M_C - TW_1)] \left(\frac{M_E}{M_S}\right) \qquad (1)$$

where:

R = result to use with calibration graph,
TW_1 = EDTA required for a sample of tap water only,
M_C = calcium ion concentration result from section 11.5,
M_E = 4.41 lbm (2 kg), and
M_S = mass of sample in pound mass (kilograms).

NOTE 7.–If desired, cement content in pound mass per cubic yard or kilograms per cubic meter may be calculated as follows:

$$C_m = \left(\frac{M_1}{M_2}\right) D \qquad (2)$$

where:

C_m = cement content in pound mass per cubic yard (kilograms per cubic meter),
M_1 = mass of cement in test sample in pound mass (kilograms),
M_2 = total mass of test sample in pound mass (kilograms), and
D = density of concrete in pound mass per cubic yard (kilograms per cubic meter), as determined in accordance with USBR 4138.

NOTE 8.–If desired, the cement content can be expressed as a percent (C_p) of total specimen mass by dividing result of equation (1) by mass of sample that calibration chart is based on, and multiplying by 100:

$$C_p = \frac{R}{M_E}(100) \qquad (3)$$

12.2 Refer to section 9.6 for statement concerning calculations.

13. Precision

13.1 The single operator standard deviation has been found to be 0.97 percent; therefore, results of two properly conducted tests by same operator on same material should not differ by more than 2.75 percent.[6] Multilaboratory precision data have not been obtained.

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[5] This is the mass of sample that the calibration chart is based on.

[6] These values represent, respectively, the 1S and D2S limits as described in ASTM C 670.

METHOD B (USA-CERL/KELLY-VAIL) — CEMENT CONTENT BY INSTRUMENTAL FLUOROMETRIC DETERMINATION

14. Apparatus

14.1 *Balance.*–Refer to section 5.1.1.

14.2 *Hand Scoop.*–The hand scoop shall have a square mouth, made of cast aluminum, and have a bowl size about 3 inches wide by 8 inches long (76 by 203 mm).

14.3 *Sample Tub.*–Refer to section 5.1.3.

14.4 *Specimen Tub.*–Refer to section 5.1.4.

14.5 *Cement Suspension Tank.*–This tank requires a polypropylene, 10-gallon (38-L) capacity "Nalgene" tank with recirculating pump and hose; 1/20-hp, d-c motor with an a-c/d-c controller for use on 115/120-volt a-c lines; watertight bushing; Jiffy mixing blade coupled through a universal joint to a 1/12-hp stirrer motor; and a cutout ring to hold 12-inch (305-mm) diameter sieves.

NOTE 9.–The washing machine described in section 5.1.5 may be substituted for the cement suspension tank.

14.6 *Sieves.*–A nest of standard, stainless-steel sieves of 12.0-inch (305-mm) diameter and consisting of No. 4 (4.75-mm), No. 50 (300-μm), and No. 100 (150-μm) sieves is required (notes 2 and 10).

NOTE 10.–If washing machine is used instead of cement suspension tank, the sieve nest described in section 5.1.6 should be used.

14.7 *Magnetic Stirrer.*–Refer to section 5.1.11.

14.8 *Syringe-Type Pipet.*–Syringe-type, variable volume, transfer pipet of 1.01-fluid ounce (30-mL) capacity.

14.9 *Eppendorf Pipets.*–Tip ejector, fixed volume pipets, one of 0.0007-fluid ounce (20-μL) capacity and one 0.0034-fluid ounce (100-μL) capacity.

14.10 *Disposable Pipet Tips.*–Disposable tips for 0.0007- and 0.0034-fluid ounce Eppendorf pipets.

14.11 *Flasks.*–One polycarbonate, 16.9-fluid ounce (500-mL) capacity Erlenmeyer flask; and one polypropylene, 8.4-fluid ounce (250-mL) capacity volumetric flask are required.

14.12 *Calcium Analyzer.*–The calcium analyzer accepts samples from 0.0007 to 0.0034 fluid ounce (20 to 100 μL), and makes fluorometric determination of calcium with precision of duplicate calcium analysis performed having a coefficient of variation of 1.4 percent for 0.0034-fluid ounce samples and 1.7 percent for 0.0007-fluid ounce samples.

NOTE 11.–One known device meeting these requirements is the Corning Model 940 Calcium Analyzer.

14.13 *Carboy.*–Refer to section 5.1.10.

15. Reagents

15.1 *Purity of Reagents.*–Refer to section 6.1.

15.2 *Nitric Acid Solution* (1 + 19).–Refer to section 6.5.

15.3 *Ethylene Glycol Bis* (aminoethylether) *Tetra-Acetic Acid* (EGTA) *Solution.*–A prepared reagent of 0.04 percent mass per unit volume.

NOTE 12.–One known source is Corning; this is a reagent for the Corning Model 940 Calcium Analyzer.

15.4 *Calcein Indicator Solution.*–Reconstitute 1 gram of dry powder calcein indicator with 0.34 fluid ounce (10 mL) ±1 percent of the calcium standard (10.00 mg percent) (note 12).

15.5 *Calcium Standard Solution.*–A prepared reagent (10.00 mg percent meq/L) (note 12).

15.6 *Potassium Hydroxide* (1.0 *N*).–A prepared reagent, 1.0 *N* potassium hydroxide prepared with deionized water (note 12).

16. Precautions

16.1 Refer to section 7.1.

17. Sampling

17.1 Refer to section 8.1.

18. Calibration and Standardization

18.1 Refer to section 9.1.

18.2 *Cement.*–Using materials and mix proportions of concrete to be tested, hand mix a 4.4-lbm (2-kg) sample of concrete. Determine mass of cement and water for this mix to nearest 0.0022 lbm (1 g), and determine mass of aggregate to nearest 0.022 lbm (10 g). Ensure that all cement from tools, mixing bowl, etc., is washed into washing machine.

NOTE 13.–If 6.6-lbm (3-kg) specimens are tested, procedure should be followed for 6.6 lbm instead of 4.4 lbm.

18.2.1 Fill washing machine or cement suspension tank with water to 10-gallon (38-L) mark on side of tank. Place nested sieves on tank and turn on agitator.

18.2.2 Transfer the 4.4-lbm specimen to sieves over tank. Start recirculating pump and wash residue from specimen container into tank using water jet from recirculating pump hose (note 13).

18.2.3 Wash the plus No. 4 (+4.75-mm) aggregate carefully using water jet from recirculating pump hose. After all cement has been washed from the aggregate retained on the No. 4 sieve (about 1 to 1.5 minutes of washing), remove No. 4 sieve.

NOTE 14.–For greater accuracy, aggregate retained on No. 4 sieve may be used in procedure of section 22.

18.2.4 Wash aggregate retained on No. 50 (300-μm) sieve until all cement has been washed from aggregate (about 1 to 1.5 minutes of washing). Remove No. 50 sieve.

NOTE 15.-When both the No. 50 (300-μm) and No. 100 (150-μm) sieves are used, aggregate retained on the No. 100 sieve should be washed an additional 1 to 1.5 minutes after No. 50 sieve has been removed. Remove No. 100 sieve when washing is complete.

18.2.5 Obtain a 1.01-fluid ounce (30-mL) representative sample of the cement suspension in the tank using the 1.01-fluid ounce syringe pipet. Place suspended material in a 16.9-fluid ounce (500-mL) Erlenmeyer flask. Refill syringe pipet with 5 percent nitric acid solution and add it to material in Erlenmeyer flask, occasionally shaking pipet while discharging to ensure that all cement that settled out when cement sample was taken is dissolved and flushed out with the acid solution. Using a volumetric flask, add 8.4 ounces (250 mL) of tap water to Erlenmeyer flask.

18.2.6 Place magnetic stirring bar in Erlenmeyer flask, and place flask onto a magnetic stirrer. Turn on stirring motor and verify stirring action is working.

18.2.7 Prepare calcium analyzer by switching power on, place MEQ/MG toggle switch to MG, fill cuvette to mark with 1.0 *N* potassium hydroxide, and add 0.0034 fluid ounce (100-μL) of reconstituted calcein reagent to cuvette using the Eppendorf pipet. Place cuvette in analyzer, use an Eppendorf pipet to add 0.0034 fluid ounce of calcium standard solution, and push titration button to condition cuvette for analysis. This latter step is required only after cuvette has been filled with a new potassium hydroxide solution.

NOTE 16.-These steps are for use with Corning Model 940 Calcium Analyzer; if another instrument is used, steps should be modified to meet manufacturer's calibration and operation procedures.

18.2.8 To calibrate the calcium meter, add 0.0034 fluid ounce (100-μL) of calcium standard to cuvette using the Eppendorf pipet, and then press titration button. Record result and repeat test by adding another 0.0034 fluid ounce of the calcium standard and titrating. Repeat test until consecutive results are less than 1.5 percent apart. Push calibration button and run an additional 0.0034-fluid ounce sample of calcium standard to ensure that calcium standard readout value is 10 (±0.1 mg percent) (note 17).

18.2.9 To determine strength of cement solution in Erlenmeyer flask, pipet a 0.0007-fluid ounce (20-μL) sample from flask into cuvette using the Eppendorf pipet, press titrate button, and record result. Repeat test until all values are less than 1.5 percent apart (note 17).

18.3 *Aggregate Blank.*-To determine the aggregate blank calibration constant, repeat the procedures outlined in sections 18.2.1 through 18.2.9, excluding the addition of the 4.4-lbm (2-kg) concrete sample to the tank. Instead, add to the tank the same amount of aggregate, additives, and water that would be in a 4.4-lbm concrete sample. Also, instead of adding a 0.0007-fluid ounce sample (sec. 18.2.9), add a 0.0034-fluid ounce sample to cuvette using an Eppendorf pipet (note 14).

18.4 *Calibration Curve.*-To construct the linear calibration curve of cement content versus calcium analyzer reading, plot zero cement and aggregate blank calibration result (sec. 18.3) divided by five as one point. Plot mass of cement in the 4.4-lbm concrete calibration sample and its calcium analyzer reading (sec. 18.2.9) as the other point. Connect the two points by a straight line to complete the calibration curve for these sources and types of cement and aggregate. All unknown cement contents are linearly proportional in terms of calcium ion content [7] (note 13).

18.5 *Calibration Requirements.*-Both the concrete and aggregate blank calibration tests must be repeated each time the water, aggregate, cement, or additive source changes. A daily cement calibration test (sec. 18.2) should be made. The results of the three most recent tests must agree within 5 percent; if they do not, three tests should be made each day. After 3 days of three-a-day test averages being within 5 percent of each other, one test per day may be resumed until deviation exceeds 5 percent.

18.6 The Bureau has never performed this test; therefore, no typical worksheets, calculations, etc., are included for Method B.

19. Procedure

19.1 Refer to section 11.1.

19.2 Follow the procedures outlined in sections 18.2.1 through 18.2.9.

20. Calculations

20.1 Determine cement content of sample by first correcting the result from section 18.2.9 to an exact 4.41-lbm (2000-g) sample, and then referring to the calibration graph. Correct data by following formula:

$$R = [TW_2 + (M_{cw} - TW_2)]\left(\frac{M_E}{M_S}\right) \qquad (4)$$

where:

TW_2 = calcium reading obtained for sample of tap water only;

M_{cw} = mass of cement and water from section 18.2, in pound mass (kilograms); and

Other terms as previously defined in equation (1).

NOTE 17.-If desired, the cement content in pound mass per cubic yard may be calculated as shown by equation (2), section 12.1.

NOTE 18.-If desired, the cement content can be expressed as a percent (C_p) of the total specimen mass by dividing the result of equation (4) by the mass of sample that the calibration chart is based on, and multiplying by 100:

$$C_p = \frac{R}{M_E}(100) \qquad (5)$$

21. Precision

21.1 The single operator standard deviation has been found to be 1.02 percent; therefore, results of two properly conducted tests by same operator on same material should not differ by more than 2.89 percent. Multilaboratory precision data have not been obtained.

22. Improved Accuracy: Correction for Sampling Errors

22.1 Small samples often do not contain representative amounts of coarse aggregate and, therefore, accuracy of cement content determination may be improved by using the following procedure.

22.1.1 Resieve the damp, coarse aggregate collected on the No. 4 (4.75-mm) sieve after sample is washed. Determine the SSD (saturated-surface-dry) mass of the damp coarse aggregate either by drying with a towel or by determining mass of sample immersed in water using procedures described in USBR 4127. For the latter method:

$$B = \frac{C}{1 - \left(\frac{1}{sg}\right)} \qquad (6)$$

where:

B = SSD mass of coarse aggregate in air, in pound mass (kilograms);
C = immersed mass of coarse aggregate, in pound mass (kilograms); and
sg = SSD specific gravity.

22.1.2 Determine coarse aggregate content of a larger sample of concrete, 0.0185 yd^3 (0.014 m^3) for example, which is representative of the batch or load of concrete. Express the SSD mass of aggregate as a decimal fraction of mass of concrete.

22.1.3 Correct the determined cement content (sec. 20.1) by multiplying it by the following fraction:

$$\frac{1 - A_t}{1 - A_s}$$

where:

$A_t = \frac{B}{M_s}$,
B = as defined in equation (6),
M_s = mass of test sample in pound mass (kilograms), and
A_s = decimal fraction of mass of concrete (sec. 22.1.2).

NOTE 19.-In some instances, it may be possible to use a theoretical A_s derived from the batch mass and coarse aggregate sieve analysis. Such values will be in error to the extent that the sieve analysis of the coarse aggregate passing the No. 4 (4.75-mm) sieve varies in individual batches.

METHOD C - CORPS OF ENGINEERS CONCRETE QUALITY MONITOR CEMENT CONTENT OF SOIL CEMENT OR ROLLER-COMPACTED CONCRETE

23. Apparatus

23.1 *Balance*.-Refer to section 5.1.1.
23.2 *Hand Scoop*.-Refer to section 14.2.
23.3 *Sample Tub*.-Refer to section 5.1.3.
23.4 *Specimen Tub*.-Refer to section 5.1.4.
23.5 *Cement Suspension Tank*.-Refer to section 14.5.
23.6 *Sieves*.-Refer to section 14.6.
23.7 *Magnetic Stirrer*.-Refer to section 5.1.11.
23.8 *Syringe-Type Pipet*.-Refer to section 14.8.
23.9 *Eppendorf Pipets*.-Refer to section 14.9.
23.10 *Disposable Pipet Tips*.-Refer to section 14.10.
23.11 *Flasks*.-Refer to section 14.11.
23.12 *Calcium Analyzer*.-Refer to section 14.12.
23.13 *Carboy*.-Refer to section 5.1.10.

24. Reagents

24.1 *Nitric Acid Solution* (1+19).-Refer to section 6.5.

24.2 *Ethylene Glycol Bis* (aminoethylether) *Tetra-Acetic Acid* (EGTA) *Solution*.-Refer to section 15.3.

24.3 *Calcein Indicator Solution*.-Refer to section 15.4.

24.4 *Calcium Standard Solution*.-Refer to section 15.5.

24.5 *Potassium Hydroxide* (1.0 *N*).-Refer to section 15.6.

25. Precautions

25.1 Refer to section 7.1.

26. Sampling

26.1 Refer to the requirements for calibration and standardization under section 27.

27. Calibration and Standardization

27.1 Prior to performing the cement content test, the test procedure must be calibrated for the calcium in the cement and the raw materials in the concrete. This is accomplished by performing the standard cement content test. To determine the aggregate blank calibration value, section 28.3 in the test procedure is excluded and the aggregate proportions and additives present in a 4-kg concrete sample are obtained and used as the "4-kg sample." In section 28.11, a 100-μL sample is analyzed in the calcium meter.

NOTE 20.-The Corning 940 calcium analyzer provides readouts in metric units only; therefore, the following procedural steps address only metric quantities.

27.2 For the concrete calibration test, a 4-kg concrete sample is hand mixed using the materials and mix proportions of the concrete to be tested (sections 28.2 through 28.11), and the results recorded.

NOTE 21.-The sieve arrangement used in the calibration procedure should be consistent with that used in the test procedure; that is, if only the 4.75-mm and 300-μm sieves are used to calibrate the cement test, the same sieves should be used during the testing. If the 4.75-mm, 300-μm, and 150-μm sieves are used, they should be used for both calibrating and testing.

27.3 The cement calibration curve is a linear plot of the cement content in grams versus the calcium analyzer reading in milligrams-percent, with zero cement being the aggregate blank calibration result in milligrams-percent divided by five. The mass of the cement in the 4-kg concrete calibration sample and corresponding calcium analyzer reading is the other set of coordinates.

27.4 The concrete calibration test must be repeated each time the cement, aggregate source or type, or water source used to produce the concrete changes; or weekly if the aggregate and cement sources or aggregate type do not change.

28. Procedure

28.1 The CQM (Concrete Quality Monitor) cement content test is based on the following assumptions:

- Cement of a given type from a given source is uniform in calcium content; that is, the aggregates either do not contain calcium or are uniform in calcium content for that proportion of the aggregates that pass the finest sieve over the cement suspension tank.
- When agitated, cement can be dispersed uniformly and suspended in water so that a representative sample can be obtained.
- Stirring without external heat will produce a quantitative solution of cement in nitric acid.
- Calcium content of cement solution can be determined by titration with the Corning 940 calcium analyzer.

28.2 Fill cement suspension tank with tap water to the 37.8-L mark on the side of the tank. Place nested sieves on tank and turn on tank's agitator.

NOTE 22.-If calcareous fines are present, it is recommended that a 150-μm sieve be nested below the 300-μm sieve. The combination of sieves used for calibration and cement content testing must be consistent.

28.3 Obtain the 15- to 30-kg concrete sample, mix sample to ensure homogeneity (or remix if used in conjunction with water test), and weigh out 4 ± 0.4 kg of fresh concrete. Record this mass to the nearest gram.

28.4 Transfer the 4-kg sample to the nest of sieves over the tank. Turn on tank's recirculating pump and wash residue from the 4-kg sample container into the tank using the water jet from the recirculating pump hose.

28.5 Wash the plus 4.75-mm aggregate carefully using the water jet from the recirculating pump hose. After all cement has been washed from the aggregate retained on the 4.75-mm sieve, which takes about 1 to 1.5 minutes, remove the sieve.

28.6 Wash aggregate retained on the 300-μm sieve until all cement has been removed (about 1 to 1.5 minutes), then remove the sieve.

NOTE 23.-When both the 300- and 150-μm sieves are used, the aggregate retained on the 150-μm sieve should be washed an additional 1 to 1.5 minutes after the 300-μm sieve has been removed. Remove the 150-μm sieve when washing is completed.

28.7 Obtain a representative sample of the cement suspension in the tank using the 30-mL syringe pipet. Place this suspended material in a 500-mL Erlenmeyer flask. Refill syringe pipet with 5 percent nitric acid and add this solution to the contents of the Erlenmeyer flask. While discharging the acid solution from the pipet, shake pipet occasionally to ensure that all material that settled out when sample was taken has dissolved and is flushed with the acid solution. Use a volumetric flask to add 250 mL of tap water to the Erlenmeyer flask.

28.8 Put a magnetic stirring bar in Erlenmeyer flask and place bar on a magnetic stirrer. Turn on stirring motor and ensure that stirring has begun.

28.9 Prepare calcium analyzer by switching power on and filling cuvette to the mark with 1.0 *N* potassium hydroxide. Then, add 100 μL of reconstituted calcein reagent using an Eppendorf pipet. Place cuvette in analyzer, add 100μL of calcium standard solution using the Eppendorf pipet, and push titration button to condition cuvette for analysis. This latter step is required only after cuvette is filled with a new potassium hydroxide solution. A single cuvette filling is enough for 15 to 20 readings.

28.10 Start the analysis by placing the meq/mg% toggle switch at mg% and adding 100μL of the calcium standard to the cuvette using an Eppendorf pipet. Press titration button. Record result and repeat test by adding another 100-μL sample. Repeat testing until consecutive results are within 1.5 percent. Push calibration button and run an additional 100-μL sample of the calcium standard to ensure that calcium standard readout value is 10 ± 0.1 mg%.

28.11 Determine strength of cement solution in Erlenmeyer flask by analyzing a 20-μL sample in the calcium analyzer. Repeat this analysis until all values are within 1.5 percent. Determine cement content by referring to the calibration graph.

28.12 For a sample recording of the calcium analyzer readings on the raw materials, see figure 1.

28.12.1 To make an accurate prediction of a calcium analyzer reading on cementitious materials for a particular size sample representing a particular batch size, a linear regression equation should be developed from readings obtained:

$$y = ax + b \tag{7}$$

where:

y = calcium reading in mg% (milligrams-percent),
x = cementitious content in grams or kilograms,
a = slope value, and
b = value where plotted line intercepts y-axis.

Examples of equation (7) using data from figure 1 and plotted on figure 2:

a = 0.1024
x = 76.9 grams of cement for a 4-kg concrete sample
b = 2.082
y = 0.1024 (76.9) + 2.082
= 9.96 mg%

a = 0.0017
x = 30.8 grams of fly ash for a 4-kg concrete sample
b = 2.214
y = 0.0017 (30.8) + 2.214
= 2.27 mg%

28.12.2 Figure 2 shows a graphical illustration of the data generated in figure 1.

28.12.3 Figures 3 and 4 are sample worksheets for the aggregate blank calibration and the concrete mix calibration curve.

28.12.4 The Bureau has never performed this test; therefore, additional graphs may need to be developed in the field to complete the analysis of the concrete mix.

29. Comparison With Mix Design Values

29.1 The water and cement contents determined by the CQM method should be compared with the batch proportion values. If this comparison varies by less than 10 percent, it may be assumed that the CQM system is operating properly, that the concrete batch is homogeneous, and that the batched proportion values are correct. If the compared results vary by more than 10 percent, a second complete CQM test should be run. The 4-kg test samples for the rerun should be obtained from the original 15- to 30-kg sample used for the initial runs. Use extreme care on the rerun to ensure that no procedural errors are made. If second test agrees closely with the batch proportion values, it may be assumed that initial test was in error. If second test is significantly different from both the batch values and initial test values or if second test agrees closely with initial test, one of three possibilities has occurred:

(1) Concrete sample is not representative of bulk, which indicates poor mixer efficiency and nonhomogeneity;

(2) Batch is not the same as indicated by batch proportions; or

(3) CQM system is incorrectly calibrated.

29.2 Figure 5 shows a series of analytical steps for determining which of the three possible problems has occurred. It is recommended that an inquiry be made as to any possible changes or problems that may have occurred at the batch plant.

30. Report

30.1 No typical reporting form is included with this test procedure.

31. References

[1] Rosen, Joseph, *Reagent Chemicals and Standards*, D. Van Nostrand Co., Inc., New York, NY.

[2] *United States Pharmacopeia and National Formulary XV*, 20th ed., Mack Publishing Co., 20th and Northampton Sts., Easton, PA, 18042, 1980.

[3] Kelly, R. T. and J. W. Vail, "Rapid Analysis of Fresh Concrete," *Concrete*, April 1968, pp. 140-145, and May 1968, pp. 206-210.

[4] Howdyshell, P. A., *Operations Guide: Water and Cement Content of Fresh Concrete*, Technical Report M-177/ADA 022697, U.S. Army Construction Engineering Research Laboratory, USA-CERL, September 1975.

[5] Howdyshell, P. A., *Revised Operations Guide for a Chemical Technique to Determine Water and Cement Content of Fresh Concrete*, Construction Engineering Research Laboratory Technical Report M-212/ADA 039120 (USA-CERL), Interstate Research Park, P O Box 4005, Champaign, IL, 61820, April 1977.

[6] Howdyshell, P. A., *Concrete Quality Monitor: Operations Guide*, Construction Engineering Research Laboratory Technical Report M-293, Interstate Research Park, P O Box 4005, Champaign, IL, 61820, May 1981.

[7] Neville, A. M., *Properties of Concrete*, p. 6, John Wiley and Sons, New York, NY, 1973.

Table 1. – Test equipment for determining cement content.

Item No.	Equipment	Quantity[1] Method A	Quantity[1] Method B	Quantity[1] Method C	Description	Source[2]
1	Balance	1	1	1	Triple beam, 2600-g min. capacity, 0.1-g sensitivity.	ES
2	Hand scoop	1	1	1	One piece, cast-aluminum, bowl size about 3.25 by 5 by 2 inches (83 by 127 by 51 mm).	ES
3	Sample tub	1	1	1	Polyethylene, 5-qt. (4.7-L) capacity.	DS
4	Specimen tub	1	1	1	Polyethylene, 2-qt. (1.9-L) capacity.	DS
5	Washing machine	1	–	–	Domestic portable type, smooth interior, side-mounted impeller, and recirculating pump and hose. Hose to be fitted with a T-piece for connecting to linked pipet. Working capacity of tub shall be 10 gal. (38 L).	DA
6	Cement suspension tank	–	1	1	Polypropylene, 10-gal. capacity "Nalgene" tank with recirculating pump and hose; 1/20-hp, d-c motor with an a-c/d-c controller for use on 115/120-V, a-c lines; watertight bushing; Jiffy mixing blade coupled through a universal joint to a 1/12-hp stirrer motor; and a cutout ring to hold 12-inch (305-mm) diameter sieves.	LES or LGS
7	Timer	1	–	–	0- to 15-min. industrial timer switch with automatic reset (115 V, 60 cycle).	LES
8	Sieve nests	1	–	–	Rectangular steel frame, 15-5/16 by 12-5/16 by 8 inches (389 by 313 by 203 mm), with a No. 50 (300-μm) sieve at bottom and a removable No. 4 (4.75-mm) sieve at midheight. A separate frame, 4 inches (102 mm) deep with a No. 100 (150-μm) sieve at bottom, shall be nested below the No. 50 sieve of top frame.	ES
		–	1	1	A nest of standard stainless-steel sieves of 12-inch diameter, and consisting of No. 4, No. 50, and No. 100 sieves.	ES
9	Wash bottle	1	–	–	Polyethylene, 1.69-fl. oz. (50-mL) capacity.	LGS
10	Dropping bottle	1	–	–	Polyethylene, 1.01-fl. oz. (30-mL), narrow-mouth bottle and dropping pipet.	LGS
11	Conical beaker	2	–	–	Narrow-mouth, glass, conical beakers or Erlenmeyer flasks. One of 16.9-fl. oz. (500-mL) capacity and one 27.05- or 33.81-fl. oz. (800- or 1000-mL) capacity. To allow for breakage, a shelf-pack of 12 is normally ordered.	LGS
12	Flasks	–	2	2	One polycarbonate, 16.9-fl. oz. Erlenmeyer flask; and one polypropylene, 8.4-fl. oz. (250-mL) volumetric flask.	LGS
13	Pipet	1	–	–	Volumetric glass pipet, class A or B, 0.84-fl. oz. (25-mL) capacity. To allow for breakage, a shelf-pack of 12 is normally ordered.	LGS

Table 1. – Test equipment for determining cement content – Continued

Item No.	Equipment	Quantity[1]			Description	Source[2]
		Method A	Method B	Method C		
14	Linked pipets	1 set	–	–	A 4.23-fl.oz. (125-mL) glass pipet with an automatic leveling and overflow device, fitted with a three-way tap. To this pipet is attached a 3.38-fl. oz. (100-mL) automatic pipet with a three-way tap that can empty its contents through the larger pipet. To allow for breakage, two sets are normally ordered.	LGS
15	Automatic pipet	1	–	–	Automatic glass pipet with three-way tap, 10.14-fl. oz. (300-mL) capacity. To allow for breakage, two are normally ordered.	LGS
16	Syringe-type pipet	–	1	1	Syringe-type, variable volume, transfer pipet of 1.01-fl. oz. (30-mL) capacity.	LGS
17	Eppendorf pipets	–	2	2	Tip ejector, fixed-volume pipets, one of 0.0007-fl. oz. (20-μL) capacity and one 0.0034-fl. oz. (100-μL) capacity.	LGS
18	Pipet tips	–	As req'd.	As req'd.	Disposable tips for pipets listed in item 17.	LGS
19	Buret	1	–	–	Acrylic body with Teflon plug, class A or B accuracy, 3.4-fl. oz. (100-mL) capacity.	LGS
20	Fixed volume dispenser	1	–	–	Polyethylene dispenser with polypropylene measuring chamber, 0.17-fl. oz. (5-mL) capacity.	LGS
21	Carboys	2	2	1	Rectangular, aspirator type with spigot and screw closure; 2-gal. (7.6-L) capacity; made of linear polyethylene.	LGS
22	Utility clamp	1	–	–	Three-pronged grip with vinylized jaws.	LGS
23	Suction bulb	1	–	–	Rubber suction bulb for use with the pipet in item 13.	LGS
24	Rubber tubing	20 ft (6.1 m)	–	–	Amber rubber latex tubing, 0.5-inch (13-mm) i.d.	LGS
25	Magnetic stirrer	1	1	1	Variable-speed magnetic stirrer (milkshake type) with Teflon-coated magnetic stirring rod and stainless-steel containers.	LGS
26	Calcium analyzer	–	1	1	A calcium analyzer that will accept samples from 0.0007 to 0.0034 fl. oz. (20- to 100-μL), and makes fluorometric determination of calcium to the precision noted in section 14.12.	LES

[1] Quantity required to conduct tests.

[2] Source:

ES indicates equipment suppliers for concrete and soils testing labs.
DS indicates domestic food freezer supplier.
DA indicates a domestic appliance store.
LGS indicates a laboratory glass supplier.
LES indicates a laboratory equipment supplier.

Spec. or Solic. No. NOT AVAILABLE	Structure ROLLER-COMPACTED CONCRETE	Tested by CORPS OF ENGINEERS Date 1982
Project WILLOW CREEK DAM HEPPNER, OR	Item RESEARCH Location TROUTDALE, OR	Computed by ~ Date
Feature WILLOW CREEK DAM	Station ~ Offset ~ Depth ~ to ~	Checked by ~ Date

CEMENT CONTENT OF FRESHLY MIXED CONCRETE

Cement: Brand ASH GROVE WEST Type II LA Location DURKEE, OR
Pozzolan: Type FLY ASH Class F Supplier POZZOLANIC INTERN'L. Location CENTRALIA, WA
Water: ☐ Well ☒ City ☐ Distilled ☐ Demineralized Description TAP WATER

Aggregate	Nominal Size Fraction	Name of Deposit	Supplier	Location Description		Quality Evaluation Sample No.
				Legal	Geographical	
Coarse:	3-inch to No. 4	PENDLETON	SAME	SEC. 7&8, T. 2N., R. 35E.,	PENDLETON, OR	M-6889
		READY MIX		WILLAMETTE MERIDIAN		
Fine:	MINUS No. 4		PENDLETON	NOT GIVEN	UMATILLA, OR	M-6890
	BLEND SAND		READY MIX	NOT GIVEN		

CALCIUM ANALYZER READINGS ON RAW MATERIALS Sample Size* ☐ 20μL ☒ 100μL

Cement		Fly Ash		Mass Proportions of Aggregate and Water**			
Mass, lbm [✓ grams]	Calcium, mg%	Mass, lbm [✓ grams]	Calcium, mg%	Ingredients	Batch Density, [✓ lbm/ft³] or yd³ kg/m³	Mass of a 4-kg Sample, lbm [✓ kg]	Calcium Reading, mg%
37.9	5.700	15.1	2.24	3 to 1½ inches	46.12	1.230	2.72
75.8	9.578	160.2	2.49	1½ to ¾ inch	31.23	0.833	
118.5	14.090			¾ inch to No. 4	25.78	0.688	
165.9	19.110			SAND	34.04	0.908	
213.3	24.600			BLEND SAND	6.04	0.161	
260.7	29.630			WATER	6.74	0.180	
				Totals	149.95	4.000	

MIX DESIGN AND CALIBRATION DATA FOR RAW MATERIALS

Mix Ingredients	Specific Gravity	Batch Mass, [✓ lbm] kg	Percent by Mass	Mass of a 4-kg Sample, lbm [✓ kg]	Calcium Reading With Water, mg%	Calcium Reading for Raw Materials	mg%
Cement	3.15	80	1.92	0.0769	9.98	9.98−2.21 =	7.77
Pozzolan	2.26	32	0.77	0.0308	2.27	2.27−2.21 =	0.06
Water	1.00	182	4.38	0.1750	2.21		2.21
3 to 1½ inch	2.72	1,245	92.93	1.1971			
1½ to ¾ inch	2.77	843		0.8106			
¾" to No. 4	2.74	696		0.6692	2.72	(2.72−2.21)0.9293 =	0.47
SAND	2.65	919		0.8837			
BLEND SAND	2.76	163		0.1567			
Totals		4,160 —	154.1 lbm/ft³	4.0000			
Cement				0	2.74		10.51

* If a 20-μL solution sample is used, multiply calcium reading by 5.

** The theoretical air-free batch density times the result of the individual batch mass divided by the total batch mass yields the individual batch density. Then, the sample specimen size times the result of the individual batch density divided by the sum of the individual batch densities yields the proportioning value. e.g. 154.1(1245/4160) = 46.12. THEN, 4(46.12/149.95) = 1.230 Kg

Figure 1. – Sample worksheet for the calibration of raw materials.

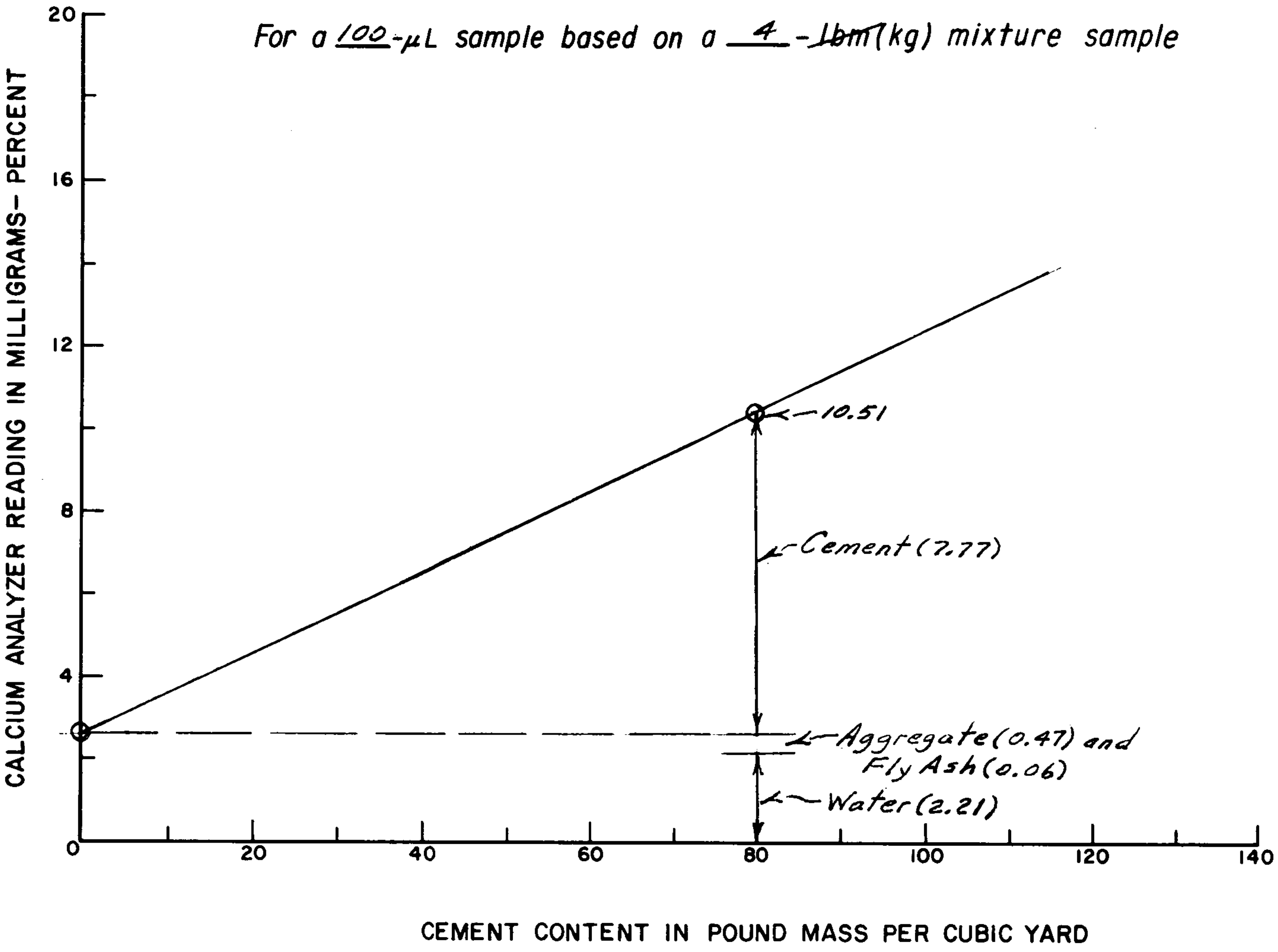


Figure 2. – Graphical illustration of data generated on figure 1.

Spec. or Solic. No. NOT AVAILABLE	Structure ROLLER-COMPACTED CONCRETE	Tested by CORPS OF ENGINEERS Date 1982
Project WILLOW CREEK DAM HEPPNER, OREGON	Item RESEARCH Location TROUTDALE, OREGON	Computed by ~ Date
Feature WILLOW CREEK DAM	Station ~ Offset ~ Depth ~ to ~	Checked by ~ Date

CEMENT CONTENT OF FRESHLY MIXED CONCRETE

Concrete Mix REFER TO FIGURE 1 Batch Mass 4,160 lbm ~~(kg)~~

Batch Density 154.1 lbm/ft³ ~~(kg/m³)~~ Sample Mass 4 ~~lbm~~ (kg)

Calcium Analyzer Volume: ☐ 20 μL ☑ 100 μL Dispersant Used: ☑ Yes ☐ No

Dispersant Brand CALGON Concentration 200 ~~ounces~~ (grams)

Ingredients	Mix Design 4-kg Sample 1.94 %	Trial Batches for Mix Calibration Curve (kilograms)				
		0 % Cement	1.5 % Cement	1.95 % Cement	2.05 % Cement	2.25 % Cement
Cement	0.0776	0.0000	0.0600	0.0780	0.0820	0.0900
Fly Ash	0.0312	0.0310	0.0310	0.0310	0.0320	0.0310
Water	0.1940	0.1940	0.1940	0.1940	0.1940	0.1940
3 TO 1½ INCHES	1.1970	0.8940	0.9275	0.9320	1.1260	0.9430
1½ TO ¾ INCH	0.8104	0.8575	0.8500	0.8710	0.8600	0.8570
¾ INCH TO No.4	0.6691	0.7450	0.7450	0.7450	0.7450	0.7450
MINUS No.4 SAND	0.8830	0.9831	0.9831	0.9831	0.9831	0.9831
BLEND SAND	0.1566	0.1744	0.1744	0.1744	0.1744	0.1744
Total Mass	4.0000	3.8790	3.9650	4.0085	4.1965	4.0175
Calcium Analyzer Reading in mg%		2.16	7.79	9.60	9.85	10.61
Cement						
Fly Ash						
Water						
Total Mass						
Calcium Analyzer Reading in mg%						
Cement						
Fly Ash						
Water						
Total Mass						
Calcium Analyzer Reading in mg%						

Remarks:

Figure 3. – Sample worksheet for aggregate blank calibration and the concrete mix calibration curve.

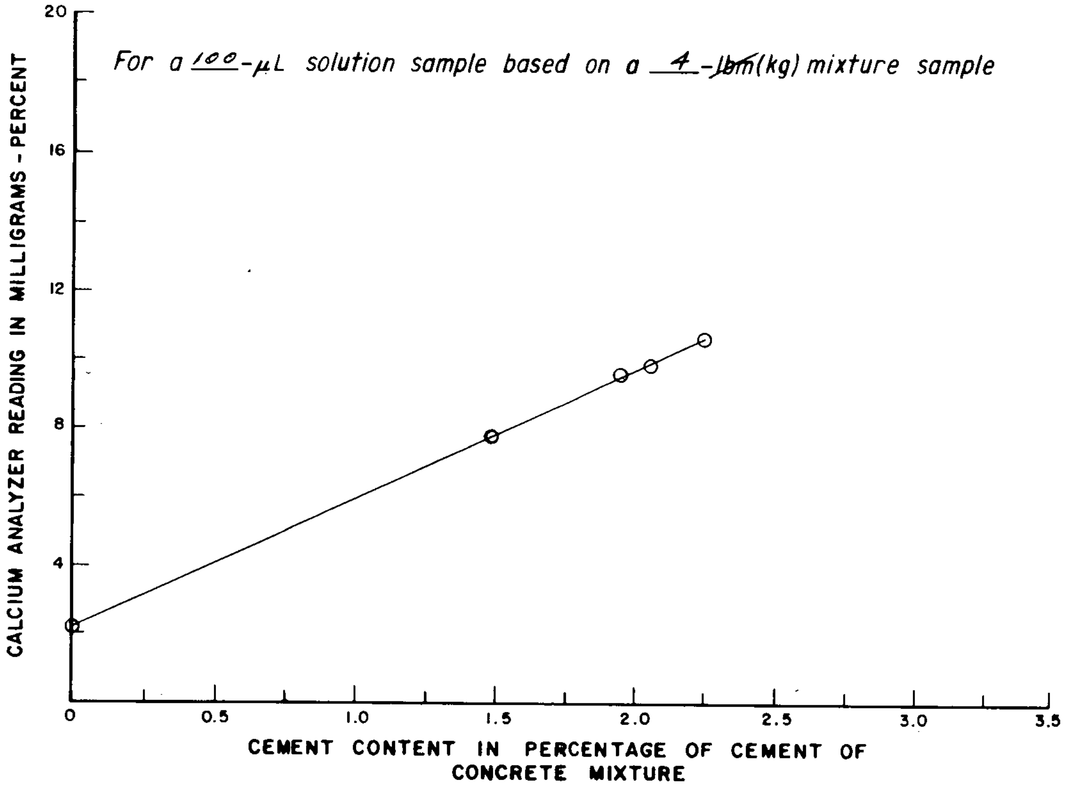


Figure 4. – Graphical illustration of data generated on figure 3.

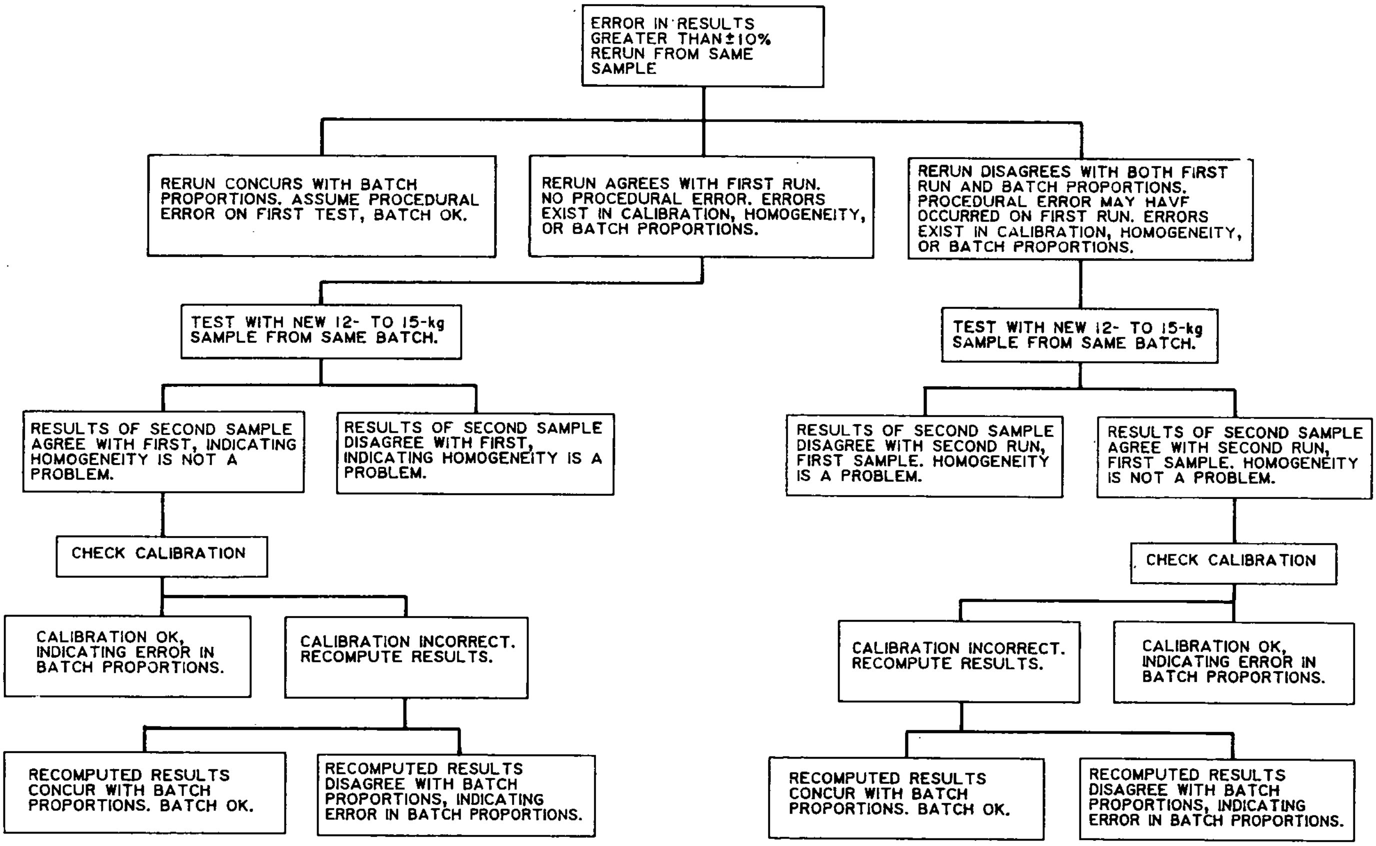


Figure 5. – Procedure for checking cause of error in cement content results.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 9300-89

PROCEDURE FOR

CHECKING, ROUNDING, AND REPORTING OF LABORATORY DATA

INTRODUCTION

This procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, and the Geotechnical Services Branch, code D-3760, of the Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 9300. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1. This designation outlines procedures for checking data on laboratory data forms, rounding numbers, and recording and reporting of the data.

1.2 This procedure is to be used by Bureau of Reclamation laboratories engaged in testing of cement, concrete, aggregates, soil, and rock, and is to be used to provide uniformity and consistency in handling data, data forms, and reports.

2. Applicable Documents

2.1 *USBR Procedures*:
USBR 3000 Using Significant Digits in Calculating and Reporting Laboratory Data

2.2 *ASTM Standards*:
E 29 Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values
E 380 Metric Practice

2.3 *Bureau Document*:
Metric Manual

3. Terminology

3.1 *A Term Specific to This Designation Is*:

3.1.1 *Rounding*.-The process of reducing the number of digits in a number according to rules relating to the required accuracy of the value.

4. Recording Data on Original Data Forms

4.1 The heading of each data form must be completed in full. The initials and surname of appropriate persons are to be entered in the space for "tested by," "computed by," and "checked by" (see example on fig. 1).

4.2 The portion of the data form for auxiliary tests must show the year of the version of the procedure used (see fig. 1).

NOTE 1.-Since procedures may be revised, it is important that the version of the procedure used be identified.

4.3 All measured or computed data are to be recorded in a legible manner on the data form. If a number is computed or recorded erroneously, draw a line through the incorrect number and write the correct value to the side or above the incorrect entry. In No Circumstance Shall the Original Value Be Erased or Written Over.

4.4 All measured or computed data must be recorded as specified in the procedure (e.g., "record to the nearest 0.01 lbm"). For those cases, where the number of digits is not specified, a value should be recorded to one more digit than prescribed by the rules of significant digits as described in USBR 3000.

4.5 Any observation made during the test that might have an effect on the results, or on use of the results, should be written on the data form. If information is placed on the back of the form, clearly indicate on the front that additional information is on the back.

5. Checking Data on Original Data Forms

5.1 All numerical data that are the result of a calculation must be checked by an individual other than the person who computed and recorded the data.

5.2 All data transferred to a data form from another source, such as other data forms, calibrations values, etc., shall be checked by an individual other than the person recording the data.

5.3 All recorded data that are correct must show a checkmark, preferably in red, by each number checked (see fig. 1).

NOTE 2.-Example data forms included in the other USBR procedures contained in this manual do not show checkmarks in order to illustrate the required data in a neat and legible manner. Completed data forms should be similar to figure 1 or 2.

5.4 If recorded data are incorrect, draw a line through the number and write the correct number to the side or above the incorrect value. In No Circumstance Shall the Original Value Be Erased or Written Over.

5.4.1 The same method or system of computation must be used for checking the data as was used in calculating the recorded values.

NOTE 3.–Numbers calculated by "chain" computations with a calculator or computer may result in different values than rounding values for each entry and using the rounded value in subsequent calculations. The calculator or computer carries more digits than the rounded number when a "chain" computation is being used.

5.4.2 Data corrected by the checker should be verified by a person other than the checker and a checkmark shown by the correct value. An entry should be made on the data form "corrections verified by ________(Name)________."

5.5 The name of the checker and the date the data were checked must be entered on the form heading. The last name of the checker must be completely written out.

5.6 It is the responsibility of the checker to ensure that all numbers are correct, recorded to the proper number of places specified in the procedure, and that rounding is in conformance with this designation. The checker should also review the measured data for reasonableness (e.g., a recorded mass of 179 lbm when the maximum capacity of a scale is known to be 100 lbm).

5.7 If necessary changes are made to data subsequent to the final checking, changes must be checked and the changes explained in the *Remarks* section of the data form.

6. Checking Data Presented on Graphs, Tables, and Figures Reporting Laboratory Data

6.1 All data shown on graphs, tables, and figures must be checked by an individual other than the person who originally prepared the graph, table, or figure.

6.2 The original figure should not show checkmarks for each value. It is recommended that a copy of the original graph or figure be made and checkmarks be placed by each value on the copy (see example on fig. 2).

6.3 Once the graph, table, or figure is considered correct, the name of the person who prepared the graph, table, or figure; the date prepared; the name of the checker; and the date the data were checked must be entered in the space provided or in the lower left corner of the original graph, table, or figure.

7. Rounding Numbers

7.1 When a numerical value is to be rounded to fewer digits than the total number available, the following procedure is to be followed:

When the first digit dropped is:	*The last digit retained is:*	*Examples*
< 5	Unchanged	2.44 to 2.4
> 5	Increased by 1	2.46 to 2.5
Exactly 5	Increased by 1	2.55 to 2.6
5 followed only by zeros	Increased by 1	2.5500 to 2.6

The same rules apply when rounding a number with many digits to a number with few digits. A computer or calculator may display the answer to a computation as ten digits and the answer is to be recorded to two digits. For example, the number 2.3456789 would be rounded to 2.3; the first digit dropped would be the 4.

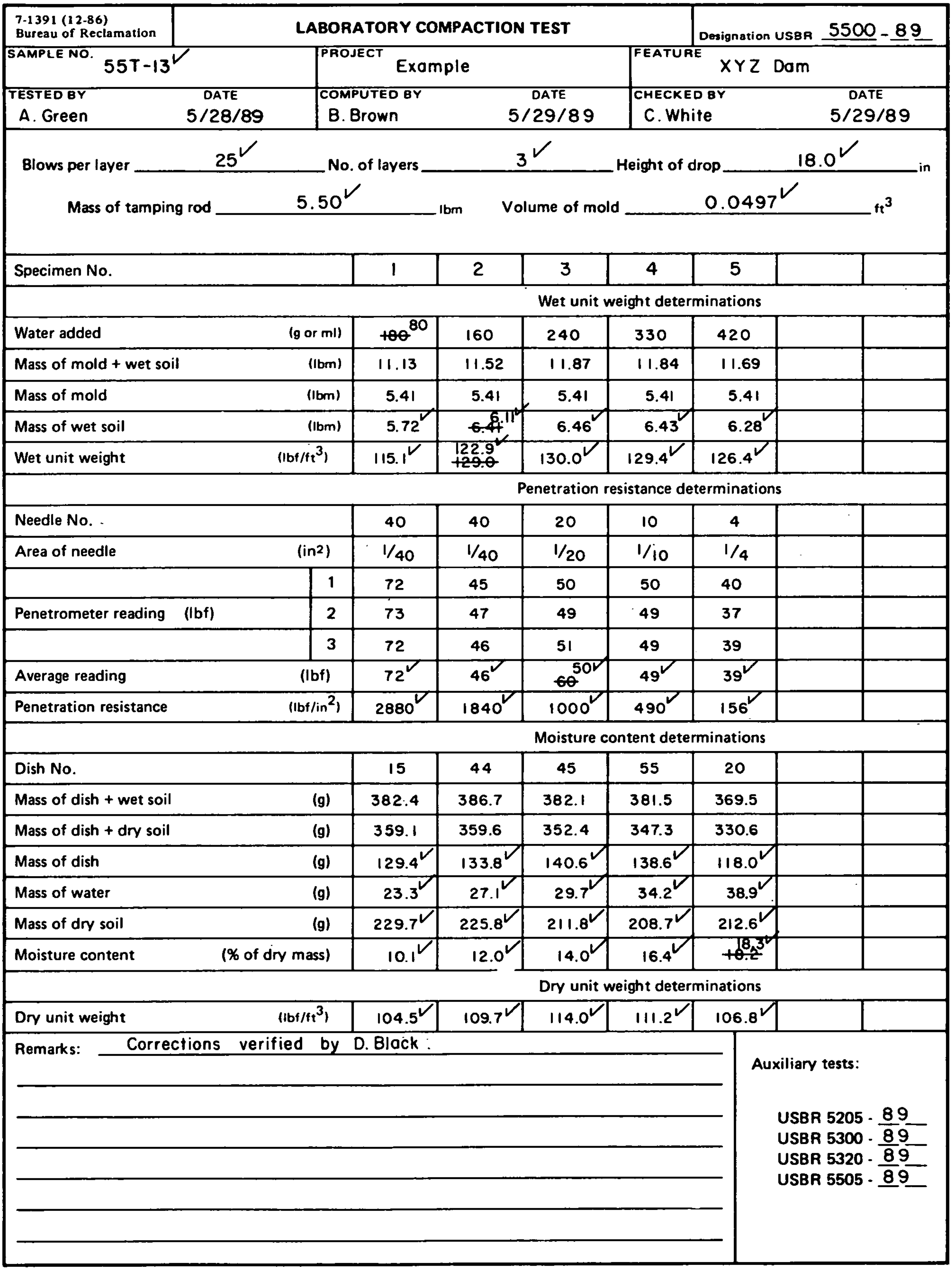
Other examples:

2.49999 to 2.5
2.49999 to 2
2.55555 to 2.56
2.55555 to 3
2.50000 to 3

7.2 The examples shown above, exactly 5 or 5 followed by zeros, are rounded differently than indicated in the USBR *Metric Manual*, ASTM E 380, and ASTM E 29. These documents all indicate that the number is to be rounded to the closest even number. In the example (shown above) 2.50000 would be rounded to 2 and not 3. Unfortunately, calculators and computers do not follow this rule and always round up. Recognizing the wide-spread use of calculators and computers, the policy as stated in subparagraph 7.1 should be followed.

8. Reporting Data

8.1 Data reported as result(s), of the test, must conform with instructions in the respective procedure, since some reported values are different than what is recorded on the data form. (For example, the computed value for liquid limit of a soil is recorded on the data form to the nearest 0.1 percent but is to be reported to the nearest 1 percent.) If the reported value is not specified, the data should be reported in accordance with the rules of significant digits as described in USBR 3000.



7-1391 (12-86)
Bureau of Reclamation

LABORATORY COMPACTION TEST

Designation USBR 5500 - 89

SAMPLE NO. 55T-13 ✓	PROJECT Example	FEATURE XYZ Dam
TESTED BY A. Green DATE 5/28/89	COMPUTED BY B. Brown DATE 5/29/89	CHECKED BY C. White DATE 5/29/89

Blows per layer 25 ✓ No. of layers 3 ✓ Height of drop 18.0 ✓ in

Mass of tamping rod 5.50 ✓ lbm Volume of mold 0.0497 ✓ ft³

Specimen No.		1	2	3	4	5		
				Wet unit weight determinations				
Water added (g or ml)		~~180~~ 80	160	240	330	420		
Mass of mold + wet soil (lbm)		11.13	11.52	11.87	11.84	11.69		
Mass of mold (lbm)		5.41	5.41	5.41	5.41	5.41		
Mass of wet soil (lbm)		5.72 ✓	~~6.41~~ 6.11 ✓	6.46 ✓	6.43 ✓	6.28 ✓		
Wet unit weight (lbf/ft^3)		115.1 ✓	122.9 ✓ ~~129.0~~	130.0 ✓	129.4 ✓	126.4 ✓		
				Penetration resistance determinations				
Needle No.		40	40	20	10	4		
Area of needle (in^2)		1/40	1/40	1/20	1/10	1/4		
	1	72	45	50	50	40		
Penetrometer reading (lbf)	2	73	47	49	49	37		
	3	72	46	51	49	39		
Average reading (lbf)		72 ✓	46 ✓	~~60~~ 50 ✓	49 ✓	39 ✓		
Penetration resistance (lbf/in^2)		2880 ✓	1840 ✓	1000 ✓	490 ✓	156 ✓		
				Moisture content determinations				
Dish No.		15	44	45	55	20		
Mass of dish + wet soil (g)		382.4	386.7	382.1	381.5	369.5		
Mass of dish + dry soil (g)		359.1	359.6	352.4	347.3	330.6		
Mass of dish (g)		129.4 ✓	133.8 ✓	140.6 ✓	138.6 ✓	118.0 ✓		
Mass of water (g)		23.3 ✓	27.1 ✓	29.7 ✓	34.2 ✓	38.9 ✓		
Mass of dry soil (g)		229.7 ✓	225.8 ✓	211.8 ✓	208.7 ✓	212.6 ✓		
Moisture content (% of dry mass)		10.1 ✓	12.0 ✓	14.0 ✓	16.4 ✓	~~18.2~~ 18.3 ✓		
				Dry unit weight determinations				
Dry unit weight (lbf/ft^3)		104.5 ✓	109.7 ✓	114.0 ✓	111.2 ✓	106.8 ✓		

Remarks: Corrections verified by D. Black.

Auxiliary tests:

USBR 5205 - 89
USBR 5300 - 89
USBR 5320 - 89
USBR 5505 - 89

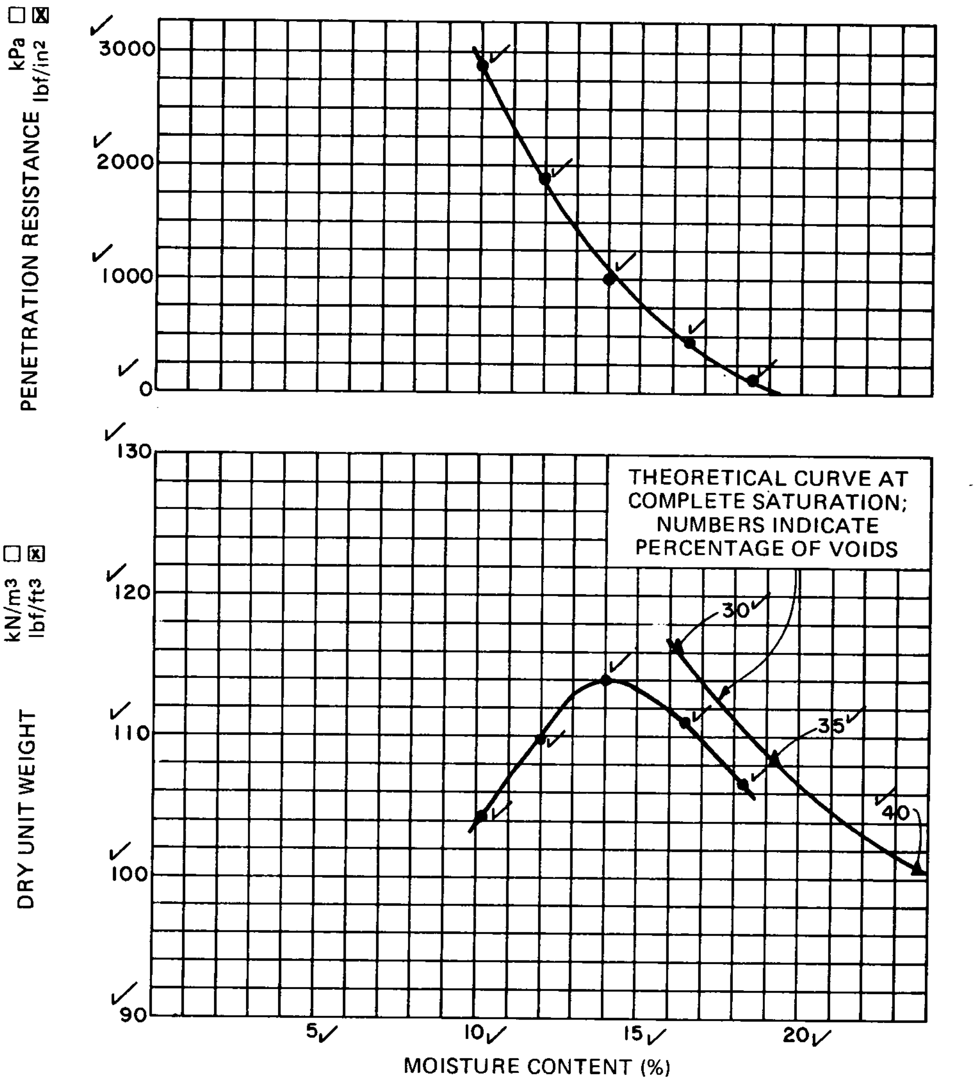
GPO 849-889

Figure 1. - Checked data sheet — example.

7-1414 (9-85) Bureau of Reclamation	**COMPACTION - PENETRATION RESISTANCE CURVES**	Designation USBR 5500 - 89✓
SAMPLE NO. 55T-13✓	FEATURE XYZ Dam	PROJECT Example

Hole No. AP-5A✓ Plotted by B. Brown Date 5/28/89

Depth 3.2 - 7.8✓ ft ☒ m ☐ Checked by C. White Date 5/29/89



CLASSIFICATION SM✓

Gravel	13✓ %
Sand	50✓ %
Fines	37✓ %

ATTERBERG LIMITS

Liquid Limit	33✓ %
Plasticity Index	4✓ %
Shrinkage Limit	%

SPECIFIC GRAVITY

Minus No. 4	2.66✓
Plus No. 4	
Bulk	
Apparent	
Absorption	%

Remarks

COMPACTION

Method	
Percent larger than tested	13✓
Maximum dry unit weight	114.0✓ ☐ kN/m3 ☒ lbf/ft3
Optimum moisture content	14.0✓ %
Degree of saturation @ opt	%
Penetration resistance @ opt	1000✓ ☐ kPa ☒ lbf/in2

GPO 848-759

Figure 2. - Checked plotting — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1000-89

PROCEDURE FOR

STANDARDS FOR LINEAR MEASUREMENT DEVICES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1000. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for ordering and maintaining quality control of linear measurement devices to be used for laboratory and field applications. Minimum requirements for tapes, calipers, micrometers, and gauge blocks are outlined in this designation. It is strongly recommended that a certificate of inspection certifying that the linear measurement device meets the standards of the applicable Federal specifications be obtained when purchasing these devices.

2. Applicable Documents

2.1 *Federal Specifications*:

GGG-T-106D	Tape Measuring, General Use
GGG-R-791F	Rules, Measuring
GGG-C-111B	Calipers and Gages, Vernier
GGG-C-105B	Caliper, Micrometer (Inside, Outside, Tube) and Gage, Depth Micrometer
GGG-C-15C	Gage Blocks and Accessories

3. Significance and Use

3.1 Accurate linear measurements must be taken to obtain proper values from laboratory and field tests.

3.2 The information in this designation is to be used whenever any of the linear measurement devices listed in paragraph 5 are purchased.

3.3 With the exception of tapes and rules, linear measurement devices should be returned to the manufacturer or to an appropriate certification agency biennially for recertification.

4. Terminology

4.1 *Traceability Certificate*.–A certificate of inspection certifying that a linear measurement device meets the Federal specifications for its particular grade or model and that its accuracy is traceable to the National Institute of Standards and Technology (National Bureau of Standards) or the international standard of length.

5. Apparatus

5.1 *Flexible Metal Printed Tape*.–A device used to obtain accurate linear measurements and is usually enclosed in a roll-up case. Flexible metal printed tapes should meet the requirements of Federal Specification GGG-T-106D. The tapes are to be housed in a suitable case. Inch-pound scale tapes having a length of 6, 8, or 12 feet are generally adequate for most laboratory and field applications. Metric scale tapes having a length of 2 to 3 meters are generally adequate for most laboratory and field applications. A certificate of inspection certifying that the flexible metal printed tape meets Federal specifications is to be obtained from the manufacturer when ordering the tape.

5.2 *Engraved Metal Rule*.–A device manufactured from tool steel which is used to obtain accurate linear measurements. Engraved metal rules should meet the requirements of Federal Specification GGG-R-791F. The rule is to be constructed in one piece without joints and is to be made of tool steel. A certificate of inspection certifying that the engraved metal rule meets Federal specifications is to be obtained from the manufacturer when ordering the rule.

5.3 *Hardwood Rule*.–A device used to obtain accurate linear measurements manufactured from hardwood. The hardwood rule should meet the requirements of Federal Specification GGG-R-791F. The hardwood rule is to be constructed in one piece of well-seasoned hardwood from birch, boxwood, or hard maple. The wood is to be straight-grained and clear throughout. A rule that is marked with the inch-pound scale (1/8-inch graduations) on one face and the metric scale (1-cm graduations) on the other face is adequate for most laboratory and field applications.

5.4 *Vernier or Dial Calipers*.–A measuring device which consists of a main scale with a fixed jaw and a sliding jaw with an attached vernier and is used to obtain precise inside, outside, or depth measurements. Vernier or dial calipers should meet the requirements of Federal Specification GGG-C-111B. Inch-pound scale vernier or dial calipers which have a measuring range of 0 to 6 inches must be graduated to read in thousandths of an inch (0.001 in). Metric scale vernier or dial calipers which have a measuring range of 0 to 150 mm must be graduated to read in two one-hundredths of a millimeter (0.02 mm). A certificate of inspection certifying that the vernier or dial caliper meets Federal specifications is to be obtained from the manufacturer when ordering the calipers.

5.5 *Outside Micrometer*.–A device which is used to obtain precise outside measurements. Outside micrometers should meet the requirements of Federal Specification

GGG-C-105B. Inch-pound scale outside micrometers which have a measuring range of 0 to 1.000 inch must be graduated to read to at least one-thousandth of an inch (0.001 in). Metric scale outside micrometers which have a measuring range of 0 to 25 mm must be graduated to read to at least two one-hundredths of a millimeter (0.02 mm). A certificate of inspection certifying that the outside micrometer meets the Federal specification is to be obtained from the manufacturer when ordering the micrometer.

5.6 *Inside Micrometers.*–A device which is used to obtain precise inside measurements. Inside micrometers should meet the requirements of Federal Specification GGG-C-105B. Inch-pound scale inside micrometers which have a measuring range of 2 to 12 inches must be graduated to read to at least one-thousandth of an inch (0.001 in). Metric scale inside micrometers which have a measuring range of 50 to 300 mm must be graduated to read to at least two one-hundredths of a millimeter (0.02 mm). A certificate of inspection certifying that the inside micrometer meets Federal specifications is to be obtained from the manufacturer when ordering the micrometer.

5.7 *Depth Micrometers.*–A device which is used to obtain precise depth measurements. Depth micrometers should meet the requirements of Federal Specification GGG-C-105B. Inch-pound scale depth micrometers which have a metering range of 0 to 10 inches must be graduated to read to at least one-thousandth of an inch (0.001 inch). Metric scale depth micrometers which have a measuring range of 250 mm must be graduated to read to at least two one-hundredths of a millimeter (0.02 mm.) A certificate of inspection certifying that the depth micrometer meets Federal specifications is to be obtained from the manufacturer when ordering the micrometer.

5.8 *Rectangular Gauge Blocks.*–Precision steel rectangular gauge blocks are designed to be used individually. Gauge blocks are suitable for checking dial caliper, vernier caliper, micrometer caliper, and dial indicator travel. Inch-pound and metric scale gauge blocks are to be compatible with the calibration requirements; i.e., dial gauges, calipers, etc. A certificate of inspection certifying that the rectangular gauge blocks meet Federal specifications is to be obtained from the manufacturer when ordering the gauge blocks.

5.9 *Square Gauge Blocks.*–Precision steel square gauge blocks are designed for stack assembly. An accessory hole is drilled through the center of each gauge block to allow the tie rod to pass through for assembly. A certificate of inspection certifying that the square gauge blocks meet Federal specifications is to be obtained from the manufacturer when ordering the gauge blocks.

6. Precautions

6.1 *Safety Precautions.*–Examine the linear measurement devices (as received or before their use) for sharp edges or burrs.

6.2 *Technical Precautions*:

6.2.1 Examine the linear measurement devices for bent or missing components each time they are used.

6.2.2 Store the linear measurement devices in a suitable case when not in use.

6.2.3 Occasionally rub or wipe the linear measurement device with an oily rag if it is used in a wet or damp environment (not applicable for hardwood rules).

6.2.4 Use extreme caution when marking control numbers on linear measurement devices. Under no circumstances should the precision gauge blocks be marked or scribed by the purchaser. The manufacturer stamps the dimensions and serial number on the block at the time of manufacture and calibration.

7. Calibration and Standardization

7.1 Verify that the certificate of inspection is current. If it is not current, the linear measurement device should not be used.

It is recommended that linear measurement devices be returned to the manufacturer or to an appropriate certification agency biennially for recertification.

8. Conditioning

8.1 Not applicable, special conditioning requirements are not needed for this procedure.

9. Procedure

9.1 *Purchasing*:

9.1.1 All information is to be recorded on the "Linear Measurement Device Acceptance Form" as shown on figure 1.

9.1.2 Determine the type of measurement device that is needed, e.g., when determining the volume of relative density measures, one needs a depth micrometer with a measuring range of 0 to 10 inches and an inside micrometer with a measuring range of 2 to 12 inches.

9.1.3 Determine the nominal range of the item or items to be measured.

9.1.4 Obtain a catalog from a reputable supplier that supplies precision linear measurement devices.

9.1.5 Determine if the supplier can furnish the linear measurement device needed to accomplish the task.

9.1.6 Determine if the supplier can furnish a certificate of inspection and if construction and accuracy comply with applicable Federal specifications.

9.2 Upon receipt of the linear measurement device, the following items should be noted.

- Date of receipt
- Type of linear measurement device
- Name of the manufacturer
- Serial number of the linear measurement device
- Are the range and scale markings on the linear measurement device as specified on the purchase order?
- Check the certificate of inspection to ensure that it is current and that the data listed on it are applicable to the device (serial number and type).

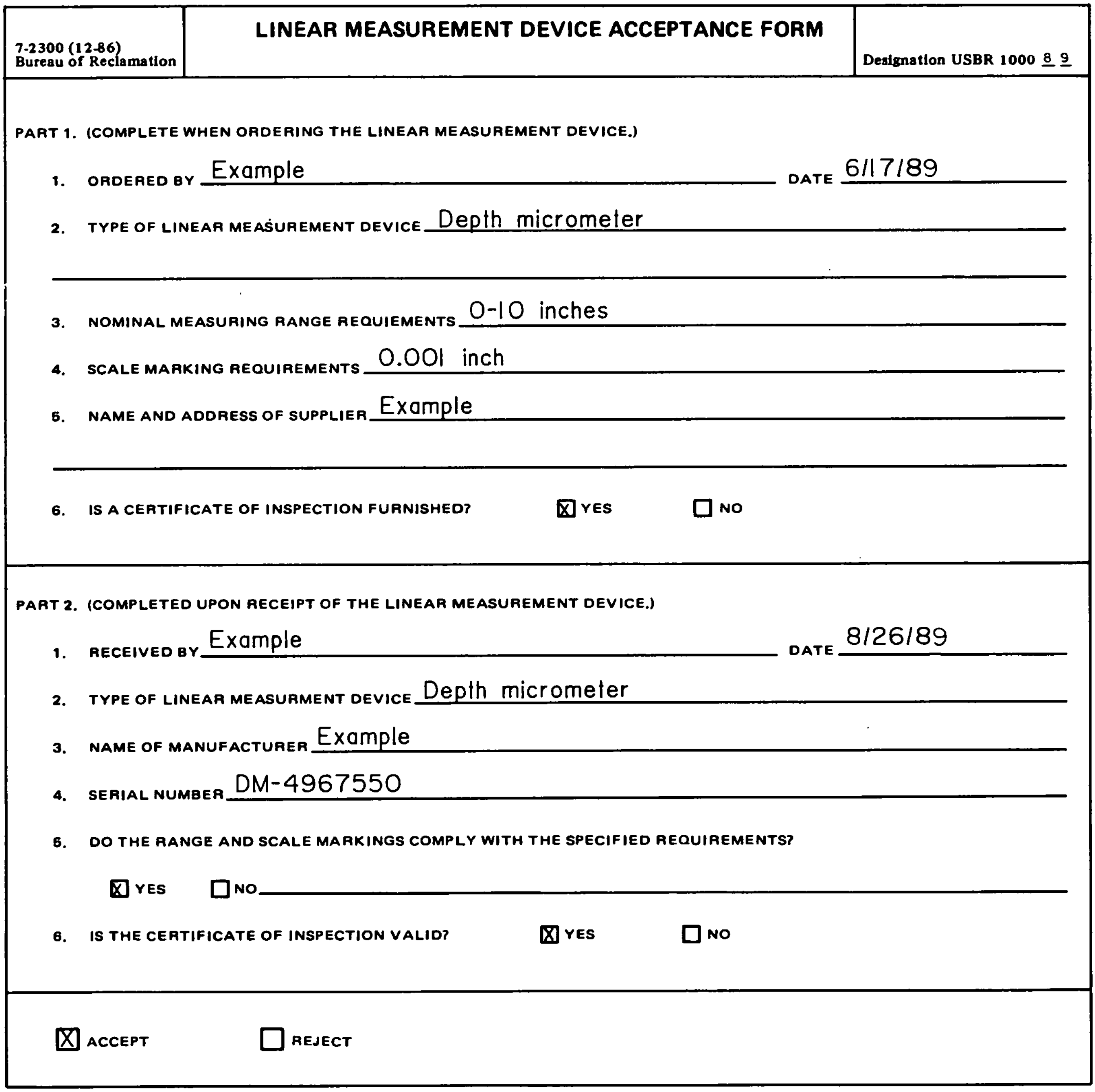
10. Interpretation of Results

10.1 Use the instructions and tables listed in the applicable Federal specifications to aid in determining if the linear measurement device complies with the special requirements.

10.2 If the linear measurement device meets all of the specified requirements, accept the device; if it does not, it is to be rejected and returned to the manufacturer.

11. Report

11.1 The report is to consist of a completed "Linear Measurement Device Acceptance Form." This information (fig. 1) should be filed with the laboratory equipment calibration records.



7-2300 (12-86)
Bureau of Reclamation

LINEAR MEASUREMENT DEVICE ACCEPTANCE FORM

Designation USBR 1000 89

PART 1. (COMPLETE WHEN ORDERING THE LINEAR MEASUREMENT DEVICE.)

1. ORDERED BY Example DATE 6/17/89
2. TYPE OF LINEAR MEASUREMENT DEVICE Depth micrometer
3. NOMINAL MEASURING RANGE REQUIEMENTS 0-10 inches
4. SCALE MARKING REQUIREMENTS 0.001 inch
5. NAME AND ADDRESS OF SUPPLIER Example
6. IS A CERTIFICATE OF INSPECTION FURNISHED? ☒ YES ☐ NO

PART 2. (COMPLETED UPON RECEIPT OF THE LINEAR MEASUREMENT DEVICE.)

1. RECEIVED BY Example DATE 8/26/89
2. TYPE OF LINEAR MEASURMENT DEVICE Depth micrometer
3. NAME OF MANUFACTURER Example
4. SERIAL NUMBER DM-4967550
5. DO THE RANGE AND SCALE MARKINGS COMPLY WITH THE SPECIFIED REQUIREMENTS?

   ☒ YES ☐ NO
6. IS THE CERTIFICATE OF INSPECTION VALID? ☒ YES ☐ NO

☒ ACCEPT ☐ REJECT

Figure 1. - Linear measurement device acceptance form — example.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1007-89

PROCEDURE FOR
CALIBRATING DIAL INDICATORS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1007. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating dial indicators for laboratory and field applications.

1.2 Method A outlines the calibration procedure using precision gauge blocks; Method B outlines the calibration procedure using a micrometer fixture.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR 1000 Standards for Linear Measurement Devices
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

2.2 *ASME Standard*:

ANSI B89.1.10 Dial Indicators (for Linear Measurement)

2.3 *Federal Specification*:

GGG-G-15C Gage Blocks and Accessories

3. Summary of Method

3.1 Comparison readings between a dial indicator and either precision gauge blocks (method A) or a micrometer fixture (method B) are used to determine the accuracy, repeatability, and hysteresis of the dial indicator. The results are used to evaluate the acceptability of dial indicators for laboratory and field use.

4. Significance and Use

4.1 Accurate linear measurements are required to obtain proper data for laboratory and field use.

4.2 Calibrate dial indicators when purchased and annually thereafter.

5. Terminology

5.1 Definitions are in accordance with USBR 3900.

5.2 Terms not included in USBR 3900 specific to this designation are:

5.2.1 *Accuracy*.–The degree to which displayed dial indicator readings vary from known spindle displacements.

5.2.2 *Graduation*.–The least measured value which is marked on the dial indicator face.

5.2.3 *Hysteresis*.–The difference in displayed dial indicator readings at any particular spindle displacement within the specified range, when the dial indicator reading is approached first with increasing and then with decreasing spindle displacements.

5.2.4 *Range*.–The measured values over which the dial indicator is intended to measure, specified by upper and lower limits.

5.2.5 *Repeatability*.–The degree to which displayed dial indicator readings vary for successive measurements of the same reference.

6. Apparatus

6.1 *Dial Indicator*.–A dial indicator used for standard laboratory or field applications.

6.2 *Method A — Precision Gauge Block Calibration*:

6.2.1 *Precision Gauge Blocks* (fig. 1a).–A set of steel gauge blocks (inch-pound or metric), usually rectangular, meeting the requirements of Federal Specifications GGG-G-15C and those requirements identified in USBR 1000 for precision gauge blocks. A gauge block set should contain sizes (or combination of sizes) necessary to satisfactorily perform the calibration procedure as outlined in paragraph 10.

6.2.2 *Dial Indicator Comparator Stand* (fig. 1b).–A stand consisting of a base; ground to a guaranteed flatness and warp-free stability; a support column and an adjustable arm onto which the dial indicator can be securely attached.

6.3 *Method B — Micrometer Fixture Calibration*:

6.3.1 *Micrometer Fixture* (fig. 2a).–A precision instrument capable of obtaining comparison readings over the full range of the dial indicator. The spindle must be nonrotating and spring loaded. The micrometer fixture is to be calibrated annually by the manufacturer.

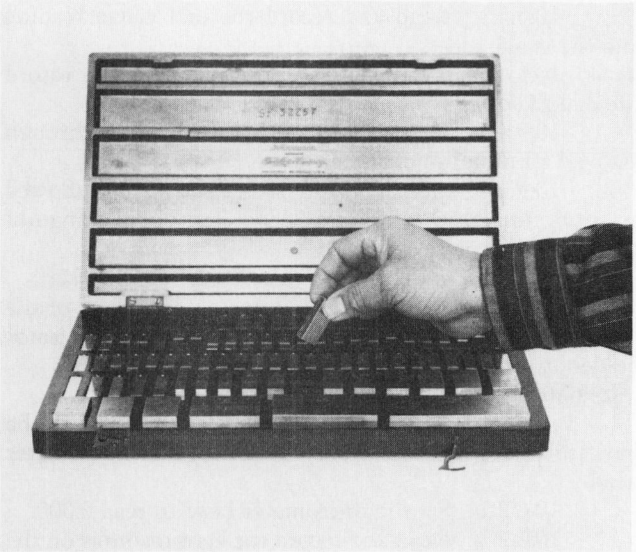
6.3.2 *Magnetic Base Dial Indicator Holder* (fig. 2b).–A magnetic base with a solid upright post adapted with a swivel snug, gauge rod, and dial indicator clamp with fine adjustment capabilities.

7. Precautions

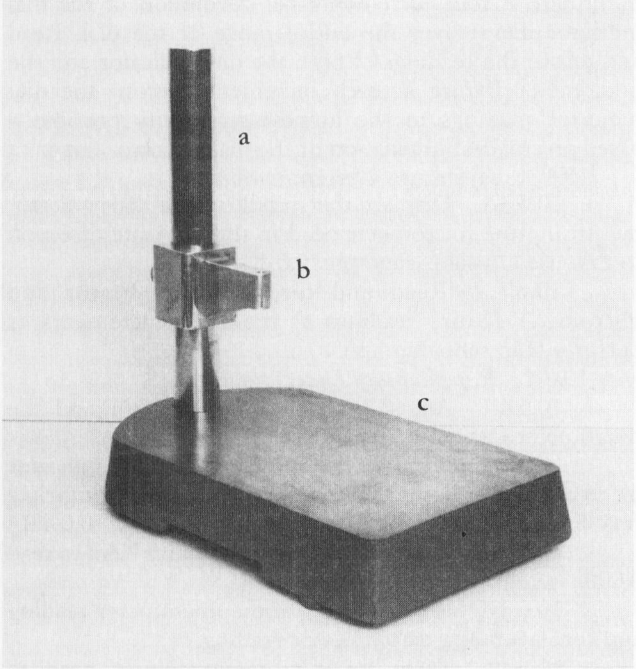
7.1 *Safety Precautions*.–The dial indicator case, stem, spindle, and contact point are to be examined for burrs and sharp edges.

7.2 *Technical Precautions*:

7.2.1 The dial face is to be examined for clarity of graduations.



(a) Precision gauge blocks.

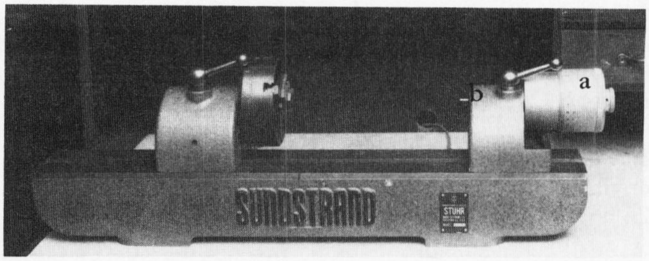


(b) Dial indicator comparator stand. a) support column, b) adjustable arm, and c) base.

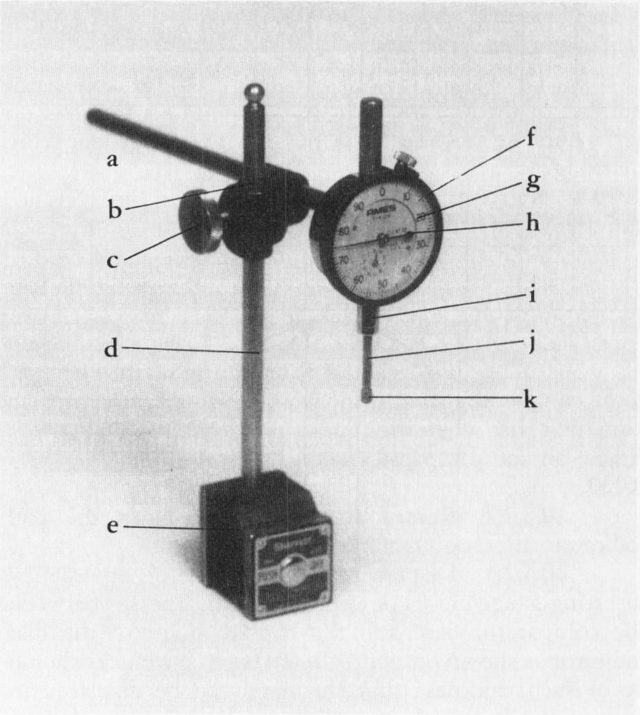
Figure 1. - Dial indicator calibration equipment (method A).

7.2.2 The dial indicator is to be replaced if there is any evidence of binding or twisting when the spindle is pushed into the stem.

7.2.3 Extreme caution is to be used when inscribing or marking control numbers on the dial indicator to prevent interference with operation or reliability of the dial indicator.



(a) Micrometer fixture. a) micrometer head, and b) spindle.



(b) Magnetic base dial indicator holder. a) gauge rod, b) swivel snug, c) dial indicator clamp, d) post, e) magnetic base, f) case, g) dial face, h) hand, i) spindle, j) stem, and k) contact point.

Figure 2. - Dial indicator calibration equipment (method B).

7.2.4 Dial indicators are to be stored in a suitable box or case when not in use.

8. Calibration and Standardization

8.1 Verify that gauge blocks used for obtaining dial indicator comparison readings (method A) are currently calibrated in accordance with USBR 1000. If the gauge block calibration is not current, perform the calibration before using the gauge blocks for this procedure.

8.2 Verify that the micrometer fixture has been currently calibrated by the manufacturer. If the calibration is not current, perform the calibration before using the micrometer fixture (method B) for this procedure.

9. Conditioning

9.1 Perform this calibration in an environment as close to 68 °F (20 °C) as possible.

9.2 The dial indicator, calibration gauge blocks, and dial indicator comparator stand and base should be in the environment in which they are to be calibrated for at least 24 hours prior to calibration.

10. Procedure

10.1 All data are to be recorded on the "Dial Indicator Calibration Sheet" as shown on figure 3.

10.2 Record the range and graduation of the dial indicator to be calibrated.

10.3 Locate and record the manufacturer and serial number of the dial indicator to be calibrated. If it has no serial number, record the model number and any identifying marking.

10.4 Record the type and serial number of the reference standard to be used.

10.5 *Method A — Precision Gauge Block Calibration*:

10.5.1 Mount the dial indicator on the dial indicator comparator stand as shown on figure 4a.

10.5.2 *Accuracy Determination*:

10.5.2.1 Position the dial indicator on the dial indicator comparator stand. Adjust the dial indicator in such a manner that when the contact point of the spindle rests firmly on the comparator stand base, the hand registers 0.000.

10.5.2.2 Record the zero reading on the dial indicator calibration form.

10.5.2.3 Displace the dial indicator spindle by inserting gauge blocks of appropriate thicknesses between the comparator base and the contact point of the dial indicator as shown on figure 4b. These gauge blocks should be of such thickness that the hand can be displaced in approximately equal increments (a minimum of four increments per revolution of the dial indicator hand) over the entire range of the dial. Record the gauge block(s) used (reference standard length) and the dial indicator reading at each increment. Record the dial indicator readings to the highest readability possible—based on smallest graduation of the dial indicator dial.

10.5.3 *Hysteresis Determination*:

10.5.3.1 Displace the spindle of the dial indicator by inserting the same gauge blocks as used in subparagraph 10.5.2.3. This time insert the gauge blocks in reverse order; i.e., thickest block to thinnest.

10.5.3.2 Read and record dial indicator readings for each gauge block used.

10.5.4 *Repeatability Determination*:

10.5.4.1 Remove all gauge blocks from beneath the contact point. Readjust the dial indicator on the support column so that the hand registers 0.000 with the contact point resting on the comparator base and record the value.

10.5.4.2 Rotate the hand of the dial indicator by displacing the dial indicator spindle using an appropriate size (or combination of) gauge block(s). (See subpar. 10.5.4.6.)

10.5.4.3 Read and record the dial gauge reading and the gauge block(s) used.

10.5.4.4 Remove the gauge block(s) and record the dial indicator reading.

10.5.4.5 Repeat subparagraphs 10.5.4.1 through 10.5.4.4 a minimum of three times.

10.5.4.6 Subparagraph 10.5.4 should be followed at approximately 25, 50, and 75 percent of full range of the dial indicator.

10.6 *Method B — Micrometer Fixture Calibration*:

10.6.1 Mount the dial indicator on the bench of the micrometer fixture utilizing the magnetic base dial indicator holder as shown on figure 5.

10.6.2 *Accuracy Determination*:

10.6.2.1 Displace the dial indicator spindle so the indicator hand registers 0.000 by turning the micrometer head.

10.6.2.2 Set the micrometer head to read 0.000.

10.6.2.3 Read and record the zero readings on the dial indicator calibration form.

10.6.2.4 Displace the dial indicator spindle by turning the micrometer head in equal increments (a minimum of four increments per revolution of the dial indicator hand) over the entire range of the dial. Read and record the readings of both the dial indicator and the micrometer fixture at each increment. Record the dial indicator readings to the highest readability possible—based on smallest graduation of the dial indicator hand.

10.6.3 *Hysteresis Determination*:

10.6.3.1 Displace the spindle of the dial indicator by turning the micrometer head in the opposite direction to that used in subparagraph 10.6.2.1.

10.6.3.2 Read and record dial indicator and micrometer fixture readings at the same increments as performed in subparagraph 10.6.2.4.

10.6.4 *Repeatability Determination*:

10.6.4.1 Adjust both the dial indicator and the micrometer fixture to read 0.000.

10.6.4.2 Displace the spindle of the dial indicator by turning the micrometer fixture to cause the appropriate revolution of the dial indicator hand. (See subpar. 10.6.4.8.)

10.6.4.3 Turn the micrometer fixture head to read 0.000.

10.6.4.4 Read and record the micrometer reading and corresponding dial indicator reading.

10.6.4.5 Turn the micrometer fixture head to return the micrometer back to zero.

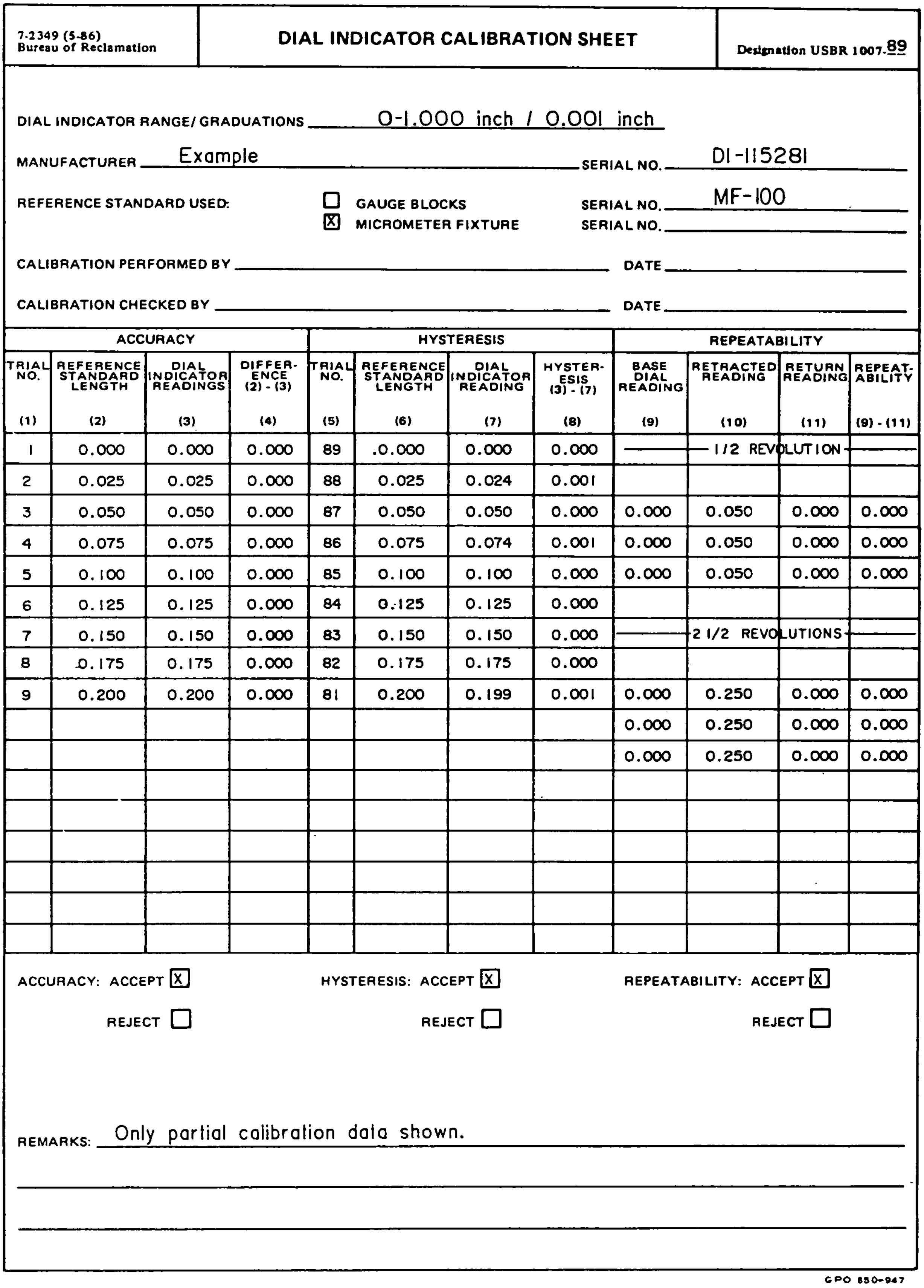
10.6.4.6 Read and record the micrometer reading and corresponding dial indicator reading.

10.6.4.7 Repeat subparagraphs 10.6.4.1 through 10.6.4.6 a minimum of three times.

10.6.4.8 Subparagraph 10.6.4 should be followed at approximately 25, 50, and 75 percent of full range of the dial indicator.

11. Calculations

11.1 Calculations for determining the accuracy, hysteresis, and repeatability of the dial indicator are as shown on the "Dial Indicator Calibration Sheet" (fig. 3).



7-2349 (5-86)
Bureau of Reclamation

DIAL INDICATOR CALIBRATION SHEET

Designation USBR 1007-89

DIAL INDICATOR RANGE/GRADUATIONS 0-1.000 inch / 0.001 inch

MANUFACTURER Example SERIAL NO. DI-115281

REFERENCE STANDARD USED: ☐ GAUGE BLOCKS SERIAL NO. MF-100

☒ MICROMETER FIXTURE SERIAL NO.

CALIBRATION PERFORMED BY ________ DATE ________

CALIBRATION CHECKED BY ________ DATE ________

ACCURACY				HYSTERESIS				REPEATABILITY			
TRIAL NO. (1)	REFERENCE STANDARD LENGTH (2)	DIAL INDICATOR READINGS (3)	DIFFERENCE (2) - (3) (4)	TRIAL NO. (5)	REFERENCE STANDARD LENGTH (6)	DIAL INDICATOR READING (7)	HYSTERESIS (3) - (7) (8)	BASE DIAL READING (9)	RETRACTED READING (10)	RETURN READING (11)	REPEATABILITY (9) - (11)
1	0.000	0.000	0.000	89	0.000	0.000	0.000	1/2 REVOLUTION			
2	0.025	0.025	0.000	88	0.025	0.024	0.001				
3	0.050	0.050	0.000	87	0.050	0.050	0.000	0.000	0.050	0.000	0.000
4	0.075	0.075	0.000	86	0.075	0.074	0.001	0.000	0.050	0.000	0.000
5	0.100	0.100	0.000	85	0.100	0.100	0.000	0.000	0.050	0.000	0.000
6	0.125	0.125	0.000	84	0.125	0.125	0.000				
7	0.150	0.150	0.000	83	0.150	0.150	0.000	2 1/2 REVOLUTIONS			
8	0.175	0.175	0.000	82	0.175	0.175	0.000				
9	0.200	0.200	0.000	81	0.200	0.199	0.001	0.000	0.250	0.000	0.000
								0.000	0.250	0.000	0.000
								0.000	0.250	0.000	0.000

ACCURACY: ACCEPT ☒ REJECT ☐

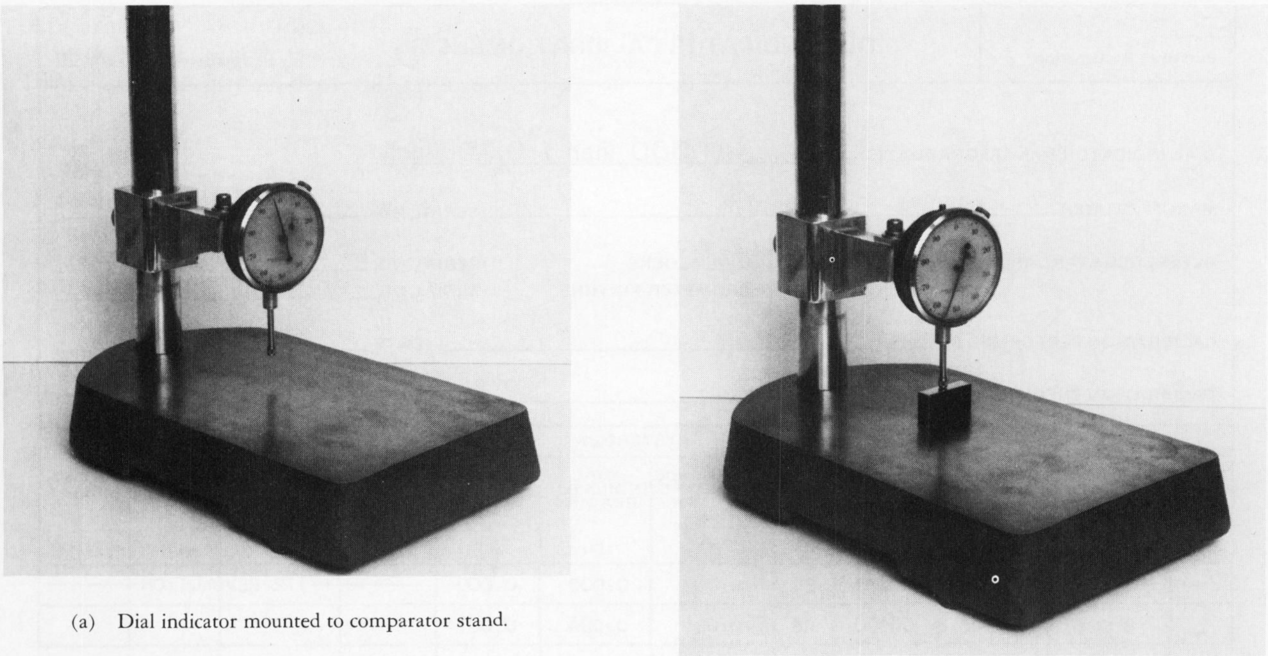
HYSTERESIS: ACCEPT ☒ REJECT ☐

REPEATABILITY: ACCEPT ☒ REJECT ☐

REMARKS: Only partial calibration data shown.

GPO 850-947

Figure 3. - Dial indicator calibration sheet — example.



(a) Dial indicator mounted to comparator stand.

(b) Displacement of dial indicator with gauge block.

Figure 4. – Dial indicator calibration assembly (method A).

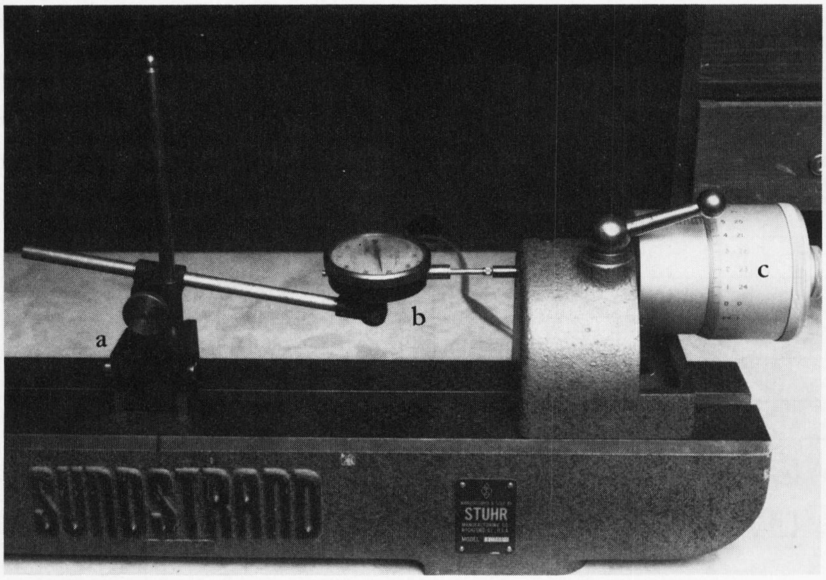


Figure 5. – Dial indicator calibration assembly (method B). (a) magnetic base dial indicator holder, (b) dial indicator, and (c) micrometer head.

12. Interpretation of Results

12.1 Table 1 shows maximum allowable deviation and is to be used to evaluate the acceptability of the dial indicator.

12.2 If deviation of the dial indicator exceeds the limits listed in table 1 for repeatability, hysteresis, or accuracy, the dial indicator must be rejected.

13. Report

13.1 The report is to consist of a completed and checked "Dial Indicator Calibration Sheet" (fig. 3). This information is to be filed with the laboratory equipment calibration records.

13.2 All calculations are to show a checkmark.

Table 1. – Dial indicator maximum deviation.

Smallest graduation		Repeatability	Hysteresis	Accuracy		
inch	mm			First 2-1/3 revolutions	First 10 revolutions	First 20* revolutions
Deviation in units of smallest graduation						
0.00005	0.001	±0.2	0.50	±1	±4	
.00010	.002	±0.2	.50	±1	±3	±4
.00050	.010	±0.2	.33	±1	±3	±4
.00100	.020	±0.2	.33	±1	±2	±4

* Over 20 revolutions consult with individual manufacturers for standard procedure.

Table 1 taken from ANSI B 89.1.10-1978 dial indicators for linear measurements.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1008-89

PROCEDURE FOR

CALIBRATING LINEAR VARIABLE DIFFERENTIAL TRANSFORMERS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1008. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating LVDTs (linear variable differential transformers).

1.2 Method A outlines the calibration procedure using precision gauge blocks; method B outlines the calibration procedure incorporating a micrometer fixture.

2. Applicable Documents

2.1 *USBR Procedure*:

USBR 1000 Standards for Linear Measurement Devices

USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

2.2. *Federal Specification*:

GGG-G-15C Gage Blocks and Accessories

3. Summary of Method

3.1 Readings from an LVDT and from either the precision gauge blocks (method A) or the micrometer fixture (method B) are compared to determine the linearity and repeatability of the LVDT. The results are used to determine the acceptability of the LVDT for laboratory use.

4. Significance and Use

4.1 LVDTs must be calibrated for use in the laboratory to ensure reliable linear measurements.

4.2 Calibrate LVDTs before initial use and at least annually thereafter.

5. Terminology (see fig.1)

5.1 Definitions are in accordance with USBR 3900.

5.2 Terms not included in USBR 3900 specific to this designation are:

5.2.1 *Null Position.*–The LVDT core position within the LVDT body that voltage output is zero.

5.2.2 *TLR* (total linear range).–Total distance that may be traveled by the LVDT core in moving from the position of maximum voltage output at one end of the body—through the null position—to the position of maximum voltage output at the opposite end of the body.

5.2.3 *Full-Scale Displacement.*–Total distance traveled by the core in moving from the null position to one end of the total linear range; i.e., one-half of the total linear range.

5.2.4 *Range.*–Total distance traveled by the core expressed in terms of percent plus or minus full-scale displacement.

5.2.5 *Repeatability.*–The degree of LVDT measurement variation for successive measurements of the same reference standard.

5.2.6 *Linearity.*–The variation of LVDT measurements from a straight line. The measurements are obtained using a series of reference standards applied over the total linear range of the LVDT.

5.2.7 *Percent Error.*–The ratio (expressed as a percent) of (1) the difference between an LVDT measurement of a reference standard and the actual length of the reference standard to (2) the total linear range of the LVDT. Percent error also may be determined over a fraction of the total linear range.

5.2.8 *Voltage Error.*–The difference in LVDT voltage output for successive measurements of the same reference standard.

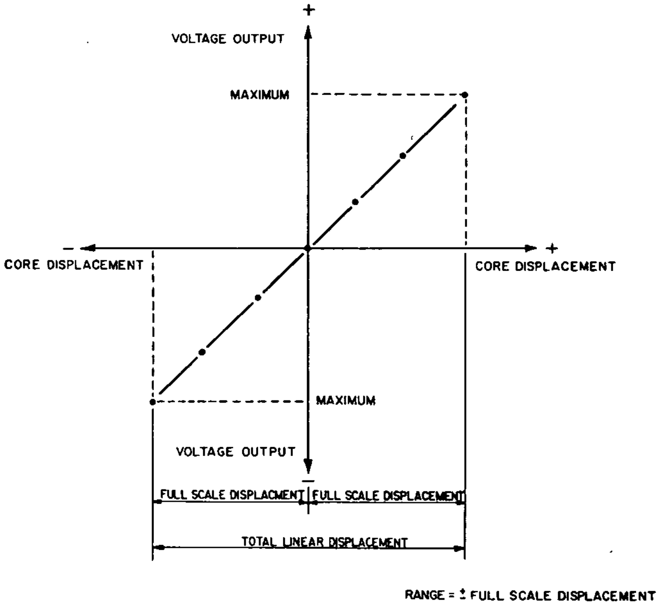
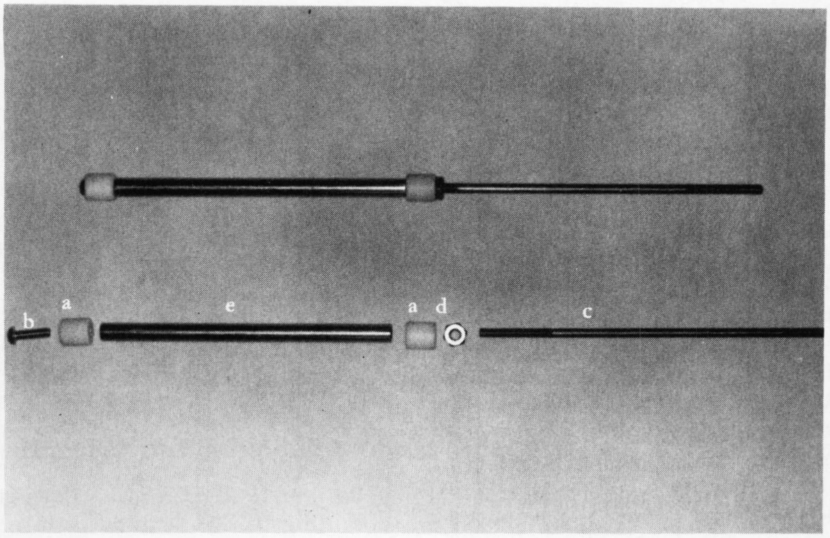
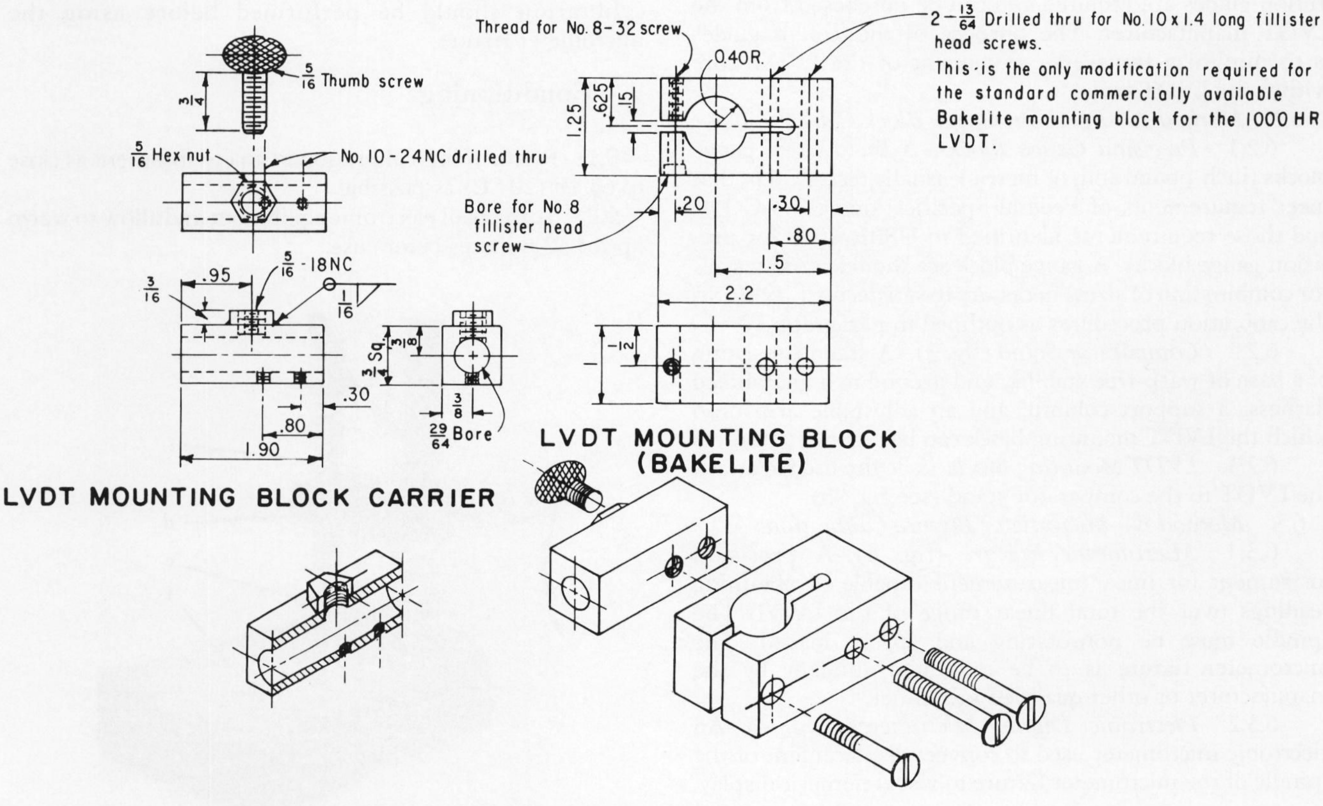


Figure 1. – Terminology of the LVDT.



(a) LVDT core/core extension rod assembly. a) teflon guide, b) No. 6-40 UNF threaded screw, c) LVDT core extension rod, d) lock nut, and e) LVDT core.



(b) Schematic of LVDT mounting block.

Figure 2. – LVDT mounting block and rod assembly.

6. Apparatus

6.1 *General Apparatus*:

6.1.1 *LVDT.*–An electrical transducer which converts linear displacement to electrical output. An LVDT (linear variable differential transformer) consists of a stationary LVDT body and a movable LVDT core. The LVDT core is threaded on both ends so the LVDT core extension rods can be attached.

6.1.2 *Signal Conditioner and Readout Equipment.*–A signal conditioner provides excitation voltage for the LVDT, as well as appropriate electronic circuitry to make the output of the transducer (LVDT) compatible with readout equipment. Readout equipment accepts output from the signal conditioner and converts it into a visual display of transducer displacement.

6.1.3 *LVDT Core Extension Rod* (fig. 2a).–A nonmagnetic rod (preferably brass), threaded on both ends. The diameter of the rod and threads must be compatible with the diameter of the hole in the LVDT core. The rod should be threaded a minimum of 1 inch (25 mm) at each end with an approximate total length of 2-1/2 inches (65 mm).

6.1.4 *LVDT Teflon Guides* (fig. 2a).–Two LVDT Teflon guides are required and can be purchased from the LVDT manufacturer. The purpose of the Teflon guides is to minimize transverse movement of the LVDT core within the LVDT body.

6.2 *Method A—Precision Gauge Block Calibration*:

6.2.1 *Precision Gauge Blocks.*–A set of steel gauge blocks (inch-pound and/or metric), usually rectangular, that meet requirements of Federal Specifications GGG-G-15C and those requirements identified in USBR 1000 for precision gauge blocks. A gauge block set should contain sizes (or combination of sizes) necessary to satisfactorily perform the calibration procedures as outlined in paragraph 10.

6.2.2 *Comparator Stand* (fig. 3).–A stand consisting of a base of warp-free stability and ground to a guaranteed flatness; a support column; and an adjustable arm onto which the LVDT mounting block can be securely attached.

6.2.3 *LVDT Mounting Block.*–A device used to attach the LVDT to the comparator stand (see fig. 2b).

6.3 *Method B—Micrometer Fixture Calibration*:

6.3.1 *Micrometer Fixture* (fig. 4).–A precision instrument for linear measurement capable of obtaining readings over the total linear range of the LVDT. The spindle must be nonrotating and spring loaded. The micrometer fixture is to be calibrated annually by the manufacturer or other qualified personnel.

6.3.2 *Electronic Digital Micrometer* (fig. 4).–An electronic micrometer used to convert displacement of the spindle of the micrometer fixture to visual numeric display.

7. Precautions

7.1 *Safety Precautions*:

7.1.1 The LVDT body should be examined for burrs and/or sharp edges.

7.1.2 Verify all electrical wiring is connected properly, and that the signal conditioner (if used) is grounded properly to prevent electrical shock to the operator.

7.2 *Technical Precautions*:

7.2.1 The LVDT core and body are a matched set as purchased from the manufacturer; for best performance, do not interchange cores with other LVDT bodies.

7.2.2 Replace the core and body if either shows any sign of dents, bending, or other defects which may affect performance of the device.

7.2.3 The LVDT core and body should be stored in a suitable box or case when not in use.

7.2.4 Do not exceed the input voltage of the LVDT as specified by the manufacturer.

8. Calibration and Standardization

8.1 *Method A.*–Verify that gauge blocks used for obtaining LVDT comparison readings are currently calibrated in accordance with USBR 1000. If the gauge block calibration is not current, the calibration procedure should be performed before using the gauge blocks.

8.2 *Method B.*–Verify that the micrometer fixture has been currently calibrated by the manufacturer or other qualified personnel. If the calibration is not current, the calibration should be performed before using the micrometer fixture.

9. Conditioning

9.1 Perform this calibration in an environment as close to 68 °F (20 °C) as possible.

9.2 Turn on all electronic equipment and allow to warm up for 30 minutes before use.

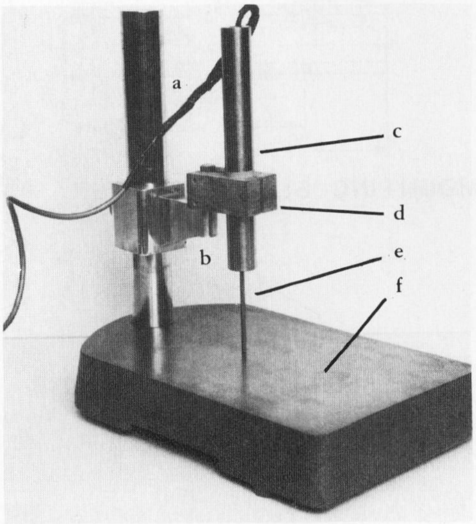


Figure 3. - LVDT Comparator stand and LVDT mounting block (method A). a) support column, b) adjustable arm, c) LVDT body, d) LVDT mounting block, e) LVDT core extension rod, and f) base.

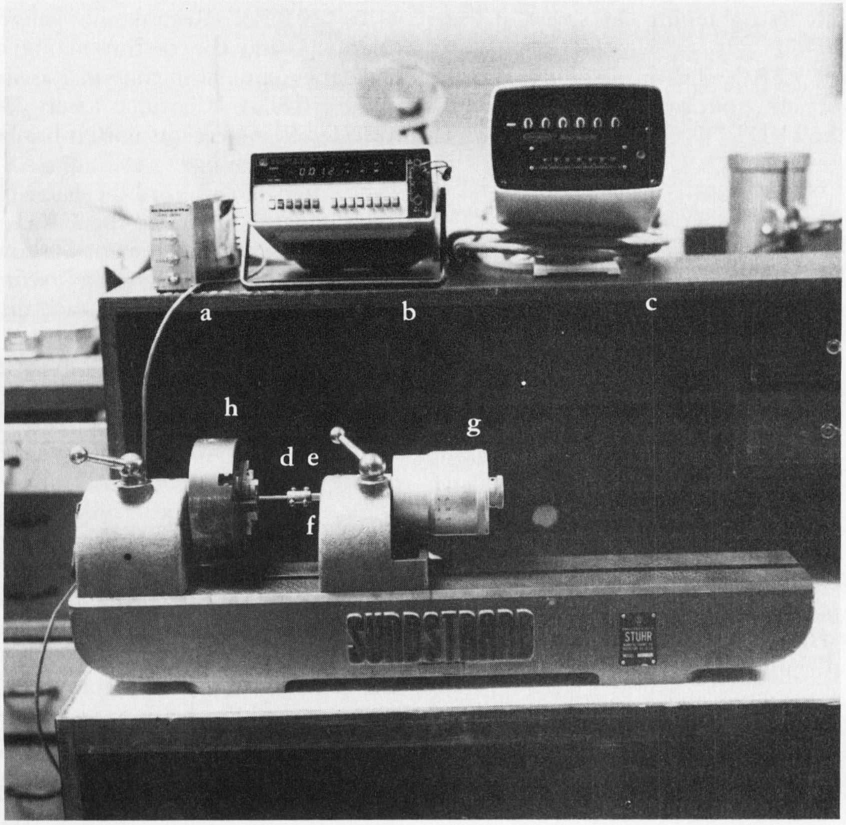


Figure 4. – LVDT Calibration assembly—micrometer fixture (method B). a) signal conditioner, b) readout equipment, c) electronic digital micrometer, d) LVDT core extension rod, e) spindle, f) micrometer head carrier, g) micrometer head, and h) chuck.

9.3 The LVDT, calibration gauge blocks, micrometer fixture, and comparator stand should be in the environment in which they are to be calibrated for at least 24 hours prior to calibration.

10. Procedure

10.1 All data are to be recorded on the "Linear Variable Differential Transformer Calibration" form as shown on figure 5.

10.2 Record type and serial number of the LVDT to be calibrated; if it has no serial number, record the model number and any other identifying markings.

10.3 Record the total linear range of the LVDT.

10.4 Record the type and serial number of the reference standard used.

10.5 Attach the cable from the LVDT to the signal conditioner; and attach the cable from the signal conditioner output to the readout equipment. Plug in the readout equipment to a power source and allow a minimum 30-minute warmup.

10.6 Slide an LVDT Teflon guide onto each end of the LVDT core as shown on figure 2a.

10.7 Attach the LVDT core extension rod to the end of the LVDT core by screwing the LVDT core extension rod into the threaded LVDT core.

10.8 *Method A—Precision Gauge Block Calibration*:

10.8.1 *Null Position of LVDT*:

10.8.1.1 Attach the LVDT mounting block to the adjustable arm of the comparator stand as shown on figure 3.

10.8.1.2 Slide the LVDT core and core extension rod assembly into the LVDT body.

10.8.1.3 Place the LVDT body into the LVDT mounting block and tighten the appropriate screw on the mounting block. (DO NOT overtighten the screw on the mounting block; this can deform the LVDT body.)

10.8.1.4 Apply voltage to the LVDT. Ensure that the line voltage is compatible with the power requirements of the signal conditioner. Refer to the manufacturer's operating instructions for voltage requirements.

10.8.1.5 Place a gauge block (or series of blocks) which has a height equal to one-half the total linear range of the LVDT under the LVDT core extension rod; i.e. for an LVDT having a 2-inch (50.8-mm) total linear range, a 1-inch (25.4-mm) gauge block is used.

10.8.1.6 Using the adjustable arm, adjust the LVDT body up or down on the comparator stand support column as necessary so the output of the readout equipment is approximately equal to 0 volt.

10.8.1.7 Secure the adjustable arm on the support column of the comparator stand in the position described in subparagraph 10.8.1.6, by tightening the screw of the adjustable arm.

10.8.1.8 Use the ZERO adjustment on the signal conditioner to obtain a reading of exactly 0.000 volt. This is the null position of the LVDT.

NOTE 1.–Adjustment of the signal conditioner may vary slightly depending on the type of signal conditioner used. Refer to the manufacturer's operating instructions for adjustment of the specific signal conditioner used.

10.8.2 *Signal Conditioner Span Setting* (LVDT factor determination):

10.8.2.1 Remove the gauge block (or series of blocks) from beneath the LVDT core extension rod.

10.8.2.2 Place a gauge block (or series of blocks) which has a height equal to the total linear range of the LVDT (as recorded in subpar. 10.3) under the core extension rod; i.e., for an LVDT with a 2-inch (50.8-mm) total linear range, a 2-inch gauge block is used.

10.8.2.3 Adjust the signal conditioner, using the GAIN control screw, so that the output of the LVDT is equal to ±10.000 volts d.c. (Polarity depends on the wiring of the LVDT.)

NOTE 2.–For convenience, subparagraph 10.8.2.3 specifies a setting of ±10.000 volts d.c. for the LVDT output at full-scale displacement. Other values of output at full LVDT displacement may be used, if desired.

10.8.2.4 Remove the gauge block (or series of gauge blocks) from beneath the core extension rod and replace it with a gauge block (or series of gauge blocks) having a height equal to one-half the total linear range of the LVDT. The readout should indicate 0.000 volt; if it does not, reset by adjusting the ZERO adjustment.

10.8.2.5 Repeat subparagraphs 10.8.2.2 through 10.8.2.4 until values of 0.000 and ±10.000 (see note 2) volts are obtained.

10.8.2.6 Record the value of LVDT output at full-scale displacement ±10.000 volts (see note 2) as "LVDT output 1" as shown on figure 5.

10.8.2.7 Remove the gauge block (or series of gauge blocks) from beneath the LVDT core extension rod and allow the LVDT core extension rod to rest on the comparator stand base.

10.8.2.8 Record the LVDT output obtained as "LVDT output 2" as shown on figure 5.

10.8.2.9 Calculate and record the LVDT output change and the "LVDT factor" as shown on figure 5.

10.8.3 *Linearity of the LVDT*:

10.8.3.1 Select appropriate displacement increments (gauge blocks) to displace the LVDT core through its total linear range. It is recommended that the gauge blocks be selected such that a minimum of four readings—equally spaced throughout the LVDT total linear range—are used.

10.8.3.2 Raise the LVDT core extension rod, and place the appropriate gauge block(s) on the comparator stand base beneath the LVDT core extension rod.

10.8.3.3 Record the gauge block(s) height in column 1 and the corresponding output of the LVDT readout equipment in column 2 as shown on figure 5.

10.8.3.4 Continue to displace the LVDT core at the selected increments until it has been displaced through its total linear range.

10.8.3.5 Record the gauge block(s) height and the corresponding output of the LVDT readout equipment at each displacement increment as shown on figure 5.

10.8.3.6 Calculate and record values of percent of TLR and percent error for each displacement increment as shown on figure 5.

10.8.3.7 Check the linearity of the LVDT in accordance with provisions in subparagraph 12.1.

10.8.4 *Repeatability of the LVDT*:

10.8.4.1 Remove the gauge block(s) from beneath the LVDT core extension rod.

10.8.4.2 Repeat subparagraphs 10.8.3.2 through 10.8.3.5 using the same displacement increments (gauge blocks) selected in subparagraph 10.8.3.1.

10.8.4.3 Calculate and record the voltage error at each corresponding displacement increment as shown on figure 5.

10.8.4.4 Check repeatability of the LVDT in accordance with provisions in subparagraph 12.2.

10.9 *Method B—Micrometer Fixture Calibration*:

10.9.1 Secure the LVDT body into the chuck of the micrometer fixture as shown on figure 4. (DO NOT overtighten the chuck around the LVDT body.)

10.9.2 Slide the LVDT core with the Teflon guides and core extension rod assembly into the LVDT body.

10.9.3 Attach the LVDT core extension rod to the spindle of the micrometer head carrier using an appropriate attachment assembly as shown on figure 4.

10.9.4 Apply voltage to the LVDT. Ensure that the line voltage is compatible with the power requirements of the signal conditioner. Refer to the manufacturer's operating instructions for voltage requirements.

10.9.5 Ensure that the signal conditioner has had a minimum 30-minute warmup time.

10.9.6 *Null Position of LVDT*:

10.9.6.1 Turn the GAIN control of the signal conditioner (see note 1) to the minimum gain setting.

10.9.6.2 Adjust the ZERO control of the signal conditioner to achieve an output of zero volt.

10.9.6.3 Turn GAIN control to approximately the midpoint position.

10.9.6.4 Remove the LVDT core by sliding the micrometer head carrier along the bed of the micrometer fixture until the output is approximately 0 volt. Tighten the micrometer head carrier to the bed of the micrometer fixture.

10.9.6.5 Rotate the micrometer head to achieve a reading of exactly 0.000 volt. This is the null position of the LVDT.

10.9.7 *Signal Conditioner Span Setting* (LVDT factor determination):

10.9.7.1 Reset the electronic digital micrometer to read 0.000.

10.9.7.2 Rotate the micrometer head until the LVDT core has been displaced a distance equal to one-half the total linear range of the LVDT; i.e. for an LVDT having a 2-inch (50.8-mm) total linear range, the digital micrometer should read ±1.000 inch (25.4 mm). Record the value of LVDT output achieved as "LVDT output 1."

10.9.7.3 Adjust the signal conditioner, using the GAIN control screw, so the output of the LVDT readout equipment is equal to ±10.000 volts d.c. (see note 2). Polarity depends on the wiring of the LVDT.

10.9.7.4 Rotate the micrometer head in the opposite direction until the electronic digital micrometer reads 0.000 volt. The readout equipment should indicate 0.000 volt; if it does not, reset by adjusting the ZERO adjustment.

10.9.7.5 Repeat subparagraphs 10.9.7.2 through 10.9.7.4 until values of 0.000 and ±10.000 volts (see note 2) are obtained.

10.9.7.6 Rotate the micrometer head until the electronic digital micrometer indicates the LVDT has been displaced a distance equal to one-half the total linear range of the LVDT. (This is to be equal displacement but opposite direction as that achieved in subpar. 10.9.7.2.)

10.9.7.7 Record the LVDT output obtained as "LVDT output 2."

10.9.7.8 Calculate and record the LVDT output change and the "LVDT factor."

10.9.8 *Linearity of the LVDT*:

10.9.8.1 Select appropriate displacement increments to displace the LVDT core through its total linear range. It is recommended that the displacement increments be selected such that a minimum of four readings—equally spaced throughout the LVDT range—are used.

10.9.8.2 Rotate the micrometer head until the electronic digital micrometer output corresponds to the desired displacement increment.

10.9.8.3 Read and record the digital micrometer output and corresponding LVDT output voltage.

10.9.8.4 Continue to displace the LVDT by rotating the micrometer head to the selected increments until the LVDT core has been displaced through its total linear range.

10.9.8.5 Record the LVDT displacement as indicated by the digital micrometer and the corresponding voltage output at each displacement increment.

10.9.8.6 Calculate and record values of percent of TLR and percent error for each displacement increment.

10.9.8.7 Check the linearity of the LVDT in accordance with provisions of subparagraph 12.1.

10.9.9 *Repeatability of the LVDT*:

10.9.9.1 Rotate the micrometer head until the digital micrometer reads 0.000 volt.

10.9.9.2 Repeat subparagraphs 10.9.8.2 through 10.9.8.5 using the same displacement increments selected in subparagraph 10.9.8.1.

10.9.9.3 Calculate and record the voltage error at each corresponding displacement increment as shown on figure 5.

10.9.9.4 Check repeatability of the LVDT in accordance with provisions in subparagraph 12.2.

11. Calculations

11.1 Calculations are as shown on the "Linear Variable Differential Transformer Calibration" form. (fig. 5).

12. Interpretation of Results

12.1 *Linearity*.–Table 1 is to be used for evaluation of LVDT linearity.

12.1.2 If percent error, at the listed percent of total linear range, exceeds the amount listed in table 1 the LVDT should be rejected.

12.2 Repeatability.–The voltage error should not exceed ±0.05 volt at any displacement. If the voltage error (col. 8, fig. 5) exceeds ±0.05 volt, the LVDT should be rejected.

13. Report

13.1 The report is to consist of a completed and checked "Linear Variable Differential Transformer Calibration" form (fig. 5).

13.2 All calculations are to show a checkmark.

14. Background Reference

"Handbook of Measurement and Control," *Handbook HB-76*, copyright 1976 by Schaevitz Engineering, Pennsauken, NJ, Library of Congress Catalog No. 76-24971.

Table 1. – LVDT percent error tolerances.

Total linear range		Range, plus or minus		Allowable percent error over indicated percent of total linear range, %		
in	mm	in	mm	50	75	100
0.10	2.5	0.050	1.25	0.10	0.25	2.00
0.20	5	0.100	2.5	.10	.25	2.00
0.40	10	0.200	5.0	.10	.25	2.00
0.60	15	0.300	7.5	.10	.25	2.00
0.80	20	0.400	10	.15	.25	2.00
1.00	25	0.500	12.5	.15	.25	2.00
2.00	50	1.000	25	.25	.25	2.00
4.00	100	2.000	50	.25	.25	2.00
6.00	150	3.000	75	.15	.25	2.00
8.00	200	4.000	100	.15	.25	2.00
10.00	250	5.000	125	.15	.25	2.00
20.00	500	10.000	250	.15	.25	2.00

7-2347 (5-86)
Bureau of Reclamation

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER CALIBRATION

Designation USBR 1008-89

LVDT TYPE HR 1000 MANUFACTURER Example SERIAL NO. 15

REFERENCE STANDARD USED: ☒ GAUGE BLOCKS SERIAL NO. GB112
☐ MICROMETER FIXTURE SERIAL NO.

CALIBRATION PERFORMED BY DATE

CALIBRATION CHECKED BY DATE

LVDT FACTOR DETERMINATION

(a) LVDT TOTAL LINEAR RANGE (TLR) 2.000 ☒ in ☐ mm
(b) LVDT OUTPUT 1 10.000 V
(c) LVDT OUTPUT 2 -9.978 V
(d) LVDT OUTPUT CHANGE (b) - (c) 19.978 V
(e) LVDT FACTOR (a)/(d) 0.100 ☒ in/V ☐ mm/V

LINEARITY

TRIAL NO.	REFERENCE STANDARD LENGTH ☒ in ☐ mm (1)	PERCENT OF TLR (%)	LVDT OUTPUT (VOLTS) (2)	CHANGE IN LVDT OUTPUT (3) = (2) - (c) (VOLTS) (3)	LVDT MEASUREMENT (4) = (3) x (e) ☒ in ☐ mm (4)	PERCENT ERROR $(5) = \frac{(1) - (4)}{(a)} \times 100$ (5)
1	0	0	-9.978	0	0	0
2	0.250	12.5	-7.480	2.498	0.2498	0.010
3	0.500	25	-4.982	4.996	0.4996	0.020
4	0.750	37.5	-2.483	7.495	0.7495	0.025
5	1.000	50	0.000	9.978	0.9978	0.110
6	1.250	62.5	2.525	12.503	1.2503	-0.015
7	1.500	75	5.037	15.015	1.5015	-0.075
8	1.750	87.5	7.533	17.511	1.7511	-0.055
9	2.000	100	10.000	19.978	1.9978	0.110

REPEATABILITY

TRIAL NO.	REFERENCE STANDARD LENGTH ☒ in ☐ mm (6)	PERCENT OF TLR (%)	LVDT OUTPUT (VOLTS) (7)	VOLTAGE ERROR (8) = (7) - (2) (VOLTS) (8)
1	0	0	-9.976	0.002
2	0.250	12.5	-7.519	-0.039
3	0.500	25	-5.003	-0.021
4	0.750	37.5	-2.522	0.039
5	1.000	50	0.000	0.000
6	1.250	62.5	2.532	0.007
7	1.500	75	5.040	0.003
8	1.750	87.5	7.531	-0.002
9	2.000	100	10.000	0.000

LINEARITY ☒ ACCEPT ☐ REJECT

REPEATABILITY ☒ ACCEPT ☐ REJECT

REMARKS

GPO 850 - 945

Figure 5. – Linear variable differential transformer calibration — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1010-89

PROCEDURE FOR
CALIBRATING UNIT WEIGHT MEASURES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1010. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating unit weight measures used for determining minimum and maximum index unit weights of cohesionless soils in accordance with USBR 5525 and 5530.

1.2 Calibration consists of determining the volume of the measure, the volume per unit height of the measure, and the reference dial reading constant for the equipment.

1.3 The volume is determined by a water-filling method and checked by a linear-measurement method.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR 1000 Standards for Linear Measurement Devices
USBR 1007 Calibrating Dial Indicators
USBR 1012 Calibrating Balances or Scales
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5525 Determining the Minimum Index Unit Weight of Cohesionless Soils
USBR 5530 Determining the Maximum Index Unit Weight of Cohesionless Soils

2.2 *ASTM Standard*:

E 1 ASTM Thermometers

3. Summary of Method

3.1 *Volume by Water Filling*.–A unit weight measure is completely filled with water. The mass of water required to fill the measure is obtained, the absolute density of water determined and, from these values, the volume of the measure is calculated.

3.2 *Volume by Linear Measurement*.–Measurements of the inside diameter and height of a unit weight measure are carefully obtained. The volume and volume per unit height of the measure are calculated using those values. The calculated volume is compared to the volume determined in subparagraph 3.1.

3.3 *Determination of Reference Dial Reading Constant*.–A calibration bar is placed across the top of a measure. Dial indicator readings are obtained on both the right and left side of the measure. The thickness of the calibration bar and surcharge baseplate is determined. From these values, a reference dial reading constant is calculated for use in the maximum index unit weight test (USBR 5530).

4. Significance and Use

4.1 The 0.1- and 0.5-ft³ (2830- and 4160-cm³) capacity measures are used in determining both the minimum and maximum index unit weights of cohesionless soils (USBR 5525, 5530). Periodic calibration of these measures must be performed to ensure reliable laboratory test results.

4.2 This calibration procedure is to be performed upon receipt of the measure, annually after receipt, before reuse after anything occurs which may affect the volume of the measure, or whenever test results are questionable.

4.3 Upon receipt, the measure is checked to verify that it conforms to the dimensional requirements shown on figure 1.

5. Terminology

5.1 Definitions are in accordance with USBR 3900.

6. Apparatus

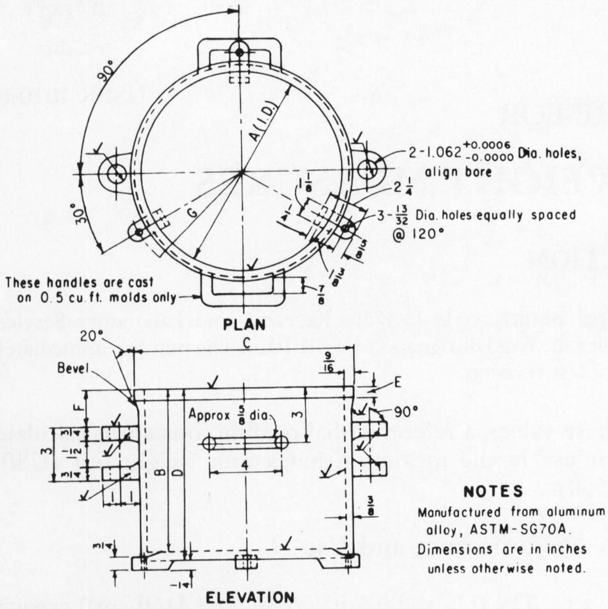
6.1 *Balance or Scale*.–Typical balances or scales used for this designation are:

Application	*Readable to*	*Approximate capacity*
Measures about 0.1 ft³		
Inch-pound units	0.01 lbm	50 lbm
SI units	1 g	20 kg
Measures about 0.5 ft³		
Inch-pound units	0.01 lbm	150 lbm
SI units	10 g	80 kg

6.2 *Unit Weight Measure* (fig. 1a).–Cylindrical unit-weight measure of 0.1 and 0.5 ft³ (2830 and 14 160 cm³) capacity, conforming to the dimensional requirements shown on figure 1.

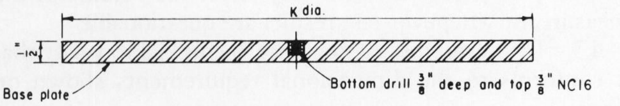
6.3 *Surcharge Baseplates* (fig. 1b).–One steel surcharge baseplate, approximately 0.5 inch (13 mm) thick for each size mold, made from cold-rolled steel.

6.4 *Dial Indicator Reference Bracket* (fig. 2).–A reference bracket which holds the dial indicator assembly to ensure that the indicator can be consistently adjusted.



SIZE MEASURE FT³ (cm³)	DIMENSIONS, IN. (mm)						
	A	B	C	D	E	F	G
0.1 (2831) 0.5 (14158)	6.000(152.4) 11.000(279.4)	6.112(155.2) 9.092(230.9)	7 1/8(181.0) 12 1/8(308.0)	6 1/2(165.1) 9 1/2(241.3)	1/2 (12.7) 5/8 (15.9)	1 1/8(28.6) 2 (50.8)	4.0(101.6) 6.5(165.1)

(a) Unit weight measure.



MEASURE SIZE ft³ (cm³)	K Dimensions in (mm)
0.1(2831) 0.5(14158)	5.969 (152) 10.938(278)

(b) Surcharge baseplate.

Figure 1. - Index unit weight testing equipment.

6.5 *Depth Micrometer.*-For inch-pound applications, a depth micrometer having a measuring range of at least 0 to 10 inches, readable to at least 0.001 inch. For metric applications, a depth micrometer having a measuring range of at least 0 to 250 mm, readable to at least 0.02 millimeter.

6.6 *Inside Micrometer.*-For inch-pound applications, an inside micrometer having a measuring range of at least 2 to 12 inches, readable to at least 0.001 inch. For metric applications, an inside micrometer having a measuring range of at least 50 to 300 mm, readable to at least 0.02 millimeter.

6.7 *Outside Micrometer.*-For inch-pound applications, an outside micrometer having a measuring range of at least 0 to 1 inch, readable to at least 0.001 inch. For metric applications, an outside micrometer having a measuring range of at least 0 to 25 mm, readable to at least 0.02 millimeter.

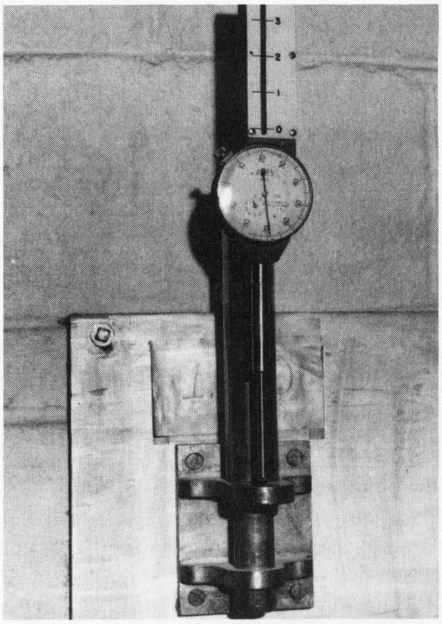


Figure 2. - Dial indicator reference bracket and dial indicator assembly.

6.8 *Dial Indicator Assembly.*-A device used for the measurement of the volume of specimens. The assembly shall consist of a dial indicator (gauge) having a 2.000-inch (50-mm) or greater range, with 0.001-inch (0.02-mm) or finer graduations, mounted on a dial indicator holder so that the indicator stem is parallel with the vertical axis of the measure. The assembly may be equipped with a spacer ring(s) used to extend the range of the assembly if desired.

6.9 *Calibration Bar.*-A steel bar having a length of 12 inches (300 mm), a width of about 3 inches (75 mm), and a thickness of 1/8 inch (3 mm).

6.10 *Plastic or Glass Plates.*-One plate approximately 8 by 8 by 1/4 inches thick (200 by 200 by 6 mm); one plate approximately 12 by 12 by 1/4-inch thick (300 by 300 by 6 mm).

6.11 *Thermometer.*-0 °C to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

6.12 Stopcock grease or similar sealant.

6.13 *Miscellaneous Equipment.*-Bulb syringe and towels.

7. Reagents and Materials

7.1 Tapwater near room temperature (20 °C) should be used for calibrating the unit weight measures.

8. Precautions

8.1 *Safety Precautions*:

8.1.1 This designation may involve hazardous materials, operations, and equipment.

8.1.2 Examine the measure (as received or before its use) for sharp edges or burrs.

8.2 *Technical Precautions.*-Examine the measure to ensure that it has a smooth finish on the inside and top surfaces. Rough machining could produce ridges or gouges which affect volume measurements.

9. Calibration and Standardization

9.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1000	Standards for Linear Measurement Devices
USBR 1007	Calibrating Dial Indicators
USBR 1012	Calibrating Balances or Scales

10. Conditioning

10.1 Perform this calibration in an area isolated from drafts and/or extreme temperature fluctuations.

10.2 The measure, measurement equipment, water, and laboratory environment must all be at about the same temperature while performing this procedure.

11. Procedure

11.1 All data are to be recorded on the "Unit Weight Measure Calibration" form as shown on figure 3.

11.2 Record the nominal volume, identification number, and type of measure.

11.3 Determine the volume of the measure using the water-filling method as described in subparagraph 11.4 and then use the linear-measurement method as described in subparagraph 11.5. Compare the results for acceptability in accordance with subparagraph 11.6.

11.4 *Determination of Measure Volume by the Water-Filling Method*:

11.4.1 Lightly grease the top of the measure; be careful not to get grease on the inside of the measure. Determine and record the mass of the measure and the glass or plastic plate using a scale of appropriate capacity to the nearest 0.01 lbm.

11.4.2 Place the measure on a firm, level surface and fill the measure slightly above its rim with water.

11.4.3 Slide the glass or plastic plate over the top surface of the measure so the measure remains completely filled with water and no air bubbles are entrapped. A bulb syringe may be useful to add or remove water as the plate is sliding into place.

11.4.4 Completely dry excess water from the outside of the measure and plate.

11.4.5 Determine and record the mass of the measure, glass, or plastic plate, and water to the nearest 0.01 lbm.

11.4.6 Remove the plate. Determine and record the temperature of the water to the nearest 0.5 °C.

11.4.7 Determine and record the absolute density of water from table 1.

11.4.8 Calculate and record the volume of the measure to the nearest 0.0001 ft^3 (1 cm^3).

11.5 *Determination of Measure Volume by the Linear-Measurement Method*:

11.5.1 Using the inside micrometer, determine the inside diameter of the measure. Make three measurements of the diameter; one near the top of the mold, one near the midheight, and one near the bottom. These measurements should be spaced equally around the circumference of the mold. Record these values to the nearest 0.001 inch (0.02 mm).

11.5.2 Using the depth micrometer, determine the inside height of the measure. Make three measurements of the inside height equally spaced around the circumference of the mold. Record these values to the nearest 0.001 inch (0.02 mm).

11.5.3 Calculate the average inside diameter and average inside height of the measure. Record these values to the nearest 0.001 inch (0.02 mm).

11.5.4 Calculate and record the volume of the measure to the nearest 0.0001 ft^3 (1 cm^3).

11.5.5 Calculate and record the volume per unit height of the measure to the nearest 0.00001 ft^3/in (0.01 cm^3/mm) as shown on figure 3.

11.6 The volumes calculated from the two methods must be within 0.0005 ft^3 for the 0.1-ft^3 measure and within 0.0025 ft^3 for the 0.5-ft^3 measure.

11.6.1 If the two volumes are not within the above limit, check all calculations and verify that all equipment is performing correctly, that all calibrations are correct, and that the procedures and techniques used are correct. If problems are not discovered, then repeat subparagraphs 11.3 through 11.6. If the values are still inconsistent, then failure to obtain agreement is an indication that the measure is badly worn or deformed and must be replaced.

11.7 Compare the volumes with previously determined values to verify that they are consistent and reasonable. If they are not, go to subparagraph 11.6.1.

11.8 *Determination of Reference Bracket Reading*:

11.8.1 Place the dial indicator in the dial indicator reference bracket and record the dial indicator reading on the calibration form and in a conspicuous location on the reference bracket. If a spacer ring is used, the dial indicator reading with the spacer ring also should be determined and posted.

NOTE 1.-The reference bracket reading is used as a check of the dial indicator to ensure consistent dial indicator readings. The reference bracket reading should be checked before using the dial indicator. If reference bracket readings are inconsistent, the dial indicator should be recalibrated prior to its use.

11.9 *Determination of Reference Dial Reading Constant*:

11.9.1 With an outside micrometer, measure the thickness of the calibration bar at a point approximately 1 inch (25 mm) from one end. Mark the point measured and record the bar thickness on the calibration form. The point measured is the point of contact of the dial gauge indicator on the calibration bar.

11.9.2 Place the calibration bar across the top of the measure along the axis of the guide brackets (fig. 4). The

7-1708 (9-86) Bureau of Reclamation	**UNIT WEIGHT MEASURE CALIBRATION**	Designation USBR 1010-89

MEASURE NO. 1	NOMINAL VOLUME 0.1 ☒ ft3 ☐ cm3	DIAL INDICATOR NO. DI-1

CALIBRATION PERFORMED BY	DATE	COMPUTED BY	DATE	CHECKED BY	DATE

DETERMINATION OF MEASURE VOLUME USING MICROMETER

			TRIAL NO.	
Inside diameter of measure			1	6.037
			2	6.046
			3	6.023
(1) Average inside diameter	☒ in	☐ mm		6.035
Inside height of measure			1	6.072
			2	6.076
			3	6.082
(2) Average inside height	☒ in	☐ mm		6.077
(3) Volume of measure = $\frac{\pi (1)^2 (2)}{4C^*}$	☒ ft^3	☐ cm^3		0.1006

DETERMINATION OF MEASURE VOLUME BY WATER FILLING METHOD

(4) Mass of measure + glass plate + water	☒ lbm	☐ g	16.32
(5) Mass of measure + glass plate	☒ lbm	☐ g	10.06
(6) Mass of water (4) - (5)	☒ lbm	☐ g	6.26
(7) Temperature of water °C			18.0
**(8) Absolute density of water	☒ lbm/ft3	☐ g/cm^3	62.34
(9) Volume of measure = $\frac{(6)}{(8)}$	☒ ft^3	☐ cm^3	0.1004
(10) Volume per unit height = $\frac{(9)}{(2)}$	☒ ft^3/in	☐ cm^3/mm	0.01652

DETERMINATION OF REFERENCE DIAL READING CONSTANT

Dial indicator readings, left side			1	1.639
			2	1.639
			3	1.639
right side			1	1.636
			2	1.635
			3	1.635
(11) Average dial indicator reading	☒ in	☐ mm		1.637
(12) Calibration bar thickness	☒ in	☐ mm		0.216

Surcharge base plate thickness			1	0.508
			2	0.508
			3	0.513
			4	0.513
(13) Average base plate thickness	☒ in	☐ mm		0.511
(14) Specimen height at zero dial = (2) - [(11) - (12) + (13)]	☒ in	☐ mm		4.145

(15) Reference bracket reading	☒ in	☐ mm	0.360

*For inch pound application, C = 1,728 and converts in^3 to ft^3
For SI metric applications, C = 1,000 and converts mm^3 to cm^3
**Absolute density value obtained from Table 1, USBR 1010

Figure 3. - Unit weight measure calibration — example.

Table 1. – Absolute density of water in grams per cubic centimeter.†

Degrees C	0	1	2	3	4	5	6	7	8	9
0	0.999841	847	854	860	866	872	878	884	889	895
1	900	905	909	914	918	923	927	930	934	938
2	941	944	947	950	953	955	958	960	962	964
3	965	967	968	969	970	971	972	972	973	973
4	973	973	973	972	972	972	970	969	968	966
5	965	963	961	959	957	955	952	950	947	944
6	941	938	935	931	927	924	920	916	911	907
7	902	898	893	888	883	877	872	866	861	855
8	849	843	837	830	824	817	810	803	796	789
9	781	774	766	758	751	742	734	726	717	709
10	700	691	682	673	664	654	645	635	625	615
11	605	595	585	574	564	553	542	531	520	509
12	498	486	475	463	451	439	427	415	402	390
13	377	364	352	339	326	312	299	285	272	258
14	244	230	216	202	188	173	159	144	129	114
15	099	084	069	054	038	023	007	*991	*975	*959
16	0.998943	926	910	893	877	860	843	826	809	792
17	774	757	739	722	704	686	668	650	632	613
18	595	576	558	539	520	501	482	463	444	424
19	405	385	365	345	325	305	285	265	244	224
20	203	183	162	141	120	099	078	056	035	013
21	0.997992	970	948	926	904	882	860	837	815	792
22	770	747	724	701	678	655	632	608	585	561
23	538	514	490	466	442	418	394	369	345	320
24	296	271	246	221	196	171	146	120	095	069
25	044	018	*992	*967	*941	*914	*888	*862	*836	*809
26	0.996783	756	729	703	676	649	621	594	567	540
27	512	485	457	429	401	373	345	317	289	261
28	232	204	175	147	118	089	060	031	002	*973
29	0.995944	914	885	855	826	796	766	736	706	676
30	646	616	586	555	525	494	464	433	402	371

† For inch-pound applications, multiply the values in this table by 62.4280 to convert to lbm/ft^3.

* First three significant figures shown in line below.

measured end of the calibration bar should be flush with the outer edge of the top of the measure.

11.9.3 Insert the dial gauge assembly in the guide bracket on the measure keeping the dial gauge stem on top of the calibration bar and on the axis of the guide brackets as shown on figure 4. The dial gauge assembly should be placed such that matchmarks on the guide brackets and assembly are aligned and the tip of the dial gauge is on the mark on the calibration bar. Record the dial indicator reading to the nearest 0.001 inch (0.02 mm).

11.9.4 Remove the dial gauge assembly from the measure.

11.9.5 Obtain two more dial indicator readings by repeating subparagraphs 11.9.3 and 11.9.4 so that a total of three readings are determined.

11.9.6 Obtain three dial indicator readings on the opposite gauge bracket in accordance with subparagraphs 11.9.3 through 11.9.5.

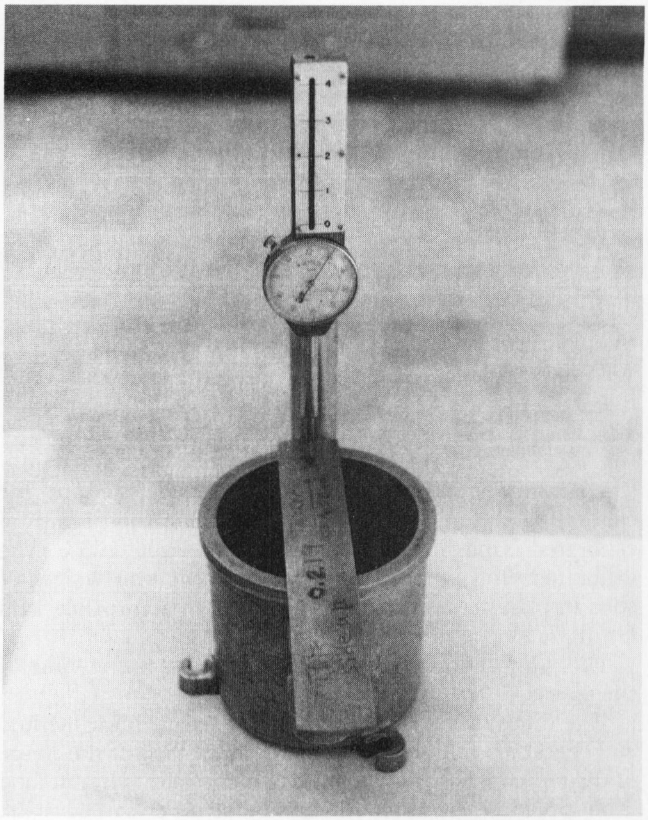


Figure 4. – Determination of reference dial reading constant.

11.9.7 Calculate and record the average dial indicator reading.

11.10 *Surcharge Baseplate Thickness*:

11.10.1 With an outside micrometer, measure the thickness of the surcharge baseplate at four equally spaced points around the perimeter approximately 1/2 inch (13 mm) from the edge. Record the values to the nearest 0.001 inch (0.02 mm).

11.10.2 Determine and record the average baseplate thickness to the nearest 0.001 inch (0.02 mm).

11.10.3 Calculate and record the specimen height at zero dial.

12. Calculations

12.1 The calculations are as shown on the "Unit Weight Measure Calibration" form (fig. 3).

13. Report

13.1 The report is to consist of a completed and checked "Unit Weight Measure Calibration" form (fig. 3).

13.2 All calculations are to show a checkmark.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1011-89

PROCEDURE FOR

CALIBRATING MEASURES FOR SAND CALIBRATION

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1011. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating the measure used to determine the density of calibrated sand in accordance with USBR 1435. The calibrated sand is used in determining the unit weight of soils in place by the sand-cone method in accordance with USBR 7205.

1.2 Calibration consists of determining the volume of the measure.

1.3 The volume is determined by a water-filling method and checked by a linear-measurement method. If the shape of the measure is such that the linear-measurement method is not practical, the water-filling method is performed twice.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR 1000 Standards for Linear Measurement Devices
USBR 1012 Calibrating Balances or Scales
USBR 1435 Calibrating Sand-Cone Equipment and Sand
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 7205 Determining Unit Weight of Soils In-Place by the Sand-Cone Method

2.2 *ASTM Standard*:

E 1 ASTM Thermometers

3. Summary of Methods

3.1 *Volume by Water Filling*.–The measure used to determine the density of calibrated sand is completely filled with water. The mass of water required to fill the measure is obtained, the absolute density of water is determined and, from these values, the volume of the measure is calculated.

3.2 *Volume by Linear Measurement*.–Measurements of the inside diameter and height of a measure used to determine the density of calibrated sand are carefully obtained. The volume of the measure is calculated using these values. The calculated volume is compared to the volume determined in subparagraph 3.1. If the shape of the measure is such that the linear-measurement method is not practical, the water-filling method is performed twice and the average volume used.

4. Significance and Use

4.1 Special measures are used in determining the density of calibrated sand (USBR 1435) for in-place unit weight determination of soil by the sand-cone method (USBR 7205). Periodic calibration of these measures must be performed to ensure reliable unit weight determination.

4.2 The volume and shape of the measure must approximate the volume and shape of the hole to be dug at the test site. Generally, measures of appropriate size are not available commercially and must be specially fabricated.

4.3 This calibration procedure is to be performed upon receipt of the measure, annually after receipt, before reuse after anything occurs which may affect the volume of the measure, and whenever test results are questionable.

5. Terminology

5.1 Definitions are in accordance with USBR 3900.

6. Apparatus

6.1 *Balance or Scale*.–Typical balances or scales used for this designation are:

Application	*Readable to*	*Approximate capacity*
Measures about 0.25 ft^3		
Inch-pound units	0.01 lbm	50 lbm
SI units	1 g	20 kg
Measures about 0.5 ft^3		
Inch-pound units	0.01 lbm	150 lbm
SI units	0.01 kg	80 kg

6.2 *Measure*.–A container having the approximate shape and volume of the test hole to be dug for the sand-cone test (USBR 7205). Details and illustrations of some measures are given on figures 1 through 3. The inside diameter, or opening, of the calibration measure must be equal to or slightly smaller than the hole diameter of the sand-cone template.

6.3 *Depth Micrometer*.–For inch-pound applications, a depth micrometer having a measuring range of 0 to 12 inches, readable to at least 0.001 inch. For SI applications, a depth micrometer having a measuring range of 0 to 300 mm, readable to at least 0.02 mm.

6.4 *Inside Micrometer.*-For inch-pound applications, an inside micrometer having a measuring range of 2 to 12 inches, readable to at least 0.001 inch. For SI applications, an inside micrometer having a measuring range of 50 to 300 mm, readable to at least 0.02 mm.

6.5 *Gauge Blocks.*-A set of precision gauge blocks that may be used to extend the measuring range of the depth micrometer if necessary.

6.6 *Thermometer.*-0 to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

6.7 *Plastic or Glass Plate.*-One plastic or glass plate, about 12 by 12 inches by 1/4-inch thick (300 by 300 by 6-mm).

6.8 Stopcock grease or similar sealant.

6.9 *Miscellaneous Equipment.*-Bulb syringe and towels.

7. Reagents and Materials

7.1 Tapwater near room temperature (20 °C) should be used for calibrating the measure.

8. Precautions

8.1 *Safety Precautions*:

8.1.1 This designation may involve hazardous materials, operations, and equipment.

8.1.2 Examine the measure for sharp edges or burrs.

8.2 *Technical Precautions.*-Examine the measure to ensure that it has a smooth finish on the inside and top surfaces. Rough machining could produce ridges or gouges which affect volume measurements.

9. Calibration and Standardization

9.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1000 Standards for Linear Measurement Devices
USBR 1012 Calibrating Balances or Scales

10. Conditioning

10.1 Perform this calibration in an area isolated from drafts and/or extreme temperature fluctuations.

10.2 The measure, measurement equipment, water, and the laboratory environment must all be at about the same temperature while performing this procedure.

11. Procedure

11.1 All data are to be recorded on the "Measure for Calibrated Sand Calibration Sheet" form as shown on figure 4.

11.2 Record the nominal sizes (capacity, diameter, height) and control number along with any other identifying markings of the measure to be calibrated.

11.3 Determine the volume of the measure using the water-filling method as described in subparagraph 11.4 and then use the linear-measurement method as described in subparagraph 11.5. Compare the results for acceptability in accordance with subparagraph 11.6.

11.3.1 If the shape of the measure is such that the linear-measurement method is not practical, perform the water-filling method twice and compare the results for acceptability in accordance with subparagraph 11.8.

11.4 *Determination of Measure Volume — Water-Filling Method*:

11.4.1 Lightly grease the top of the measure; be careful not to get grease on the inside of the measure. Determine and record the mass of the measure and plastic or glass plate to the nearest 0.01 lbm (either 1 or 10 g, as appropriate).

11.4.2 Place the measure on a firm, level surface and fill the measure slightly above its rim with water.

11.4.3 Slide the glass or plastic plate over the top surface of the measure so that it remains completely filled with water and no air bubbles are entrapped. A bulb syringe may be useful to add or remove water.

11.4.4 Completely dry any excess water from the outside of the measure and plate.

11.4.5 Determine and record the mass of the measure, glass or plastic plate, and water to the nearest 0.01 lbm (either 1 or 10 g, as appropriate).

11.4.6 Calculate the mass of water used to fill the measure.

11.4.7 Remove the plate. Determine and record the temperature of the water to the nearest 0.5 °C.

11.4.8 Determine and record the absolute density of water at the measured temperature from table 1.

11.4.9 Calculate and record the volume of the measure to the nearest 0.0001 ft^3 (1 cm^3).

11.4.10 Empty the water from the measure.

11.4.11 Clean and dry the measure thoroughly.

11.5 *Determination of Measure Volume — Linear Measurement Method*:

11.5.1 Using the inside micrometer caliper, determine the inside diameter of the measure. Make six measurements of the diameter; three near the top of the measure, and three near the bottom. Space the measurements equally around the circumference of the measure at each location. Record these values to the nearest 0.001 inch (0.02 mm).

11.5.2 Using the depth micrometer, determine the inside height of the measure. Make three measurements of the inside height equally spaced around the circumference of the mold. Record these values to the nearest 0.001 inch (0.02 mm).

NOTE 1.-If the measuring range of the depth micrometer is not sufficient, place a gauge block of known height on the bottom of the measure and add its height to the measured depth of the depth micrometer.

11.5.3 Calculate the average inside diameter at top and at bottom of the measure. Record these values to the nearest 0.001 inch (0.02 mm).

11.5.4 Calculate and record the average inside diameter of the measure to the nearest 0.001 inch (0.02 mm).

Table 1. – Absolute density of water in grams per cubic centimeter.†

Degrees C	0	1	2	3	4	5	6	7	8	9
0	0.999841	847	854	860	866	872	878	884	889	895
1	900	905	909	914	918	923	927	930	934	938
2	941	944	947	950	953	955	958	960	962	964
3	965	967	968	969	970	971	972	972	973	973
4	973	973	973	972	972	972	970	969	968	966
5	965	963	961	959	957	955	952	950	947	944
6	941	938	935	931	927	924	920	916	911	907
7	902	898	893	888	883	877	872	866	861	855
8	849	843	837	830	824	817	810	803	796	789
9	781	774	766	758	751	742	734	726	717	709
10	700	691	682	673	664	654	645	635	625	615
11	605	595	585	574	564	553	542	531	520	509
12	498	486	475	463	451	439	427	415	402	390
13	377	364	352	339	326	312	299	285	272	258
14	244	230	216	202	188	173	159	144	129	114
15	099	084	069	054	038	023	007	*991	*975	*959
16	0.998943	926	910	893	877	860	843	826	809	792
17	774	757	739	722	704	686	668	650	632	613
18	595	576	558	539	520	501	482	463	444	424
19	405	385	365	345	325	305	285	265	244	224
20	203	183	162	141	120	099	078	056	035	013
21	0.997992	970	948	926	904	882	860	837	815	792
22	770	747	724	701	678	655	632	608	585	561
23	538	514	490	466	442	418	394	369	345	320
24	296	271	246	221	196	171	146	120	095	069
25	044	018	*992	*967	*941	*914	*888	*862	*836	*809
26	0.996783	756	729	703	676	649	621	594	567	540
27	512	485	457	429	401	373	345	317	289	261
28	232	204	175	147	118	089	060	031	002	*973
29	0.995944	914	885	855	826	796	766	736	706	676
30	646	616	586	555	525	494	464	433	402	371

† For inch-pound applications, multiply the values in this table by 62.4280 to convert to lbm/ft^3.

* First three significant figures shown in line below.

11.5.5 Calculate and record the average inside height of the measure to the nearest 0.001 inch (0.02 mm).

11.5.6 Calculate and record the volume of the measure to the nearest 0.0001 ft^3 (1 cm^3).

11.6 Determine the acceptability of the values obtained from the linear-measurement method and the water-filling method by dividing either value by the other. If the value of the ratio is between 0.995 and 1.005, inclusive, use the value obtained by the water-filling method as the volume of the measure. If the value of the ratio falls outside the limits, go to subparagraph 11.7.

11.6.1 Compare the volumes with previously determined values to see if they are consistent and reasonable. If they are, go to paragraph 13. If they are not, go to subparagraph 11.7.

11.7 Check calculations and verify that all equipment is performing correctly, that all calibrations are correct, and that the procedures and techniques used are correct. Check the measure for out-of-roundness. If problems are not discovered, then repeat subparagraphs 11.3 through 11.6. If the values are still inconsistent, then failure to obtain agreement between the methods within the limits is an indication that the measure is badly worn or deformed and must be replaced.

11.8 If the water-filling method was performed twice (see subpar. 11.3.1) determine the acceptability of the two results by dividing either value by the other. If the value of the ratio is between 0.995 and 1.005, inclusive, average the two values and use the average as the volume of the measure. If the value of the ratio falls outside the limits, go to subparagraph 11.9.

11.8.1 Compare the value with previously determined values to check if it is consistent and reasonable. If so, go to paragraph 13. If not, go to subparagraph 11.9.

11.9 Check calculations and verify that all equipment is performing correctly, that all calibrations are correct, and that the procedures and techniques used are correct. If problems are not discovered then repeat subparagraphs 11.3 through 11.4 and subparagraph 11.8. Failure to obtain agreement is an indication of equipment malfunction or the procedure has been performed incorrectly.

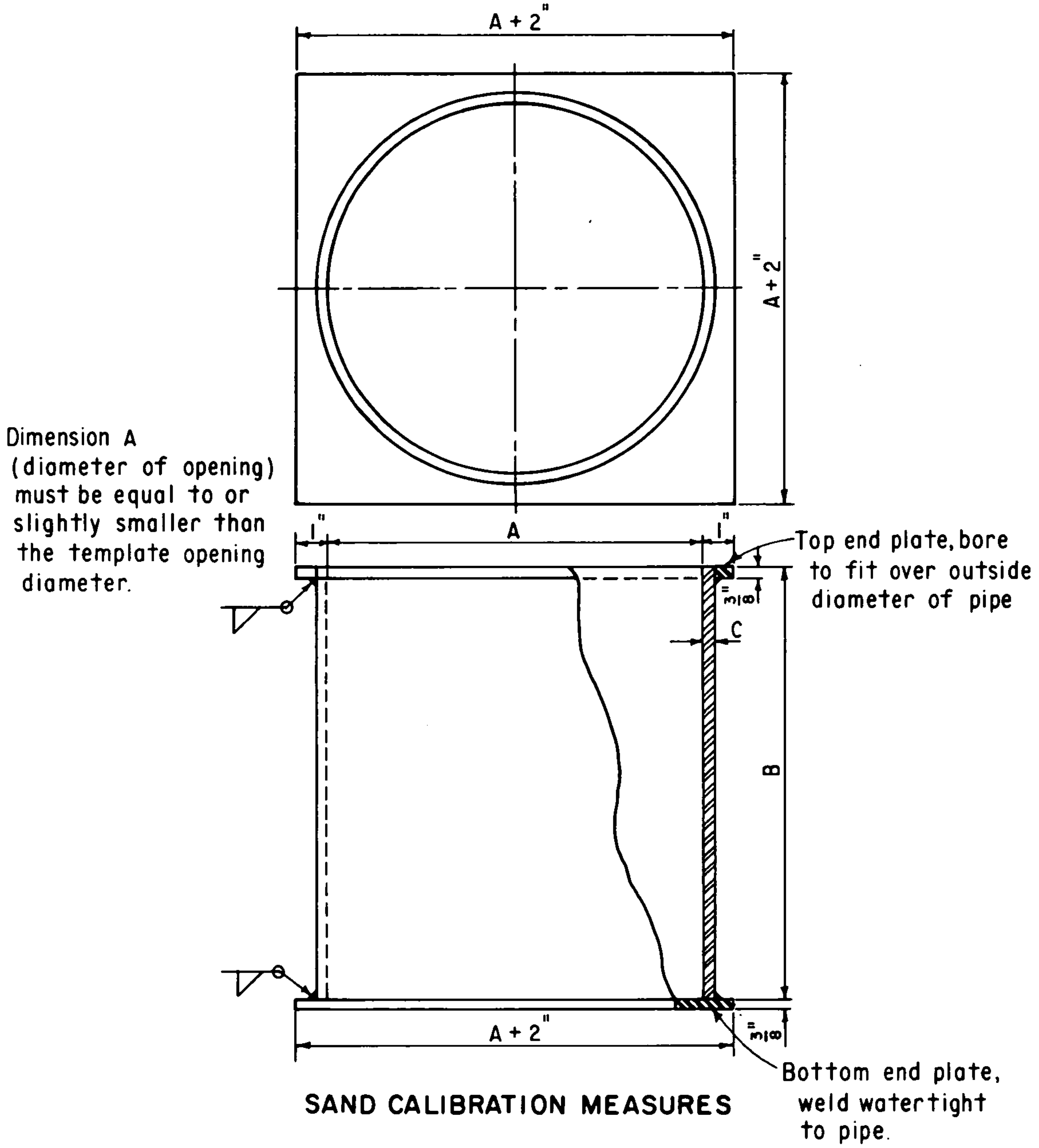
12. Calculations

12.1 The calculations are as shown on the "Measure for Calibrated Sand Calibration" form (fig. 4).

13. Report

13.1 The report is to consist of a completed and checked "Measure for Calibrated Sand Calibration Sheet" form (fig. 4).

13.2 All calculations are to show a checkmark.



Dimension A (diameter of opening) must be equal to or slightly smaller than the template opening diameter.

Top end plate, bore to fit over outside diameter of pipe

Bottom end plate, weld watertight to pipe.

SAND CALIBRATION MEASURES

NOTES

May be fabricated from standard weight steel pipe.

Weld top and bottom end plates perpendicular to bore of pipe.

NOMINAL VOLUME (CU. FT.)	A	B	C
	NOMINAL DIAMETER (INCHES)	NOMINAL HEIGHT	WALL* THICKNESS (INCHES)
0.35	8	12	0.322
0.92	12	14	0.375

* If standard pipe is used

Figure 1. - Sand calibration measures.

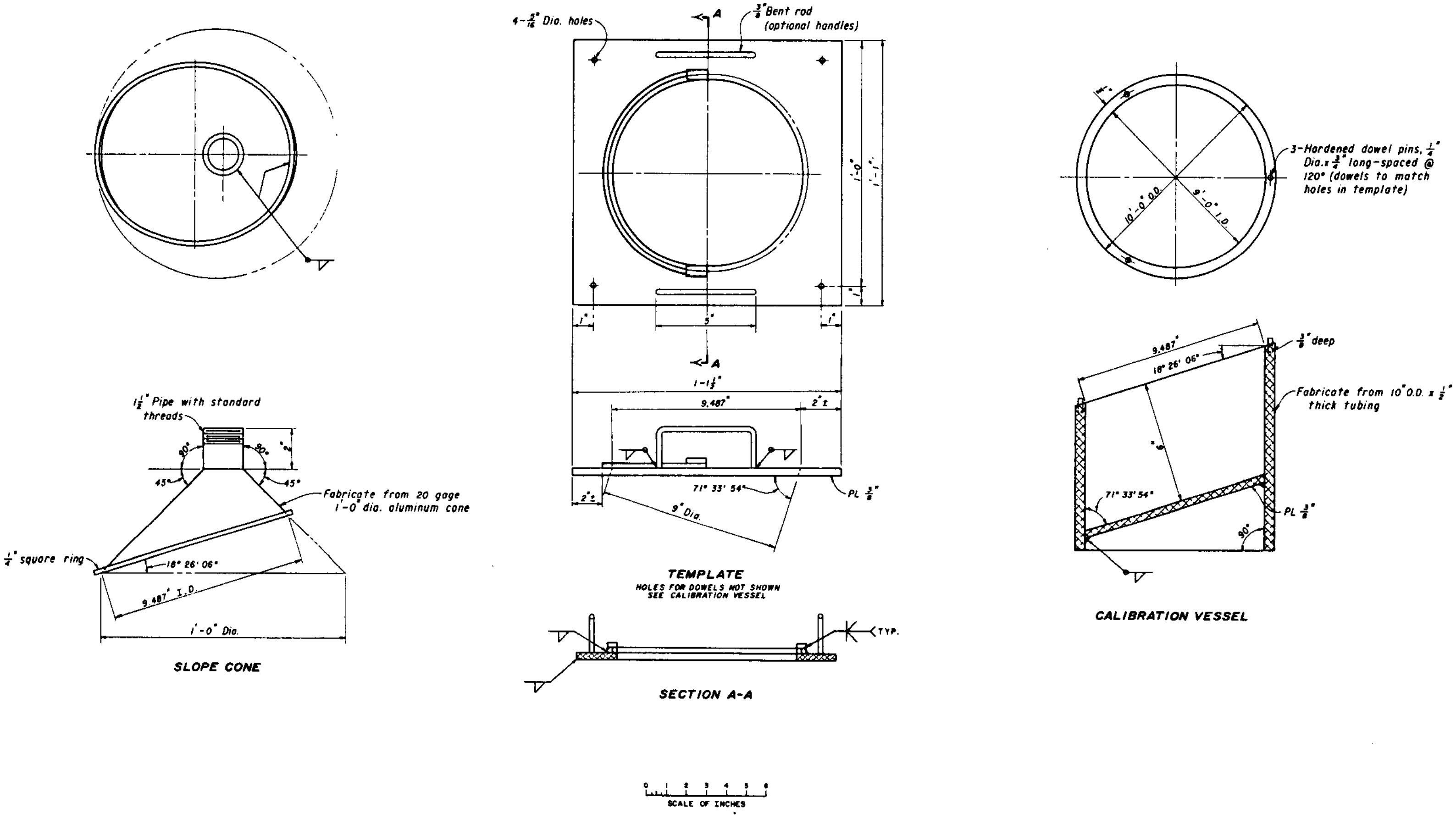


Figure 2. - Sand calibration measure for slope cone.801-D-227

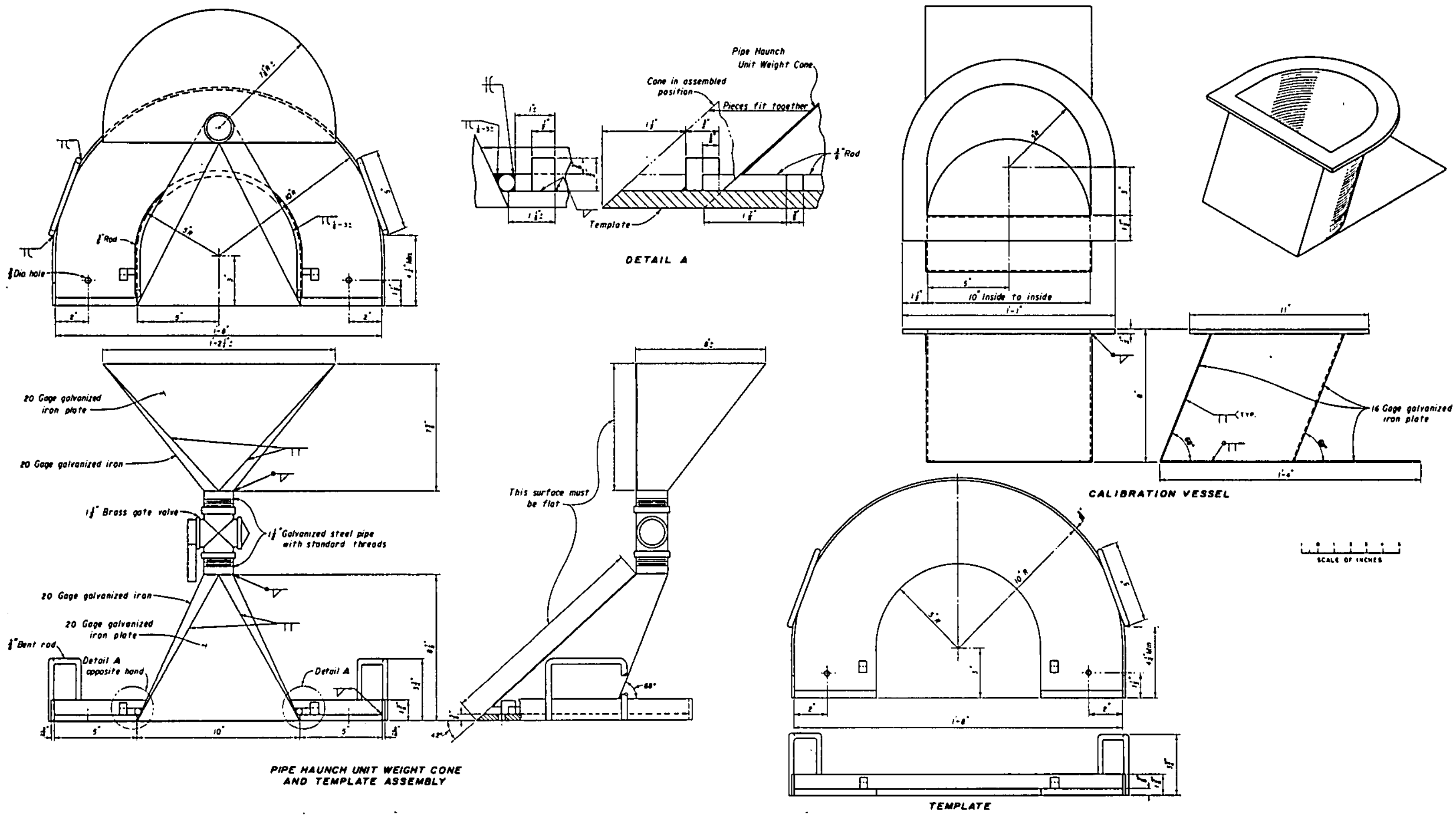
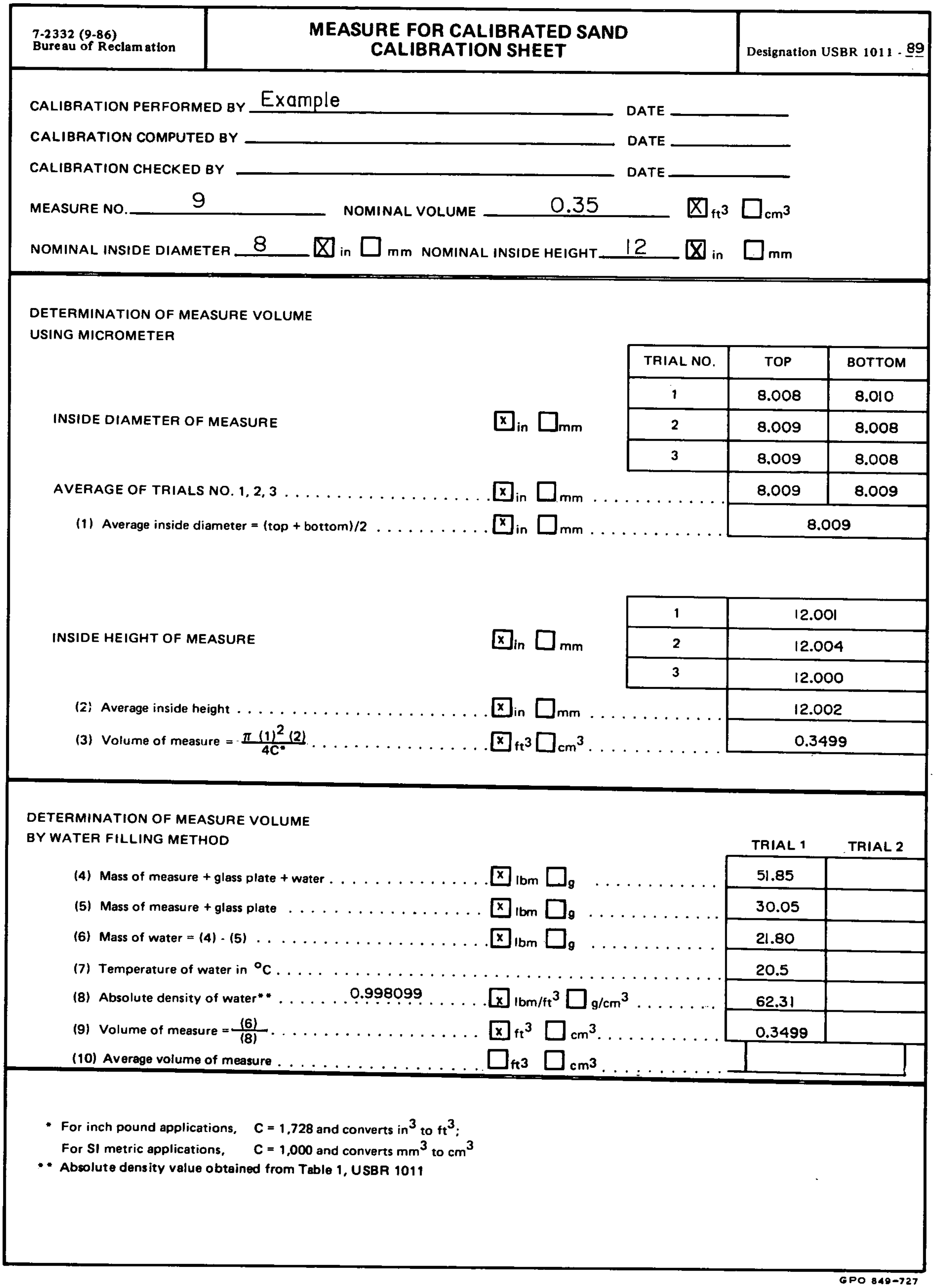


Figure 3. - Sand calibration measure for haunch cone. 801-D-223



7-2332 (9-86)
Bureau of Reclamation

MEASURE FOR CALIBRATED SAND CALIBRATION SHEET

Designation USBR 1011 - 89

CALIBRATION PERFORMED BY Example DATE ______
CALIBRATION COMPUTED BY ______ DATE ______
CALIBRATION CHECKED BY ______ DATE ______
MEASURE NO. 9 NOMINAL VOLUME 0.35 ☒ ft^3 ☐ cm^3
NOMINAL INSIDE DIAMETER 8 ☒ in ☐ mm NOMINAL INSIDE HEIGHT 12 ☒ in ☐ mm

DETERMINATION OF MEASURE VOLUME USING MICROMETER

		TRIAL NO.	TOP	BOTTOM
INSIDE DIAMETER OF MEASURE	☒ in ☐ mm	1	8.008	8.010
		2	8.009	8.008
		3	8.009	8.008
AVERAGE OF TRIALS NO. 1, 2, 3	☒ in ☐ mm		8.009	8.009
(1) Average inside diameter = (top + bottom)/2	☒ in ☐ mm		8.009	

INSIDE HEIGHT OF MEASURE	☒ in ☐ mm	1	12.001
		2	12.004
		3	12.000
(2) Average inside height	☒ in ☐ mm		12.002
(3) Volume of measure = $\frac{\pi (1)^2 (2)}{4C^*}$	☒ ft^3 ☐ cm^3		0.3499

DETERMINATION OF MEASURE VOLUME BY WATER FILLING METHOD

		TRIAL 1	TRIAL 2
(4) Mass of measure + glass plate + water	☒ lbm ☐ g	51.85	
(5) Mass of measure + glass plate	☒ lbm ☐ g	30.05	
(6) Mass of water = (4) - (5)	☒ lbm ☐ g	21.80	
(7) Temperature of water in °C		20.5	
(8) Absolute density of water** 0.998099	☒ lbm/ft^3 ☐ g/cm^3	62.31	
(9) Volume of measure = $\frac{(6)}{(8)}$	☒ ft^3 ☐ cm^3	0.3499	
(10) Average volume of measure	☐ ft^3 ☐ cm^3		

* For inch pound applications, C = 1,728 and converts in^3 to ft^3;
For SI metric applications, C = 1,000 and converts mm^3 to cm^3
** Absolute density value obtained from Table 1, USBR 1011

GPO 849-727

Figure 4. – Measure for calibrated sand calibration sheet — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1012-89

PROCEDURE FOR
CALIBRATING BALANCES OR SCALES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, Code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1012. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating balances or scales used for standard laboratory testing.

1.2 This procedure is used to determine the calibration of a balance or scale over its full capacity range. The method described is used to periodically check laboratory balances or scales. If stringent calibration tolerances are required, this procedure should not be used; the apparatus should be inspected and calibrated by an appropriate certifying agency.

2. Applicable Documents

2.1 *USBR Procedure*:
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

2.2 *ASTM Standard*:
E 617 Standard Specification for Laboratory Weights and Precision Mass Standards

2.3 *National Bureau of Standards.*-Handbook 44 [1][1].

3. Summary of Method

3.1 Calibrated masses are placed on a balance or scale. The known mass value is compared to the balance or scale reading. The percent error is calculated, and the acceptability of the balance or scale is determined.

4. Significance and Use

4.1 Mass determinations are performed as part of virtually every laboratory soil testing procedure. Accurate mass determinations are required to ensure reliable laboratory test results. The following balances or scales are commonly used in soils laboratories: portable platform scale, fan scale, two-pan balance, and electronic balance.

4.2 It is recommended that each laboratory maintain a service contract with a company certified to perform maintenance and calibration on all scales or balances used by the laboratory. The contract should provide for annual inspection, and calibration if necessary.

4.3 If it is not feasible to maintain such a contract, the calibration checks should be performed by laboratory personnel. These should be performed annually, or more frequently if it is suspected that any scales or balances are not operating properly. Certified personnel should perform any necessary adjustments.

5. Terminology

5.1 Definitions are in accordance with USBR 3900.

5.2 Terms not included in USBR 3900 specific to this designation are:

5.2.1 *Error.*-The arithmetic difference between the mass of the precision mass standard and the balance or scale reading obtained for that standard.

5.2.2 *Percent Error.*-The ratio expressed as a percent of (1) the error calculated for a given precision mass standard, to (2) the mass of the precision mass standard.

5.2.3 *Tolerance.*-The acceptable mass deviation (error) within which a balance or scale is acceptable for most soil laboratory applications.

6. Apparatus

6.1 *Precision Mass Standards.*-Precision mass standards used for calibration of balances or scales must be of known accuracy. If suitable testing facilities for the calibration of these masses are not available locally, masses calibrated by the National Institute of Standards and Technology (formerly National Bureau of Standards) are available on request from the Bureau's Denver Office, code D-3730. Calibrated masses required for this procedure are to be such that the balance or scale may be loaded in increments equal to one-fourth, one-half, three-fourths, and total capacity of the balance or scale.

7. Precautions

7.1 *Safety Precautions*:

7.1.1 Ensure that electronic scales or balances are properly grounded and that power cords are not frayed or cut.

7.1.2 Inspect the portable scales to ensure proper mounting on the platform and that the platform and frame are constructed so as to provide sufficient strength and rigidity to prevent collapse when the scale or balance is in use.

---

[1] Number in brackets refers to the reference.

7.2 *Technical Precautions*.–Tables and floors on which the balances or scales are placed must not deflect.

8. Calibration and Standardization

8.1 Verify that the precision mass standards used for comparison readings are currently calibrated and meet the standards outlined in ASTM E 617. If the calibration is outdated, the precision mass standards should be calibrated before they are used for this procedure.

9. Conditioning

9.1 Perform this calibration procedure in an area that is isolated from heat sources, air currents, and vibrations. It is recommended that this calibration be performed in an environment which is as close to 68 °F (20 °C) as possible.

9.2 The balance or scale and the precision mass standards are to be placed in the environment in which they are to be calibrated for a period of at least 24 hours prior to calibration.

10. Procedure

10.1 All data are to be recorded on the "Balance or Scale Calibration" form as shown on figure 1.

10.2 Check the balance or scale to ensure that it is level and isolated from heat sources, air currents, and/or vibrations.

10.3 *Mechanical Balances or Scales*:

10.3.1 Balance the beam with no mass applied.

10.3.2 Place precision mass standards corresponding to 25, 50, 75, and 100 percent of the capacity of the balance or scale on the beam or pan.

10.3.3 Record the mass of the precision mass standard applied and the balance or scale reading for each mass.

10.3.4 Calculate error for each mass measurement.

10.3.5 Calculate percent error for each mass measurement.

10.4 *Electronic Balances or Scales*:

10.4.1 Plug the power cord into a power supply compatible to the power requirements of the electronic balance or scale.

NOTE 1.–A warmup period may be required for some electronic balances or scales.

10.4.2 Tare the balance or scale and check for a zero balance reading. Record the balance or scale reading as shown on figure 1.

10.4.3 Place precision mass standards corresponding to 25, 50, 75, and 100 percent capacity of the balance or scale on the beam or pan.

10.4.4 Record the mass of the precision mass standard applied and the balance or scale reading for each mass measurement.

10.4.5 Calculate error for each mass measurement.

10.4.6 Calculate percent error for each mass measurement.

11. Calculations

11.1 Calculate error for each mass measurement.

$$(4) = (2) - (3) \qquad (1)$$

where:

(4) = error, g or lbm
(2) = mass of precision mass standard, g or lbm
(3) = balance or scale reading, g or lbm

11.2 Calculate percent error for each mass measurement.

$$(5) = 100 \frac{(4)}{(2)} \qquad (2)$$

where:

(5) = percent error
(4) = error, g or lbm
(2) = mass of precision mass standard, g or lbm
100 = convert from decimal to percent

12. Interpretation of Results

12.1 The following tables (1 and 2) are to be used to determine the acceptability of a balance or scale for most soil laboratory applications. If the computed error, for any precision mass standard placed on the calibrated balance or scale, is outside the acceptable tolerances—given in these tables—the balance or scale should be adjusted by certified personnel. These tables have been adapted in part from the National Bureau of Standards Handbook 44.

13. Report

13.1 The report is to consist of a completed and checked "Balance or Scale Calibration" form (fig. 1).

13.2 All calculations are to show a checkmark.

14. Reference

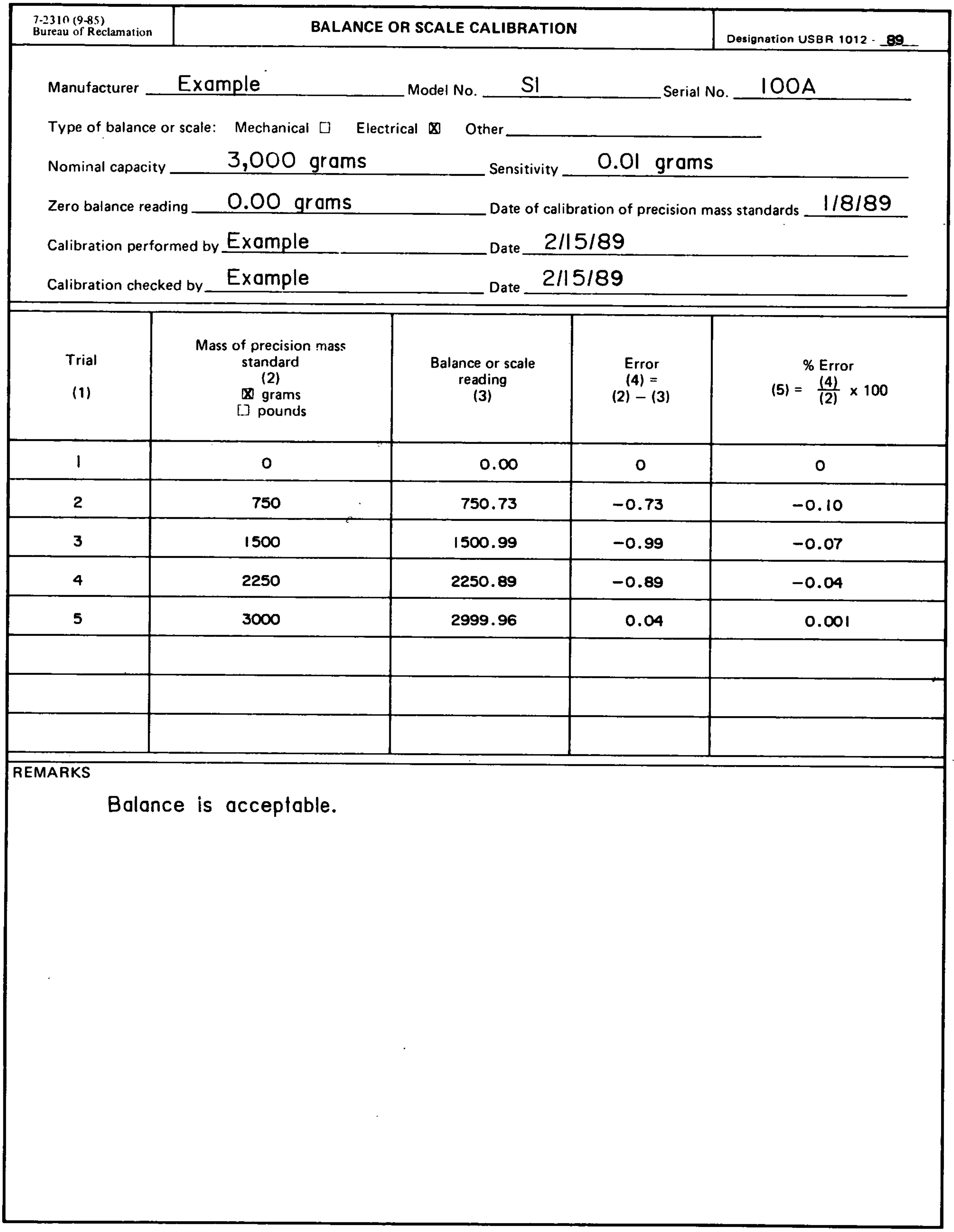
[1] National Bureau of Standards, Handbook 44, "*Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*," U.S. Department of Commerce, Washington, D.C., 1983.

Table 1.–Basic tolerances for balances or scales, inch-pound units.

Test mass		Maximum allowable error, tolerance ±
From	To, but not including	
Pounds		*Pounds*
0	1	0.002
1	2	.004
2	4	.008
4	7	.012
7	10	.016
10	15	.020
15	20	.023
20	30	.031
30	40	.039
40	50	.047
50	75	.062
75	100	.094
100	150	.125
150	200	.188
200	300	.250
300	400	.375
400	600	.500
600	800	.750
800	1000	.875
1000 and over		0.1 percent of test mass

Table 2.–Basic tolerances for balances or scales, SI units.

Test mass		Maximum allowable error, tolerance ±
From	To, but not including	
Grams		*Milligrams*
0	10	15
10	20	50
20	40	100
40	60	150
60	100	250
100	150	350
150	200	500
200	300	650
300	400	800
		Grams
400	500	1.0
500	750	1.5
750	1000	2.0
Kilograms		
1	2	4.0
2	3	5.5
3	5	7.5
5	10	11.0
10	15	15.0
15	20	19.0
20	30	25.0
30	40	35.0
40	50	45.0
50 kilograms and over		0.1 percent of test mass



7-2310 (9-85) Bureau of Reclamation	**BALANCE OR SCALE CALIBRATION**	Designation USBR 1012 - 89

Manufacturer Example Model No. SI Serial No. 100A

Type of balance or scale: Mechanical ☐ Electrical ☒ Other ________

Nominal capacity 3,000 grams Sensitivity 0.01 grams

Zero balance reading 0.00 grams Date of calibration of precision mass standards 1/8/89

Calibration performed by Example Date 2/15/89

Calibration checked by Example Date 2/15/89

Trial (1)	Mass of precision mass standard (2) ☒ grams ☐ pounds	Balance or scale reading (3)	Error (4) = (2) – (3)	% Error $(5) = \frac{(4)}{(2)} \times 100$
1	0	0.00	0	0
2	750	750.73	−0.73	−0.10
3	1500	1500.99	−0.99	−0.07
4	2250	2250.89	−0.89	−0.04
5	3000	2999.96	0.04	0.001

REMARKS

Balance is acceptable.

GPO 848-600

Figure 1. – Balance or scale calibration — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1020-89

PROCEDURE FOR

CALIBRATING OVENS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1020. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating ovens used for standard laboratory testing. This calibration procedure is limited to ovens operating to a maximum temperature of 300 °C. Ovens operating at higher temperatures require special handling and, therefore, should be periodically checked by the manufacturer.

1.2 This procedure is to be used for periodic checks of laboratory ovens. If stringent calibration tolerances are required, this procedure should not be used and ASTM designation: E 145 is to be consulted.

2. Applicable Documents

2.1 *ASTM Standard*:

E 1 ASTM Thermometers

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens

3. Summary of Method

3.1 A thermometer is placed in an oven which is set at the desired operating temperature. The temperature reading of the thermometer is compared to the oven thermostat reading. The appropriate thermostat adjustment is determined.

4. Significance and Use

4.1 Accurate temperature control is important for many soil testing procedures in order to obtain accurate results.

4.2 Ovens are used primarily for determination of moisture content in soils. The ovens should have minimum inside dimensions of 3 feet wide by 2 feet deep by 2 feet high. For most soils laboratory application ovens should be thermostatically controlled at 110±5 °C. Since it is necessary that a uniform temperature be maintained throughout the oven, the mechanical convection or forced-draft ovens are recommended.

NOTE 1.–Ovens slightly smaller than the recommended size may be used, but oven temperature varies significantly when the door is opened, and calibration will be more difficult.

4.3 This calibration procedure is to be performed upon receipt of the oven and annually thereafter.

5. Apparatus

5.1 *Oven.*–An oven, thermostatically controlled, forced-draft or mechanical convection, horizontal air flow type.

5.2 *Thermometer.*–Etched stem glass thermometer with eye-hook at the end for hanging, 0 to 300 °C, 2 °C divisions, mercury filled, conforming to the requirements of ASTM E 1.

5.3 *Gloves.*–Asbestos, 1 pair, to be used whenever handling equipment heated to elevated temperatures.

6. Precautions

6.1 *Safety Precautions*:

6.1.1 All electrical wires and cords are to be checked for damage. If any damage is observed, it is to be repaired before attempting to use the oven.

6.1.2 Care should be exercised in handling any equipment that is heated to elevated temperatures. Gloves are to be worn whenever handling such equipment or materials.

7. Calibration and Standardization

7.1 Verify that the thermometer to be used for this procedure has a certificate of inspection or calibration verification from the manufacturer. If there is doubt as to the accuracy of the thermometer, it should not be used for this procedure; a thermometer with a verifiable accuracy is to be obtained and used.

8. Conditioning

8.1 During the calibration procedure, the room temperature should not vary more than ±10 °C.

9. Procedure

9.1 All data are to be recorded on the "Oven Calibration" form as shown on figure 1.

9.2 Locate and record the serial number, or any other identifying markings, of the oven to be calibrated.

9.3 Remove any material (sample containers, pans, etc.) from the oven.

9.4 Carefully hang the thermometer by its eye-hook with a piece of wire as close to the center of the oven chamber as possible. Make sure that the thermometer hangs freely.

9.5 Determine the applicable temperature at which the oven will be calibrated and set the thermostat of the oven to that temperature.

NOTE 2.–For most geotechnical purposes, the oven will be calibrated at 110 °C. If calibration is desired at another temperature, the procedure is similar. If a range of calibrated temperatures is desired, the calibration should be performed in intervals of 5 °C over the desired range of temperatures.

9.6 Allow sufficient time for the oven temperature to stabilize and record the oven thermostat reading.

9.7 Determine the thermometer reading and record the value.

NOTE 3.–The oven temperature will drop drastically when the oven door is opened. The thermometer reading should be taken as quickly as possible once the door is opened.

9.9 Calculate the thermostat correction and record the value.

9.10 If the thermometer reading is within ±5 °C of the thermostat reading, the calibration procedure is completed. If the thermometer reading differs from the thermostat reading by more than 5 °C, or if a more stringent calibration is desired, see subparagraph 1.2.

9.11 Adjust the thermostat by the amount of the thermostat correction.

9.12 Repeat subparagraphs 9.6 through 9.11 until the desired calibration accuracy has been achieved.

10. Calculations

10.1 Calculate the thermostat correction using the following expression:

$$\text{Thermostat correction} = (1) - (2)$$

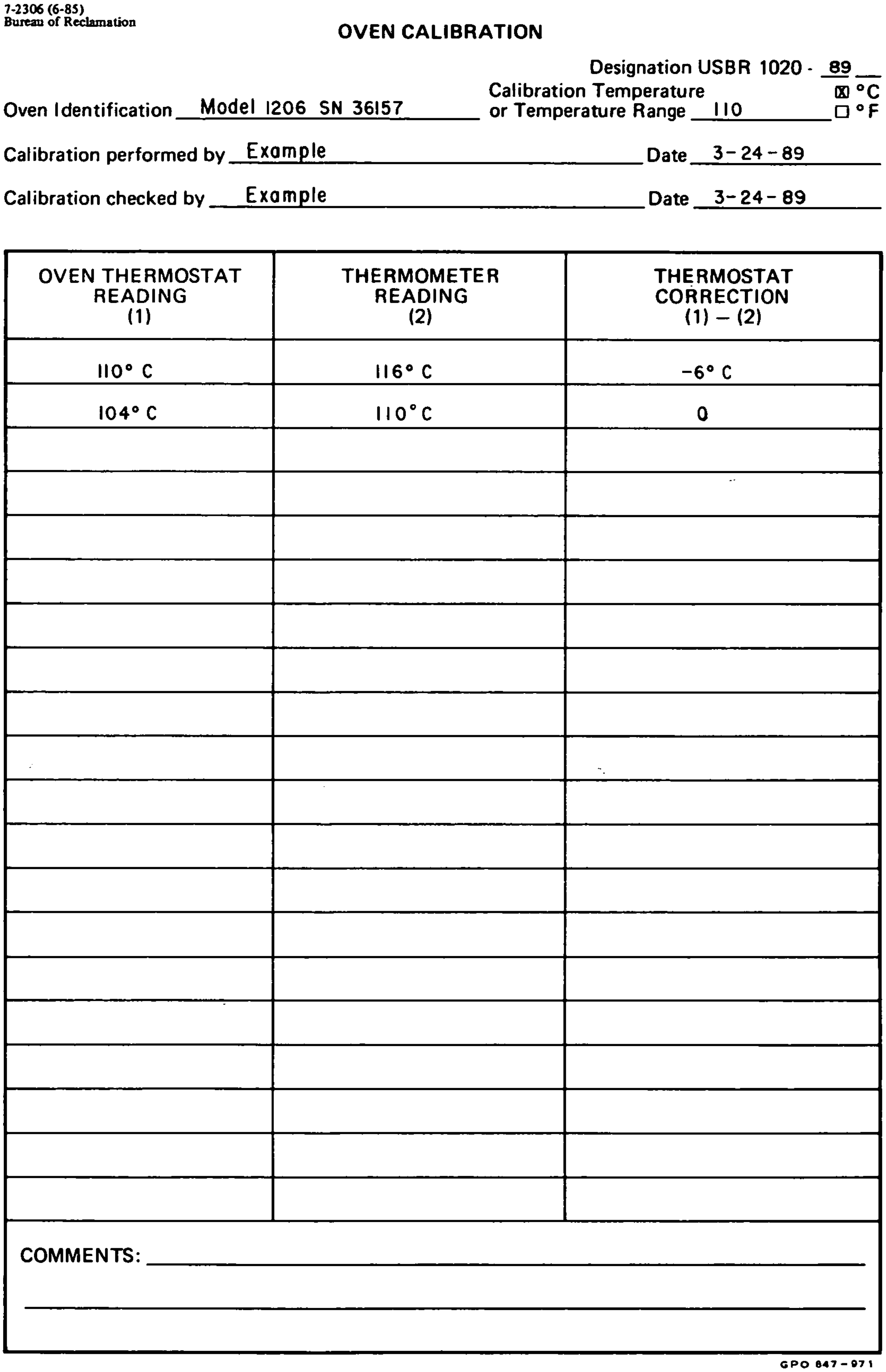
where:

(1) = oven thermostat reading
(2) = thermometer reading

11. Report

11.1 The report is to consist of a completed and checked "Oven Calibration" form (fig. 1).

11.2 All calculations are to show a checkmark.



7-2306 (6-85)
Bureau of Reclamation

OVEN CALIBRATION

Designation USBR 1020 - 89

Oven Identification Model 1206 SN 36157

Calibration Temperature or Temperature Range 110 ☒ °C ☐ °F

Calibration performed by Example Date 3-24-89

Calibration checked by Example Date 3-24-89

OVEN THERMOSTAT READING (1)	THERMOMETER READING (2)	THERMOSTAT CORRECTION (1) – (2)
110° C	116° C	-6° C
104° C	110° C	0

COMMENTS:

GPO 847-971

Figure 1. - Oven calibration — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1025-89

PROCEDURE FOR

CHECKING SIEVES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. This procedure is issued under the fixed designation USBR 1025. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for checking sieves used in laboratory gradation analysis procedures. This procedure can be used for checking both wire cloth and perforated-plate sieves. The sieves shall conform to ASTM specifications E-11 for wire-cloth sieves and E-323 for perforated plate sieves.

1.2 Four methods are discussed to check the conformance of sieves. More than one method may apply for the same sieve as outlined.

(a) Method A describes the procedure for checking wire cloth sieves having apertures as large as 4.75 mm (No. 4) and as small as 38 μm (No. 400) using a "sieve inspector" which is a mechanical device using dial indicators or linear variable differential transformers (LVDTs) to make linear measurements as shown on figure 1.

NOTE 1.–The sieve inspector shown on figure 2 can be adapted to use LVDTs and a computer to facilitate wire diameter and aperture dimension measurements. Information concerning these adaptations can be obtained by contacting the Bureau's Geotechnical Services Branch, code D-3760, Denver Office, Denver, Colorado.

(b) Method B describes the procedure for checking wire-cloth sieves having apertures from 9.5 mm (3/8-in) to 100 mm (4 in) using plug gauges and a linear measurement device, see figure 3.

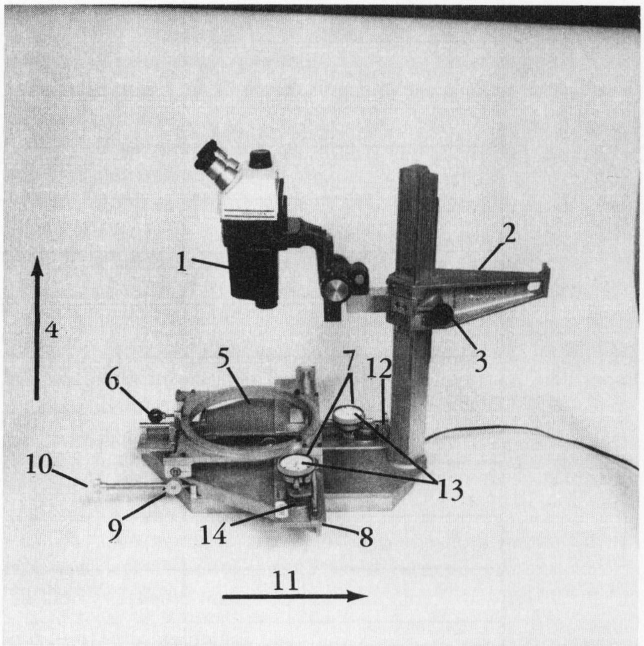
(c) Method C describes the procedure for checking wire-cloth sieves having apertures from 2.36 mm (No. 8) to 150 mm (6 in) using a linear measurement device (fig. 3).

(d) Method D describes the procedure for checking perforated-plate sieves having apertures from 4.75 mm (No. 4) to 150 mm (6 in) using a linear measurement device (fig. 3).

2. Auxiliary Tests

2.1 Dial indicators or LVDTs used to measure aperture dimensions and wire diameters of sieves (method A) must be calibrated in accordance with USBR 1007 or 1008 respectively, prior to performing this procedure.

2.2 Plug gauges used to check aperture dimensions of sieves (method B) are to comply with specifications given in table 1.



NOTE: Sieve inspector is adaptable to various sieves and other linear measurement devices.

Figure 1. – Sieve inspector with dial indicators. 1) monocular microscope, 2) microscope support arm, 3) microscope adjustment knob, 4) warp direction, 5) stage, 6) locking bolt, 7) bezel, 8) guide rail, 9) warp adjustment knob, 10) shoot adjustment knob, 11) shoot direction, 12) guide rail, 13) dial indicator, and 14) magnetic holders.

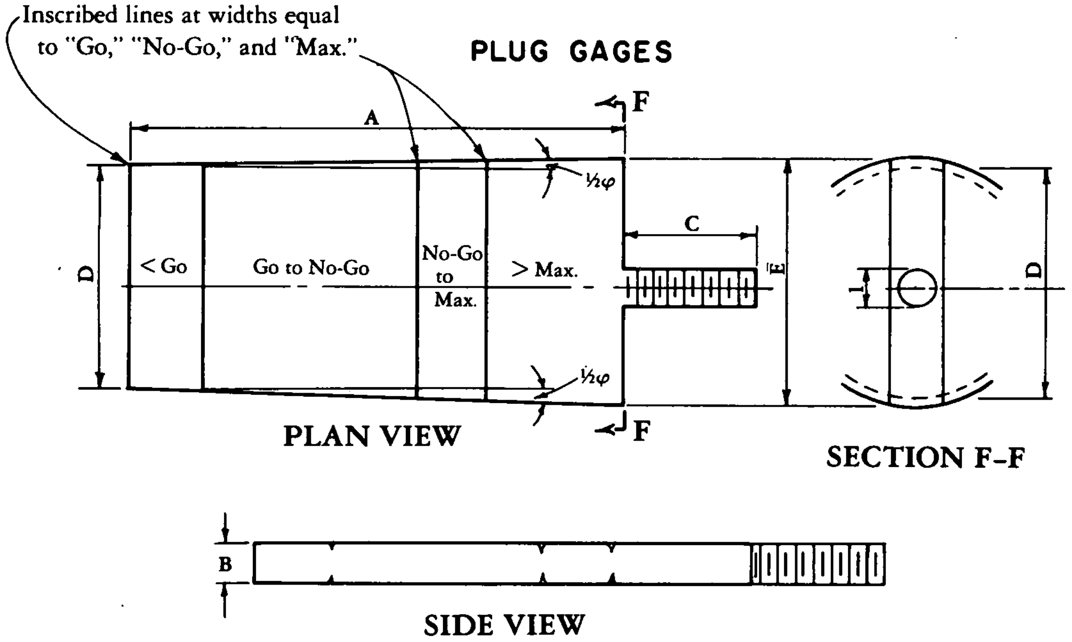
2.3 Vernier or dial calipers (linear measurement devices) used to measure aperture dimensions and wire diameters of sieves (methods B, C, and D) must conform to requirments specified in USBR 1000 prior to performing this procedure.

3. Applicable Documents

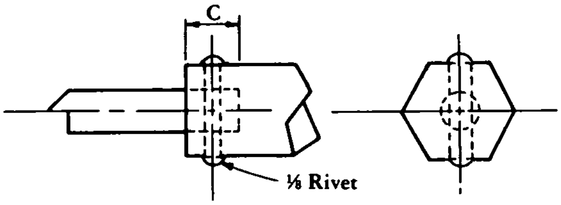
3.1 *USBR Procedures*:
USBR 1000 Standards for Linear Measurement Devices

Table 1. - Plug gauges — plug gauge dimensions.

Sieve designation Standard millimeter	Sieve designation Alternative inch	A in	B in	C in	D in	E in	ϕ	Threads	Handle	Allowable dimensions Minimum "Go" mm	Allowable dimensions Maximum "No-Go" mm	Maximum individual opening "max" mm	Maximum not more than 5% mm
9.5	⅜	2.00	0.15	½	0.3550	0.4043	1° - 25′	6 - 32 - NC	⅜-in Hex. X 2-¾ in	9.20	9.80	10.16	9.97
12.5	½	2.50	0.15	½	0.4625	0.5375	1° - 43′	6 - 32 - NC	⅜-in Hex. X 2-¾ in	12.11	12.89	13.31	13.10
16.0	⅝	3.00	0.20	½	0.5686	0.6814	2° - 9′	10 - 24 - NC	⅜-in Hex. X 2-¾ in	15.5	16.5	17.0	16.7
19.0	¾	3.00	0.20	½	0.6825	0.8175	2° - 35′	10 - 24 - NC	⅜-in Hex. X 2-¾ in	18.4	19.6	20.1	19.9
22.4	⅞	3.00	0.20	½	0.7962	0.9537	3° - 0′	10 - 24 - NC	⅜-in Hex. X 2-¾ in	21.7	23.1	23.7	23.4
25.0	1	3.00	0.25	½	0.9100	1.0900	3° - 26′	¼ - 20 - NC	⅜-in Hex. X 2-¾ in	24.2	25.8	26.4	26.1
31.5	1-¼	3.00	0.25	½	1.1600	1.3400	3° - 26′	¼ - 20 - NC	½-in Hex. X 3 in	30.5	32.5	33.2	32.9
38.1	1-½	3.00	0.25	¾	1.4100	1.5900	3° - 26′	¼ - 20 - NC	½-in Hex. X 3 in	36.8	38.6	39.5	39.1
45.0	1-¾	3.00	0.25	¾	1.6450	1.8551	3° - 45′	¼ - 20 - NC	½-in Hex. X 3 in	43.6	46.4	47.4	46.9
50.0	2	3.00	0.25	¾	1.8800	2.1200	4° - 34′	¼ - 20 - NC	½-in Hex. X 3 in	48.5	51.5	52.6	52.1
63.0	2-½	3.00	0.25	¾	2.3500	2.6500	5° - 44′	¼ - 20 - NC	½-in Hex. X 3 in	61.1	64.9	66.2	65.6
75.0	3	3.00	0.30	¾	2.8200	3.1800	6° - 52′	¼ - 20 - NC	½-in Hex. X 3 in	72.8	77.2	78.7	78.1
90.0	3-½	3.00	0.30	¾	3.3070	3.7800	9° - 0′	¼ - 20 - NC	½-in Hex. X 3 in	87.3	92.7	94.4	93.6
100.0	4	3.00	0.30	¾	3.7600	4.2400	9° - 9′	¼ - 20 - NC	½-in Hex. X 3 in	97.0	103.0	104.8	104.0



Material:
High carbon or alloy steel to be hardened before final grinding.



Alternate method of attaching handles on smaller size gauges

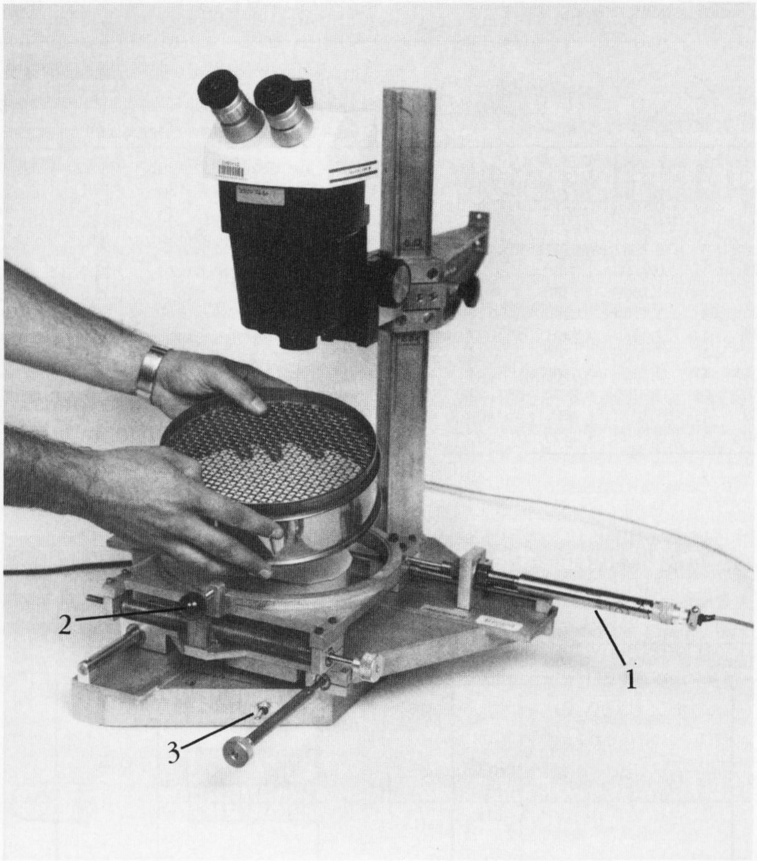


Figure 2. – Placing an 8-inch-diameter brass sieve on a sieve inspector having LVDTs. 1) LVDT, 2) locking bolt, and 3) light switch.

USBR 1007 Calibrating Dial Indicators
USBR 1008 Calibrating Linear Variable Differential Transformers
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

3.2 *ASTM Standards*:

E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes
E 323 Standard Specification for Perforated-Plate Sieves for Testing Purposes

3.3 *Federal Specification*:

GGG-C-111B Calipers and Gages, Vernier

4. Significance and Use

4.1 Permeability, compressibility, and shear strength of a soil mass are influenced by the percentage of various particle sizes present in the soil mass. In order to obtain an accurate, quantitative measure of the distribution of particle sizes, sieves meeting standard nominal dimensions must be used.

4.2 This procedure is to be performed upon receipt of the sieves, at least annually thereafter, and before use after repairs or other occurrences which may affect test results significantly—and whenever test results are questionable.

5. Precautions

5.1 *Safety Precautions*: Care should be exercised while handling sieves to avoid possible injury from sharp edges or protrusion on the sieve.

5.2 *Technical Precautions*: Periodically, check the sieves visually for tears or breaks in the wire cloth.

6. Terminology

6.1 Definitions are in accordance with USBR 3900.

6.2 Terms not included in USBR 3900 specific to this designation are:

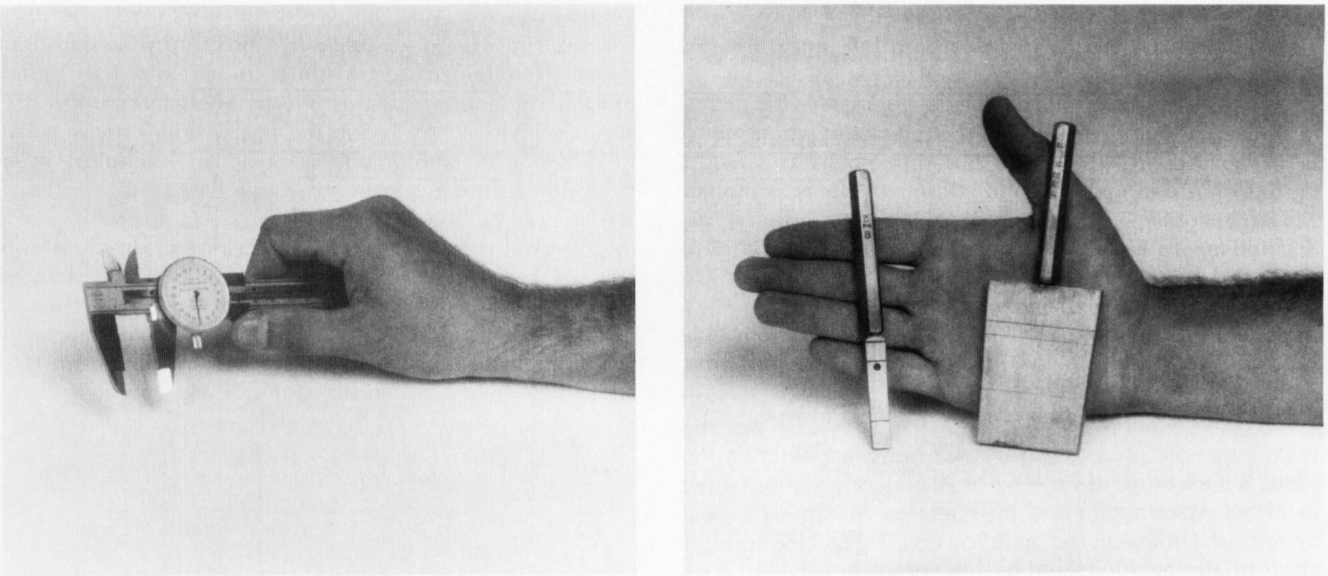
6.2.1 *Aperture.*–The opening or hole between parallel wires in a sieve.

6.2.2 *Warp.*–Direction of travel across the sieve parallel to one set of wires as shown on figure 4.

6.2.3 *Shoot.*–Direction of travel from top to bottom and perpendicular to the warp as shown on figure 4.

6.2.4 *Sieve.*–An instrument with a frame and wire-cloth or perforated bottom used for separating coarse from fine parts of loose matter.

6.2.5 *Stage.*–The apparatus on the sieve inspector which holds the sieve and moves in the X and Y (warp and shoot) direction.



(a) Linear measurment device capable of measuring to the nearest 0.02 mm.

(b) Plug gauges.

Figure 3. - Linear measurement device and plug gauge.

Figure 4. - Sieve measuring pattern for two sets (not mandatory pattern).

6.2.6 *Bridgewidth.*-The distance between the nearest edges of two adjacent apertures in a perforated plate.

6.2.7 *Pitch.*-The distance between the centers of two adjacent apertures in a perforated plate.

6.2.8 *Field.*-The area, usually circular, in which the image is rendered by the lens system of the optical instrument.

6.2.9 *Set.*-A number of apertures and wires measured and grouped together as one.

METHOD A

Checking Wire-Cloth Sieve Using a Sieve Inspector (Optical Linear Measurements With Dial Indicators)

7. Summary of Method — Method A

7.1 Method A is used to check sieves having aperture dimensions from 38-μm (No. 400) to a 4.75 mm (No. 4). Perform a visual inspection of the sieve. Place the sieve in the sieve inspector and check a minimum of 10 sets of 10 aperture dimensions and wire diameters. Five sets are checked in the warp *X* direction and five sets are checked in the shoot *Y* direction (fig. 4). Sieve aperture dimensions and wire diameters are measured using dial indicators attached to the sieve inspector. Average sieve aperture dimensions are calculated for both the warp *X* and shoot *Y* directions and compared to maximum and minimum nominal dimensions for standard test sieves. Average wire diameters are calculated for both the warp *X* and shoot *Y* directions and are compared to maximum and minimum allowable diameters. The percent of sieve aperture dimensions larger than specified is calculated, and the largest sieve opening is determined. A decision to accept or reject the sieve for laboratory use is based on the sieve meeting specified dimensions.

8. Apparatus — Method A

8.1 *Sieve Inspector.*-A sieve inspector is shown on figure 1.

8.1.1 The sieve inspector is a mechanical device which can be used to measure the distance between points on an object mounted to the manually driven *X* - *Y* stage. Movement of the *X* - *Y* stage is measured directly by dial indicators mounted parallel to the *X* and *Y* axis of the stage. A sieve is mounted on the stage and backlighted. The stage can be moved independently along either the *X*-axis (warp direction) or along the *Y*-axis (shoot direction) by means of drive screws moving on stationary half-nuts. The surface of the sieve is observed through a vertically mounted microscope. Crosshairs in the microscope are used to locate measurement points on the sieve. A wide range of sieve sizes can be accurately measured in either system of units by selecting SI (International System of Units) or inch-pound (units) dial indicators of appropriate sensitivity and having sufficient travel to span at least one aperture dimension and wire diameter. A rack and pinion driven microscope support overarm is moved vertically on the column to focus on the wire-cloth. Easily positioned magnetic dial indicator holders facilitate zeroing the dial indicators for direct measurement and will break away if over travel occurs. Rapid traverse of either *X* or *Y* axis is provided by lifting either drive screw out of its half-nut and sliding the stage to the new location.

The sieve inspector is adaptable to check a 17- by 25-inch frame with a Gilson™ sieve as shown on figure 5. The sieve mounting bracket is used to place the Gilson™ sieve on the sieve inspector. The microscope pivoting arm allows the microscope to reach all apertures on the sieve.

9. Calibration and Standardization — Method A

9.1 Verify that dial indicators have been calibrated in accordance with USBR 1007. If the calibration is not current, perform the calibration before using the dial indicators for this procedure.

10. Conditioning — Method A

10.1 Prior to performing this procedure, place the sieve inspector and sieves in the same environment in which they are to be checked for several hours until their temperatures are approximately the same.

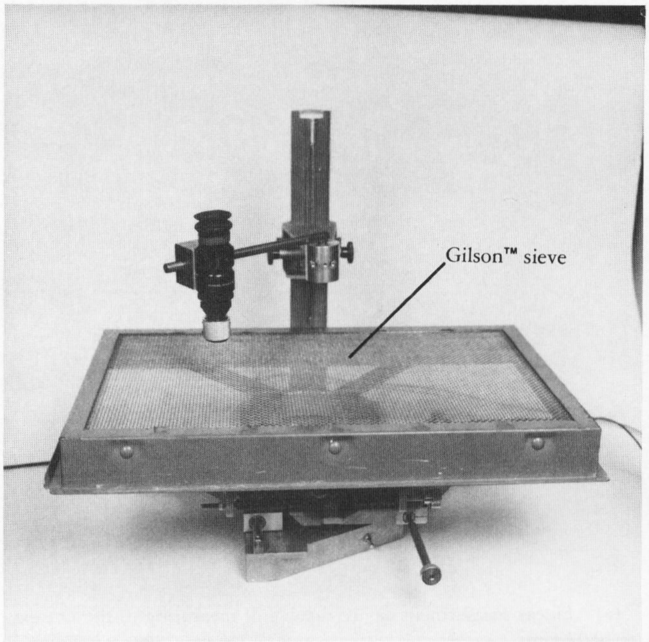
11. Procedure — Method A

11.1 All data are to be recorded on the "Checking Wire-Cloth Sieve" form as shown on figure 6.

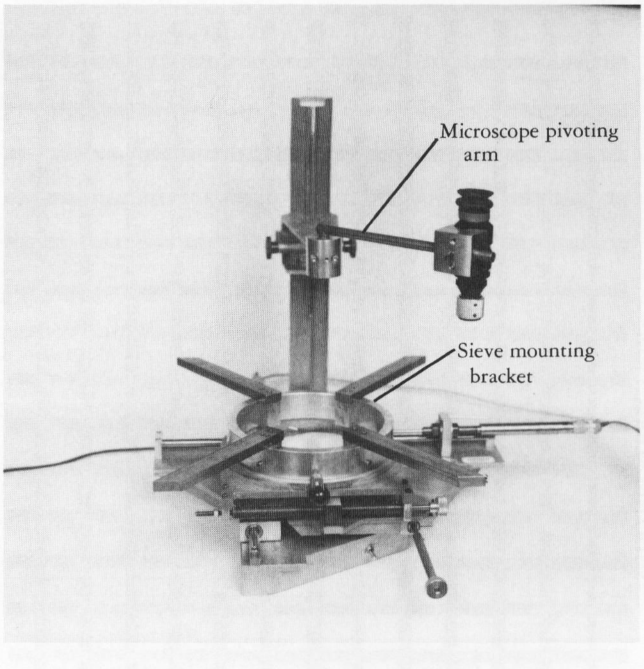
11.2 Place the sieve inspector on a level and sturdy table. Plug the light cord into a power outlet.

11.3 Record the sieve size in both SI and inch-pound units. Also record the sieve control number, if applicable, as shown on figure 6.

11.4 Visually examine the sieve — preferably with a magnifying glass, for any tears, excessive wear, and/or wire displacement. If—upon completion of the visual inspection—flaws are not apparent or if suitable repairs are made, check the accepted box; if not, check the rejected box. The sieve, if rejected, shall be discarded.



(a) Placement of Gilson™ sieve in sieve inspector.



(b) Sieve mounting bracket used to accommodate Gilson™ sieve.

Figure 5. - Adapting the sieve inspector to calibrate the Gilson™ sieve.

7-2396 (1-87)
Bureau of Reclamation

CHECKING WIRE-CLOTH SIEVE

Designation USBR 1025 - 89

PROJECT EXAMPLE	FEATURE	LAB. LOCATION

CALIBRATION PERFORMED BY	DATE	CALIBRATION CHECKED BY	DATE

Sieve Size 4 No. inches 4.75 mm

Visual Inspection: ☒ Accepted ☐ Rejected

Sieve Control No. A

Wire Diameter (mm)						Aperture Dimension (mm)				
Direction & Set No.	Reading No.	Initial Reading	Final Reading	Wire Diameter		Reading No.	Initial Reading	Final Reading	Aperture Dimension	
				X	Y				X	Y
1(X)	1	0.00	1.54	1.54		1	1.54	6.29	4.75	
	2	6.29	7.87	1.58		2	7,87	12,55	4.68	
	3	12,55	14.09	1.54		3	14.09	18.97	4.88	
	4	18.97	20.53	1.56		4	0.00	4.73	4.73	
	5	4.73	6.30	1.57		5	6.30	11.17	4.87	
	6	11.17	12.72	1.55		6	12.72	17.47	4.75	
	7	17.47	18.99	1.52		7	0.00	4.83	4.83	
	8	4.83	6.39	1.56		8	6.39	11.25	4.86	
	9	11,25	12.78	1,53		9	12.78	17.59	4.81	
	10	17.59	19.16	1.57		10	0.00	4.85	4.85	
2(Y)	1	0.00	1,54		1,54	1	1.54	6.29		4.75
	2	6.29	7.84		1.55	2	7.84	12,59		4.75
	3	12,59	14.12		1.53	3	14.12	19.00		4.88
	4	19.00	20,54		1.54	4	0.00	4.85		4.85
	5	4.85	6.38		1.53	5	6.38	11.26		4.88
	6	11.26	12.80		1.54	6	12.80	17.61		4,81
	7	17.61	19.51		1.54	7	0.00	4.86		4.86
	8	4.86	6,39		1.53	8	6.39	11.24		4.85
	9	11.24	12.76		1.52	9	12.76	17.59		4.83
	10	17.59	19.14		1.55	10	0.00	4.79		4.79

	Allowable		Measured	
	min	max	X	Y
Average Wire Diameter (mm)	1.46	1.62	1.55	1.54
Average Aperture (mm)	4.60	4.90	4.80	4.83
Largest Aperture (mm)	5.14		4.88	4.88
5 % of Apertures can exceed	5.02 (mm)		0 %	

Remarks: Only partial sieve checking data shown.

Accepted ☒
Rejected ☐

SHEET ____ OF ____

Figure 6. - Checking wire-cloth sieve — using sieve inspector — example.

11.5 Select the appropriate lens for the microscope to achieve the specified magnification, table 2. The lens selection is based on the field diameter dimensions allowing approximately 4 wire diameters and 4 aperature dimensions in the field of vision.

Table 2. - Lens sizes.

Sieve size	Lens
No. 4 through No. 40	0.5X
No. 40 through No. 200	2X

NOTE 2.-The sieve inspector can be used to check sieves larger than 4.75 mm (No. 4) if the lens and focal point are adjusted. Also, dial indicators will need to be adapted to allow measurement of one wire diameter with one adjacent aperture dimension. It is recommended that a plug gauge or linear measurement device be used for sieves larger than 4.75 mm (No. 4).

11.6 Secure the lens selected in subparagraph 11.5 into the lower end of the microscope.

11.7 Select appropriate dial indicators to achieve the specified range and accuracy, table 3.

Table 3 - Dial indicator selection.

Sieve size	Dial range
Larger than No. 6	25 mm travel X 0.01 mm/division
No. 6 or smaller	5 mm travel X 0.0002 mm/division

11.8 Secure the dial indicators selected in subparagraph 11.7 onto the sieve inspector as shown on figure 1.

11.9 Turn on the light of the sieve inspector.

NOTE 3.-When checking a Gilson™ sieve, attach the appropriate fixtures as shown on figure 5 before mounting the sieve.

11.10 Invert the sieve and place it on the backlighted stage such that the wires run in the warp *X* and shoot *Y* directions.

11.11 Focus the microscope by turning the adjustment knob on the microscope support overarm along with selecting the proper magnification setting located on top of the microscope.

11.12 Align the crosshairs of the microscope with the wires of the sieve. Verify that the sieve is set inplace properly by turning the warp adjustment knob. The warp wires should move parallel with one crosshair during movement of the stage in the warp direction. The shoot wires should move parallel with the other crosshair during movement of the stage in the shoot direction. Adjust the sieve as needed to align the wires with the crosshairs. Tighten the locking bolt located on the front of the stage, as necessary, to secure the sieve in place. Take care not to overtighten the bolt; it could deform the sieve frame.

11.13 Locate a minimum of 10 sets—each containing 10 aperture dimensions and wire diameters—as shown on figure 7. Five sets will run in the warp *X* direction and five sets will run in the shoot *Y* direction. The sets should be selected to uniformly cover the entire surface of the sieve or wherever excessive wear is shown. If there are fewer than 100 apertures in the sieve, check all apertures. If 10 sets of 10 apertures and wire diameters cannot be located, then randomly select 100 apertures and wire diameters, 50 in the warp *X* direction and 50 in the shoot *Y* direction to evenly represent the sieve.

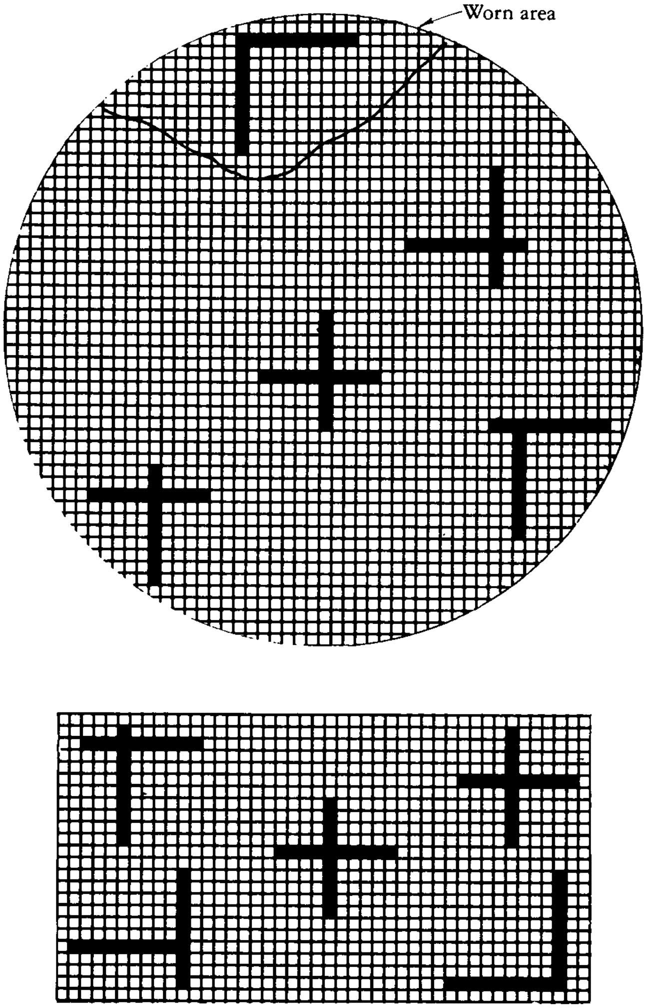


Figure 7. - Appproximate location of aperture sets on the sieve surface.

11.14 Set the position of the crosshairs of the microscope so they are diagonal to the axes of the wire mesh as shown at the top of figure 8.

11.15 Adjust the position of the stage so the crosshairs coincide with the center of the left edge of the wire (right side of aperture) running in the shoot *Y* direction — shown as location 1 on figure 8.

11.16 Slide the magnetic holder for the warp direction dial gauge along its guide rail until the dial indicator registers near zero. Rotate the bezel to read 0.00 and record as *Initial reading* in the "Wire Diameter" section (fig. 6).

11.17 Move the stage of the sieve inspector by turning the warp adjustment knob until the crosshairs coincide with a point directly across the wire from position 1 — shown as position 2 on figure 8.

11.18 Read and record the dial indicator reading as *Final reading* in the "Wire Diameter" section (fig. 6).

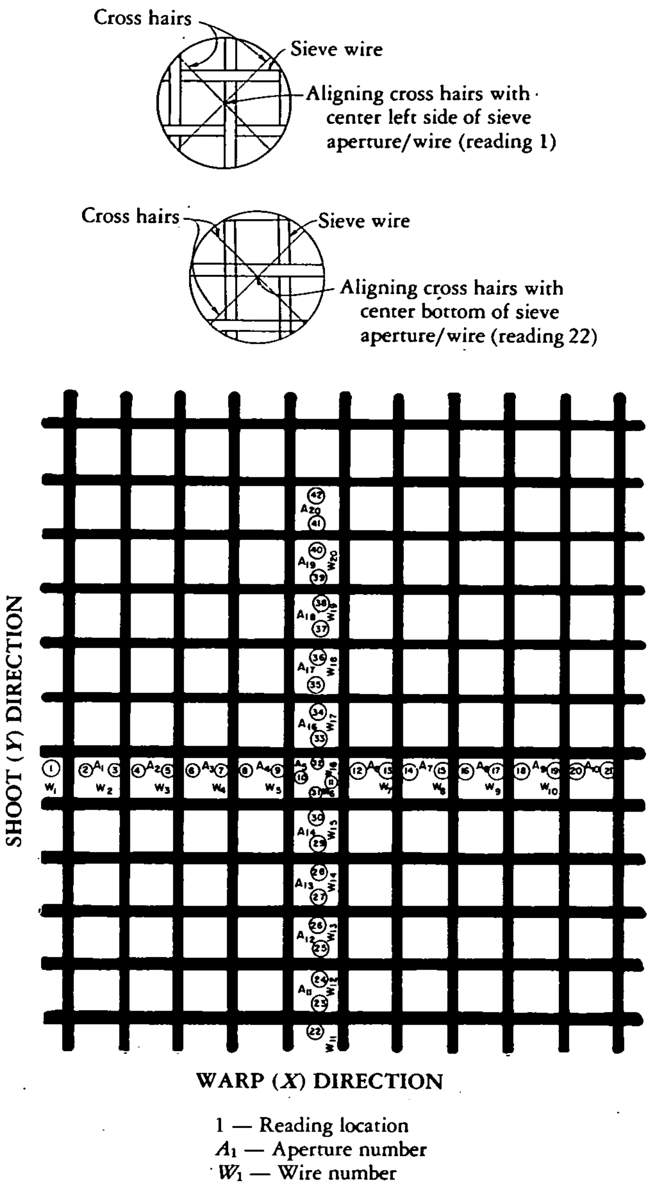


Figure 8. - Sequence of aperture dimension and wire diameter readings for one set.

11.19 Record the dial indicator reading obtained in subparagraph 11.18 as *Initial reading* in the "Aperture Dimension" section (fig. 6).

11.20 Move the stage along the warp axis until the crosshairs coincide with a point directly across the sieve aperture from position 2 — shown as position 3 on figure 8. Read and record the dial indicator as *Final reading* in the "Aperture Dimension" section (fig. 6).

11.21 Record the dial indicator reading obtained in subparagraph 11.20 as *Initial reading* in the "Wire Diameter" section (fig. 6).

11.22 As necessary, slide the magnetic holder for the warp direction dial gauge along its guide rail until the dial indicator registers nearly zero. Rotate the bezel to 0.00 and record in the appropriate column.

11.23 Repeat subparagraph 11.17 through 11.22 using the appropriate positions (shown on figure 8) until one set containing a minimum of 10 wire diameters and 10 aperture dimensions has been measured.

11.24 Adjust the position of the stage so that the crosshairs coincide with position 22 at the center of the bottom edge of the bottom wire (top of aperture) running in the shoot Y direction, of set 2 — shown as position 22 on figure 8.

11.25 Slide the magnetic holder for the shoot direction dial gauge along its guide rail until the dial indicator registers nearly zero. Rotate the bezel to 0.00 and record as *Initial reading* in the "Wire Diameter" section (fig. 6).

11.26 Move the stage of the sieve inspector by turning the shoot adjustment knob until the crosshairs coincide with a point directly across the wire from position 22 — shown as position 23 on figure 8.

11.27 Read and record the dial indicator reading as *Final reading* in the "Wire Diameter" section (fig. 6).

11.28 Record the dial indicator reading obtained in subparagraph 11.27 as *Initial reading* in the "Aperture Dimension" section (fig. 6)

11.29 Move the stage along the shoot axis until the crosshairs coincide with a point directly across the aperture from position 23 — shown as position 24 on figure 8. Read and record the dial indicator as *Final reading* in the "Aperture Dimension" section (fig. 6).

11.30 Record the dial indicator reading obtained in subparagraph 11.29 as *Initial reading* in the "Wire Diameter" section (fig. 6).

11.31 As necessary, slide the magnetic holder for the warp direction dial gauge along its guide rail until the dial indicator registers nearly zero. Rotate the bezel to 0.00 and record in the appropriate column.

11.32 Repeat subparagraphs 11.26 through 11.31 using the appropriate position (shown on figure 8) until the second set containing a minimum of 10 wire diameters and 10 aperture dimensions has been measured. Movement of the crosshairs during measurements, for each set, should follow the sequence shown on figure 8; however the exact position of the sets may vary.

11.33 Repeat subparagraphs 11.15 through 11.32 until a minimum of 10 sets, 5 sets running in the warp X direction and 5 sets running in the shoot Y direction, have been checked (see subpar. 11.13).

11.34 Obtain the following values from table 4 and record as shown on figure 6:

- Average wire diameter limits
- Average aperture dimension limits
- Largest allowable aperture dimension
- Aperture dimension of which 5 percent of the measured apertures can exceed

NOTE 4.-If table 4 does not list the tolerances needed for a certain size sieve, refer to appendix X1, table X1.1.

11.35 Calculate and record to the nearest 0.01 mm, the average aperture dimension and average wire diameter in both the warp X and shoot Y directions as shown on figure 6.

11.36 Locate and record to the nearest 0.01 mm the largest sieve aperture dimension in both the warp X and shoot Y direction as shown on figure 6.

Table 4.–Wire-cloth sieves for testing purposes — standard specifications.

Sieve size		Wire diameter			Aperture dimension			
		Average		Nominal	Average		Largest	5% can
		minimum	maximum		minimum	maximum	allowable	exceed
mm	inch	mm	mm	mm	mm	mm	mm	mm
150	6	9.50	10.50	10.0	145.6	154.4	157.0	156.0
125	5	7.60	8.40	8.00	121.3	128.7	130.9	130.0
90	3-½	5.78	6.38	6.08	87.3	92.7	94.4	93.6
75	3	5.51	6.09	5.80	72.8	77.2	78.7	78.1
63	2-½	5.23	5.78	5.50	61.1	64.9	66.2	65.6
50	2	4.80	5.30	5.05	48.5	51.5	52.6	52.1
45	1-¾	4.61	5.09	4.85	43.6	46.4	47.4	46.9
37.5	1-½	4.36	4.82	4.59	36.4	38.6	39.5	39.1
31.5	1-¼	4.02	4.44	4.23	30.5	32.5	33.2	32.9
25.0	1	3.61	3.99	3.80	24.2	25.8	26.4	26.1
22.4	7/8	3.33	3.68	3.50	21.7	23.1	23.7	23.4
19.0	3/4	3.14	3.47	3.30	18.4	19.6	20.1	19.9
11.2	7/16	2.33	2.57	2.45	10.85	11.55	11.94	11.75
16.0	5/8	2.85	3.15	3.00	15.5	16.5	17.00	16.7
9.50	3/8	2.16	2.38	2.27	9.20	9.80	10.16	9.97
8.00	5/16	1.97	2.17	2.07	7.75	8.25	8.58	8.41
4.75	No. 4	1.46	1.62	1.54	4.60	4.90	5.14	5.02
4.00	No. 5	1.30	1.44	1.37	3.87	4.13	4.35	4.23
2.36	No. 8	0.95	1.05	1.00	2.280	2.440	2.600	2.515
2.00	No. 10	.855	0.945	0.900	1.930	2.070	2.215	2.135
1.18	No. 16	.618	.683	.650	1.135	1.225	1.330	1.270
600 µm	No. 30	.361	.419	.390	575 µm	625 µm	695 µm	660 µm
425 µm	No. 40	.268	.312	.290	406 µm	444 µm	502 µm	471 µm
300 µm	No. 50	.199	.231	.215	286 µm	314 µm	363 µm	337 µm
150 µm	No. 100	.102	.118	.110	142 µm	158 µm	192 µm	174 µm
75 µm	No. 200	.0477	.0583	.053	70 µm	80 µm	103 µm	091 µm
45 µm	No. 325	.027	.033	.030	42 µm	48 µm	66 µm	57 µm

Note: If table 4 does not list the sieve size needed, refer to appendix X1, table X1.1.

11.37 Calculate and record to the nearest one percent the percentage of apertures greater than the allowable limit as shown on figure 6.

12. Calculations — Method A

12.1 Calculate the wire diameters and aperture dimensions using the following expression:

Wire diameter or aperture dimension = final reading – initial reading

12.2 Calculate the average aperture dimension in both the warp *X* and shoot *Y* direction for the entire sieve.

$$A_a = \frac{a_1 + a_2 + a_3 \ldots + a_n}{N_a} \tag{1}$$

where:

A_a = average aperture dimension in either the *X* or *Y* direction, mm

a_1, a_2, a_3, and a_n = measured sieve aperture dimension in either the *X* or the *Y* direction, mm

N_a = total number of aperture measurements in either the *X* or *Y* direction

12.3 Calculate the measured percentage of aperture dimensions greater than the allowable percentage (5% of apertures can exceed) for the entire sieve.

$$\% \text{ Greater} = 100 \left(\frac{A}{N} \right) \tag{2}$$

where:

A = number of aperture measurements greater than the limit

N = total number of aperture measurements for sieve

100 = convert from decimal to percent

12.4 Calculate the average wire diameter in both the warp *X* and shoot *Y* direction for the entire sieve.

$$W_a = \frac{w_1 + w_2 + w_3 \ldots + w_n}{N_w} \tag{3}$$

where:

W_a = average wire diameter in either the *X* or *Y* direction, mm

w_1, w_2, w_3, and w_n = measured individual wire diameters in either the *X* or *Y* direction, mm

N_w = total number of wire diameter measurements in either the *X* or *Y* direction

13. Interpretation of Results — Method A

13.1 The sieve will be accepted if the following criteria are met:

- The visual inspection is acceptable
- The average wire diameter, of the warp *X* and shoot *Y* directions (taken seperately), falls within the specified limits

- The average aperture dimension, in both the warp *X* and shoot *Y* direction, is within the specified limits
- The largest measured aperture dimension is less than the specified limit
- The percentage of measured aperture dimensions greater than the specified limit is 5 percent or less

13.2 If the criteria in subparagraph 13.1 are met, check the accepted box; if not, check the rejected box. If the sieve is rejected and cannot be repaired, it should be discarded.

14. Report — Method A

14.1 The report is to consist of a completed and checked "Checking Wire-Cloth Sieve" form (fig. 6).

14.2 All calculations are to show a checkmark.

METHOD B
Checking Wire-Cloth Sieve Using a Plug Gauge
and Linear Measurement Device

15. Summary of Method — Method B

15.1 Method B is used to check sieves having aperture dimensions from 9.5 mm (3/8-in) to 100-mm (4-in). Perform a visual inspection of the sieve. Check a minimum of 10 sets of 10 aperture dimensions and wire diameters. Five sets are checked in the warp *X* direction and five sets are checked in the shoot *Y* direction (fig. 4). A plug gauge is used to check aperture dimensions against required "go/no go" criteria. A linear measurement device is used to measure wire diameters adjacent to the apertures. Average wire diameters are calculated for both the warp *X* and shoot *Y* directions and compared to maximum and minimum allowable diameters. Aperture dimensions are checked for allowable oversize and maximum aperture dimension. A decision to accept or reject the sieve for laboratory use is based on the sieve meeting specified dimensions.

16. Apparatus — Method B

16.1 *Plug Gauges.*-A set of plug gauges (fig. 3), conforming to the requirements in table 1, and a schematic is shown on figure 9. Each plug gauge is inscribed with three parallel lines at blade widths corresponding to—in order of increasing dimension—the "go" dimension, the "no-go" dimension, and the "max." dimension. Thus inscribed, the face of the blade is divided into four regions. The regions—in order of increasing blade width—are referred to as the "< go" region, the "go to no-go" region, the "no-go to max." region, and the "> max." region. When the plug gauge is inserted into an aperture in a sieve, the dimension of the aperture can be visually classified into one of the four regions. For most soil and concrete laboratory applications, plug gauges are required for the following sieve sizes: 9.5-, 19.0-, 37.5-, 75-mm, (3/8-, 3/4-, 1-1/2-, and 3-inch, respectively).

16.2 *Linear Measurement Devices.*-A vernier or dial caliper (fig. 3) used to measure the wire diameters. The linear measurement device is to meet requirements of Federal Specifications GGG-C-111B, and conform to any additional requirements specified in USBR 1000.

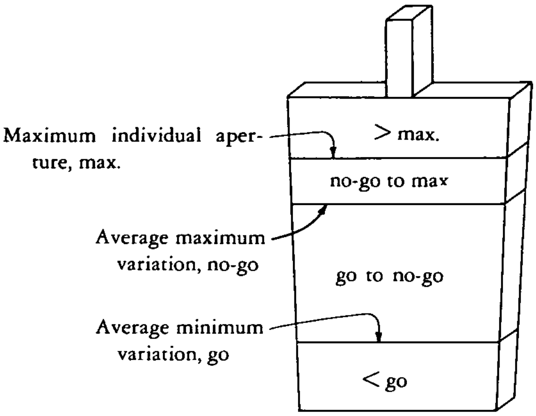


Figure 9. - Plug gauge schematic.

17. Calibration and Standardization — Method B

17.1 Initially (when received) verify that plug gauges conform to the requirements as specified in table 1. If a linear measurement device is used, verify that it meets the requirements of USBR 1000. If the calibration is not current, perform the calibration before using the linear measurement device for this procedure.

18. Conditioning — Method B

18.1 Prior to performing this procedure, place the plug gauges, linear measurement devices, and sieves in the same environment in which they are to be checked for several hours until their temperatures are approximately the same.

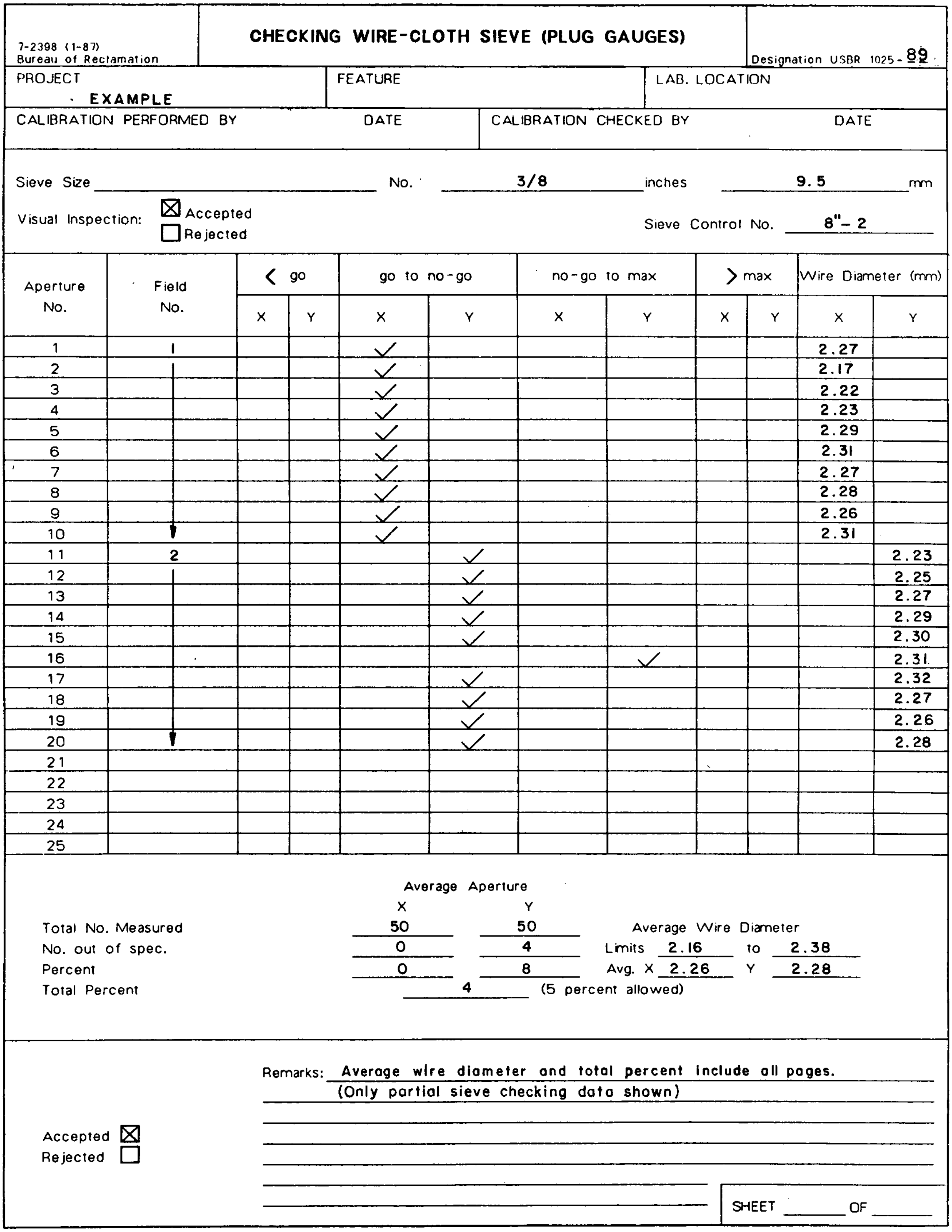
19. Procedure — Method B

19.1 All data are to be recorded on the "Checking Wire-Cloth Sieve (Plug Gauges)" form as shown on figure 10.

19.2 Record the sieve size in both SI and inch-pound units. Also, record the sieve control number, if applicable.

19.3 Visually examine the sieve—preferably with a magnifying glass, for any tears, excessive wear, and/or wire displacement. If—upon completion of the visual inspection—flaws are not apparent or if suitable repairs are made, check the accepted box; if not, check the rejected box. The sieve, if rejected, shall be discarded.

19.4 Locate a minimum of 10 sets—each containing 10 aperture dimensions and wire diameters—as shown on figure 7. Five sets will run in the warp *X* direction and five sets will run in the shoot *Y* direction. The sets should be selected to uniformly cover the entire surface of the sieve or wherever excessive wear is shown. If there are fewer than 100 apertures in the sieve, check all apertures. If 10 sets of 10 aperture dimensions and wire diameters cannot be located, then randomly select 100 apertures and wire diameter, 50 in the warp *X* direction and 50 in the shoot *Y* direction to evenly represent the sieve.



7-2398 (1-87)
Bureau of Reclamation

CHECKING WIRE-CLOTH SIEVE (PLUG GAUGES)

Designation USBR 1025-89

PROJECT EXAMPLE

FEATURE

LAB. LOCATION

CALIBRATION PERFORMED BY

DATE

CALIBRATION CHECKED BY

DATE

Sieve Size ________ No. 3/8 inches 9.5 mm

Visual Inspection: ☒ Accepted ☐ Rejected

Sieve Control No. 8"- 2

Aperture No.	Field No.	< go		go to no-go		no-go to max		> max		Wire Diameter (mm)	
		X	Y	X	Y	X	Y	X	Y	X	Y
1	1			✓						2.27	
2				✓						2.17	
3				✓						2.22	
4				✓						2.23	
5				✓						2.29	
6				✓						2.31	
7				✓						2.27	
8				✓						2.28	
9				✓						2.26	
10	↓			✓						2.31	
11	2				✓						2.23
12					✓						2.25
13					✓						2.27
14					✓						2.29
15					✓						2.30
16							✓				2.31
17					✓						2.32
18					✓						2.27
19					✓						2.26
20	↓				✓						2.28
21											
22											
23											
24											
25											

	Average Aperture X	Average Aperture Y
Total No. Measured	50	50
No. out of spec.	0	4
Percent	0	8
Total Percent	4 (5 percent allowed)	

Average Wire Diameter
Limits 2.16 to 2.38
Avg. X 2.26 Y 2.28

Remarks: Average wire diameter and total percent include all pages.
(Only partial sieve checking data shown)

Accepted ☒
Rejected ☐

SHEET ____ OF ____

Figure 10. - Checking wire-cloth sieves (plug gauges) — example.

19.5 Obtain the correct plug gauge for the sieve to be tested, matching the sieve size with the plug gauge size.

19.6 Insert the plug gauge in the first aperture (A_1) of the first set with the long horizontal axis of the gauge blade oriented in the warp X direction (fig. 8). Visually determine the region of the plug gauge blade that is intersected by the surface of the sieve and place a checkmark in the appropriate column corresponding to the plug gauge reading as shown on figure 10. Figure 11 shows a plug gauge placed in a sieve.

19.7 Using the linear measurement device, measure the first wire diameter W_1 of the first set (fig. 8) to the nearest 0.01 mm and record as shown on figure 10.

19.8 Repeat subparagraphs 19.6 and 19.7 using the appropriate positions until a minimum of 10 aperture dimensions and wire diameters for the set running in the warp X direction have been checked (see subpar. 19.4).

19.9 Insert the plug gauge in the first aperture A_{11} of the second set with the long horizontal axis of the gauge blade oriented in the shoot Y direction (fig. 8). Visually determine the region of the plug gauge blade that is intersected by the surface of the sieve and place a mark in the appropriate column corresponding to the plug gauge reading as shown on figure 10.

19.10 Using the linear measurement device, measure the first wire diameter W_{11} of the second set (fig. 8) to the nearest 0.01 mm and record as shown on figure 10.

19.11 Repeat subparagraph 19.9 and 19.10 using the appropriate positions until a minimum of 10 aperture dimensions and wire diameters for the set running in the shoot Y direction have been checked (see subpar. 19.4).

19.12 Repeat subparagraphs 19.8 and 19.11 until a minimum of 10 sets, 5 sets running in the warp X direction and 5 sets running in the shoot Y direction, have been checked.

19.13 Obtain the appropriate minimum and maximum allowable limits for the average wire diameter from table 4 and record as shown on figure 10. If the sieve size is not shown on table 4, obtain the specified values from appendix X1, table X1.1.

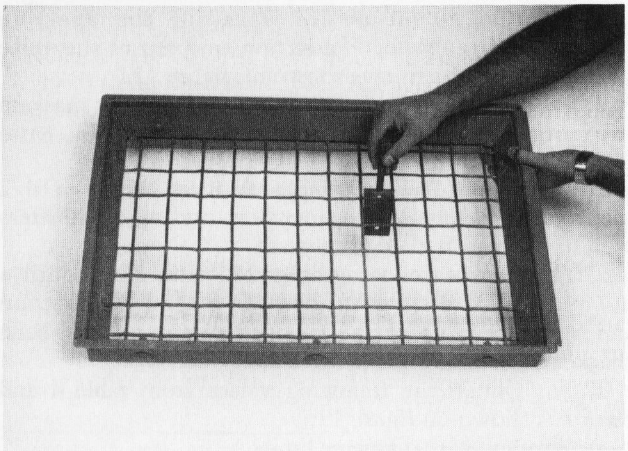


Figure 11. – Square frame wire cloth sieve.

19.14 Calculate the percentage of openings which fall in the "no-go to max." region for both the warp X and shoot Y directions and record to the nearest 1 percent as shown on figure 10. Calculate the total percentage and record as shown on figure 10.

19.15 Calculate and record to the nearest 0.01 mm the average wire diameter in both the warp X and shoot Y directions as shown on figure 10.

20. Calculations — Method B

20.1 Calculate the percent of oversize apertures in the "no-go to max." column in the warp X or shoot Y direction for the entire sieve.

$$P_i = 100 \left(\frac{t_i}{N_i} \right) \tag{4}$$

where:

P_i = percent of oversized apertures, %

t_i = total number of apertures in the "no-go to max." column

N_i = total number of apertures measured

100 = convert from decimal to percent

NOTE 5.–The subscript i denotes either the warp X or shoot Y direction.

20.2 Calculate the total percentage of apertures in the "no-go to max." region for the entire sieve.

$$P_t = \frac{P_x + P_y}{2} \tag{5}$$

where:

P_t = total percentage of apertures in the "no-go to max." region, %

P_x = percent apertures in the "no-go to max." region in the warp X direction, %

P_y = percent apertures in the "no-go to max." region in the shoot Y direction, %

20.3 Calculate the average wire diameter in either the warp X or shoot Y direction.

$$W_a = \frac{w_1 + w_2 + w_3 \ldots + w_n}{N_w} \tag{6}$$

where:

W_a = average wire diameter in either the X or Y, mm

w_1, w_2, w_3, and w_n = measured individual wire diameters in either the X or Y direction, mm

N_w = total number of wire diameter measurements in either the X or Y direction

21. Interpretation of Results — Method B

21.1 The sieve will be accepted under the following criteria:

- The visual inspection is acceptable
- The average wire diameter, of the warp X and shoot Y directions (taken separately), falls within the specified limits

- Either all the checkmarks are in the "go to no-go" columns or less than 5 percent of the checkmarks fall in the "no-go to max." column.
- There are no aperture dimensions in the "< go" or "> max." columns

21.2 If there are greater than 5-percent openings in the "no-go to max." column, recalibrate the sieve using method C.

21.3 If the sieve does not meet the criteria of subparagraph 21.1, except as noted in subparagraph 21.2, the sieve is to be rejected. It may be repaired and rechecked, otherwise discard if rejected.

22. Report — Method B

22.1 The report is to consist of a completed and checked "Checking Wire-Cloth Sieve (Plug Gauges)" form (fig. 10).

22.2 All calculations are to show a checkmark.

METHOD C
Checking Wire-Cloth Sieve Using a Linear Measurement Device

23. Summary of Method — Method C

23.1 Method C is used to check sieves having aperture dimensions from 2.36 mm (No. 8) to 150 mm (6 in). Perform a visual inspection of the sieve. Use a linear measurement device to check a minimum of 10 sets of 10 aperture dimensions and wire diameters as shown in figure 7. Five sets are checked in the warp *X* direction and five sets are checked in the shoot *Y* direction (fig. 4). Average wire diameter and aperture dimensions are calculated for both the warp *X* and shoot *Y* directions and compared to maximum and minimum allowable dimensions. Aperture dimensions are checked for allowable oversize percentage and maximum aperture dimension. A decision to accept or reject the sieve for laboratory use is based on the sieve meeting specified dimensions.

24. Apparatus — Method C

24.1 *Linear Measurement Devices.*-A vernier or dial caliper (fig. 3) is used to measure aperture dimensions and wire diameters. The linear measurement device is to meet requirements of Federal Specifications GGG-C-111B, and conform to any additional requirements specified in USBR 1000.

25. Calibration and Standardization—Method C

25.1 Verify that the linear measurement device has been calibrated in accordance with USBR 1000. If the calibration is not current, perform the calibration before using the linear measurement device for this procedure.

26. Conditioning — Method C

26.1 Prior to performing this procedure, place the linear measurement device and sieves in the same environment in which they are to be checked for several hours until their temperatures are approximately the same.

27. Procedure — Method C

27.1 All data are to be recorded on the "Checking Wire-Cloth Sieve (Measurement Devices)" form as shown on figure 12.

27.2 Record the sieve size in both SI and inch-pound units. Also record the sieve control number, if applicable, as shown on figure 12.

27.3 Visually examine the sieve—preferably with a magnifying glass, for any tears, excessive wear, and/or wire displacement. If—upon completion of the visual inspection—flaws are not apparent or if suitable repairs are made, check the accepted box; if not, check the rejected box. The sieve, if rejected, shall be discarded.

27.4 Locate a minimum of 10 sets — each containing 10 aperture dimensions and wire diameters — as shown on figure 7. Five sets will run in the warp *X* direction and five will run in the shoot *Y* direction. The sets should be selected to uniformly cover the entire surface of the sieve or wherever excessive wear is shown. If there are fewer than 100 apertures in the sieve, check all apertures. If 10 sets of 10 aperture dimensions and wire diameters cannot be located, then randomly select 100 apertures and wire diameters, 50 in the warp *X* direction and 50 in the shoot *Y* direction to evenly represent the sieve.

27.5 Beginning with the first aperture (A_1, fig. 8) of the first set, measure the aperture dimension using a linear measurement device. Measure the aperture dimension in the warp *X* direction, and record the value to the nearest 0.01 mm as shown on figure 12.

27.6 Using the linear measurement device, measure the first wire diameter W_1 of the first set (fig. 8) to the nearest 0.01 mm and record as shown on figure 12.

27.7 Repeat subparagraphs 27.5 and 27.6 until a minimum of 10 aperture dimensions and wire diameters each have been checked for the set.

27.8 Beginning with the first aperture (A_{11}, fig. 8) of the second set, measure the aperture dimension using a linear measurement device. Measure the aperture dimension in the shoot *Y* direction, and record the value to the nearest 0.01 mm as shown on figure 12.

27.9 Using the linear measurement device, measure the first wire diameter W_{11} of the second set (fig. 8) to the nearest 0.01 mm and record on figure 12.

27.10 Repeat subparagraphs 27.8 and 27.9 until a minimum of 10 aperture dimensions and wire diameters each have been checked for the set.

27.11 Repeat subparagraphs 27.7 and 27.10 until a minimum of 10 sets, 5 sets running in the warp *X* direction and 5 sets running in the shoot *Y* direction, have been checked.

27.12 Obtain the following values from table 4 and record as shown on figure 12:

- Average wire diameter limits
- Average aperture dimension limits
- Largest allowable aperture dimension

7-2397 (12-86)
Bureau of Reclamation

CHECKING WIRE-CLOTH SIEVE (MEASUREMENT DEVICES)

Designation USBR 1025 - 89

PROJECT EXAMPLE	FEATURE	LAB. LOCATION

CALIBRATION PERFORMED BY	DATE	CALIBRATION CHECKED BY	DATE

Sieve Size ______ No. 3 inches 75 mm

Visual Inspection: ☒ Accepted ☐ Rejected

Sieve Control No. 8"- 3

Aperture No.	Field No.	Aperture Dimension (mm)		Wire Diameter (mm)	
		Warp (X)	Shoot (y)	Warp (X)	Shoot (Y)
1	1	74.2	74.0	5.75	5.78
2	↓	75.0	76.0	5.83	5.80
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

	Allowable min	Allowable max	Measured X	Measured Y
Average Wire Diameter (mm)	5.51	6.09	5.79	5.79
Average Aperture (mm)	73.8	77.2	74.6	75.0
Largest Aperture (mm)	78.7		75.0	76.0
5 % of Apertures can exceed	78.1 (mm)		0 %	

Remarks: Only two apertures on 8-inch diameter sieve.

Accepted ☒
Rejected ☐

SHEET ____ OF ____

Figure 12. – Checking wire-cloth sieve (measurement devices) — example.

- Aperture dimension of which 5 percent of the measured apertures can exceed

NOTE 6.-If table 4 does not list the tolerances needed for a certain sieve size, refer to appendix X1, table X1.1.

27.13 Calculate and record to the nearest 0.01 mm the average aperture dimension and average wire diameter in both the warp X and shoot Y directions as shown on figure 12.

27.14 Locate and record to the nearest 0.01 mm the largest sieve aperture dimension in both the warp X and shoot Y directions as shown on figure 12.

27.15 Calculate and record to the nearest one percent the percentage of apertures greater than the allowable limit as shown on figure 12.

28. Calculations — Method C

28.1 Calculate the average aperture dimension in both the warp X and shoot Y direction for the entire sieve.

$$A_a = \frac{a_1 + a_2 + a_3 \ldots + a_n}{N_a} \qquad (7)$$

where:

A_a = average aperture dimension in either the X or Y direction, mm

a_1, a_2, a_3, and a_n = measured sieve aperture dimension in either the X or the Y direction, mm

N_a = total number of aperture measurements in either the X or the Y direction

28.2 Calculate the measured percentage of aperture dimensions greater than the limit for the entire sieve.

$$\text{\% Greater} = 100 \left(\frac{A}{N}\right) \qquad (8)$$

where:

A = number of aperture measurements greater than the limit

N = total number of aperture measurements for the sieve

100 = convert from decimal to percent

28.3 Calculate the average wire diameter in both the warp X and shoot Y direction for the entire sieve.

$$W_a = \frac{w_1 + w_2 + w_3 \ldots + w_n}{N_w} \qquad (9)$$

where:

W_a = average wire diameter in either the X or Y direction, mm

w_1, w_2, w_3, and w_n = measured individual wire diameter in either the X or Y direction, mm

N_w = total number of wire diameter measurements in either the X for Y direction

29. Interpretation of Results — Method C

29.1 The sieve will be accepted if the following criteria are met:

- The visual inspection is acceptable
- The average wire diameter, of the warp X and shoot Y directions (taken separately), falls within the specified limits
- The average aperture dimension in both the warp X and shoot Y direction is within the specified limits
- The largest measured aperture dimension is less than the specified limit
- The percentage of measured aperture dimensions greater than the specified limit is 5 percent or less

29.2 If the criteria in subparagraph 29.1 are met, check the accepted box; if not, check the rejected box. If the sieve is rejected and cannot be repaired it should be discarded.

30. Report — Method C

30.1 The report is to consist of a completed and checked "Checking Wire-Cloth Sieve (Measurement Devices)" form (fig. 12).

30.2 All calculations are to show a checkmark.

METHOD D

Checking Perforated Plate Sieve
Using a Linear Measurement Device

31. Summary of Method — Method D

31.1 Method D is used to check perforated plate sieves having aperture dimensions from 4.75 mm (No. 4) to 150 mm (6 inch). Perform a visual inspection of the sieve. Use a linear measurement device to measure aperture dimension, bridgewidth, and plate thickness along two lines. Aperture pitch is calculated. The dimensions obtained are individually compared with specified dimensions. A decision to accept or reject the perforated plate sieve for laboratory use is based on the sieve meeting specified dimensions.

32. Apparatus — Method D

32.1 *Linear Measurement Devices.*-A vernier or dial caliper (fig. 3) is used to measure bridgewidth and aperture dimension. The plate thickness is measured using any reliable linear measuring device. The linear measurement devices are to meet requirements of Federal Specifications GGG-C-111B, and conform to any additional requirements specified in USBR 1000.

33. Calibration and Standardization — Method D

33.1 Verify that the linear measurement devices have been calibrated in accordance with USBR 1000. If the calibration is not current, perform the calibration before using the linear measurement device for this procedure.

34. Conditioning — Method D

34.1 Prior to performing this procedure, place the linear measurement devices and sieves in the same environment in which they are to be checked for several hours until their temperatures are approximately the same.

35. Procedure — Method D

35.1 All data are to be recorded on the "Checking Perforated Plate Sieve" form as shown on figure 13.

35.2 Record the sieve size in both SI and inch-pound units. Also record the sieve control number, if applicable, as shown on figure 13. Locate from figure 14 and record, as shown on figure 13, sieve aperture dimension limits, bridgewidth dimension limit, pitch dimension limits, and plate thickness dimension limits for the appropriate sieve size. If the sieve size is not shown on figure 14, specified values can be obtained from appendix X1, table X1.2.

35.3 Visually examine the perforated plate sieve—preferably with a magnifying glass, for any flaws. If—upon completion of the visual inspection—flaws are not apparent or if suitable repairs are made, check the accepted box; if not, check the rejected box. The sieve, if rejected, shall be discarded. A typical perforated plate sieve is shown on figure 15.

NOTE 6.-The plug gauges which where used for the wirecloth sieves are unacceptable for the perforated plate sieves due to the change in allowable dimensions.

35.4 Check all dimensions using a linear measurement device. Because of the manner in which the sieve is fabricated, each aperture is tapered so be sure to make measurements on the side of the plate on which the manufacturer indicated the aperture size.

35.5 The two straight lines used for checking square apertures are separated by either 90 degrees (perpendicular), or 63 degrees 26 minutes to each other as shown on figure 14. The two straight lines used for checking round apertures are separated by 60 degrees.

35.6 The apertures selected to verify that the sieve is within allowable dimensions are those which lie along two straight lines, each at least 100-mm (3.94-in) in length, or a total of 20 apertures (10 in the direction of each line) whichever is greater. If these requirements cannot be met, check all apertures in the sieve.

35.6.1 Beginning with straight line 1 (0 degrees), measure and record the aperture dimensions to the nearest 0.01 mm in both the warp X and shoot Y directions as shown on figure 13.

35.6.2 Measure and record the bridgewidth dimensions (Z_i, fig. 14) to the nearest 0.01 mm between the apertures measured in subparagraph 35.6.1.

35.6.3 Measure and record the plate thickness to the nearest 0.01 mm on 25 percent of the bridges measured as shown on figure 13. Preferably this should be done on the bridges that show the most wear—apparent by the smallest bridgewidth dimension. Repeat subparagraphs 35.6.1 and 35.6.4 until the required number of apertures or a distance of 100 mm have been checked.

35.6.4 Calculate and record to the nearest 0.01 mm the pitch distance as shown on figure 13.

35.7 Beginning at subparagraph 35.6.1 and continuing through subparagraph 35.6.4 check the sieve in the other direction of travel along line 2 as shown on figure 14. Record the data on a second form. If the aperture dimensions, pitch dimensions, bridgewidth, and plate thicknesses fall within the required limits, place a checkmark in the approved box. Record any remarks at the bottom of figure 13.

36. Calculations — Method D

36.1 Calculate the pitch dimension.

$$\text{Pitch} = \tfrac{1}{2} X_i + \tfrac{1}{2} X_{i+1} + Z_i \qquad (10)$$

where:

Pitch = center-to-center distance of adjacent apertures, mm

X_i = aperture dimension; X for line 1; Y for line 2, mm

X_{i+1} = aperture dimension of the following aperture: X for line 1; Y for line 2, mm

Z_i = bridgewidth of bridge between apertures X_i and X_{i+1} or Y_i and Y_{i+1}, mm

37. Interpretation of Results — Method D

37.1 The sieve will be accepted if the following criteria are met:

- The visual inspection is acceptable
- All aperture dimensions are within specified limits
- All bridgewidth dimensions are within specified limit
- All pitch distances are within specified limits
- Plate thickness falls within specified limits

37.2 If the criteria in subparagraph 37.1 are met, check the accepted box; if not, check the rejected box. If the sieve is rejected and cannot be repaired, it should be discarded.

38. Report — Method D

38.1 The report is to consist of a completed and checked "Checking Perforated Plate Sieve" form (fig. 13).

38.2 All calculations are to show a checkmark.

7-2399 (1-87)
Bureau of Reclamation

CHECKING PERFORATED PLATE SIEVE

Designation USBR 1025 - 89

PROJECT EXAMPLE
FEATURE
LAB. LOCATION

CALIBRATION PERFORMED BY
DATE
CALIBRATION CHECKED BY
DATE

Direction of Travel 0°
Line No. 1

Visual Inspection: ☒ Accepted ☐ Rejected

Sieve Size 4
No. 3/16 inches 4.75 mm
Sieve Control No.

	Sieve Aperture Dimension (mm)		Bridgewidth Dimension (mm) Z	Pitch Dimension (mm) Pitch		Plate Thickness (mm)
	X	Y		X	Y	
1	4.72	4.67	2.66	7.38		
2	4.71	4.63	2.21	6.92		1.41
3	4.70	4.61	2.62	7.36		
4	4.78	4.62	2.64	7.38		
5	4.66	4.68	2.44	7.08		1.33
6	4.61	4.68	2.58	7.22		
7	4.68	4.69	2.50	7.18		1.54
8	4.68	4.65	2.48	7.12		1.46
9	4.61	4.70	2.57	7.20		
10	4.64	4.62	2.51	7.14		
11	4.62	4.61	2.70	7.35		
12	4.68	4.71	2.71	7.39		
13	4.68	4.72	2.57	7.23		
14	4.62	4.61	2.58	7.21		
15	4.64	4.61	2.63	7.28		
16	4.68	4.64				
17						
18						
19						
20						
21						
22						
23						
24						
25						

Sieve Aperture Dimension Limits (mm)	Bridgewidth Dimension Less than the Limit (mm)	Pitch Dimension Limits (mm)	Plate Thickness Limits (mm)
4.61 to 4.89	1.03	5.8 to 7.8	0.8 to 1.5

Remarks:

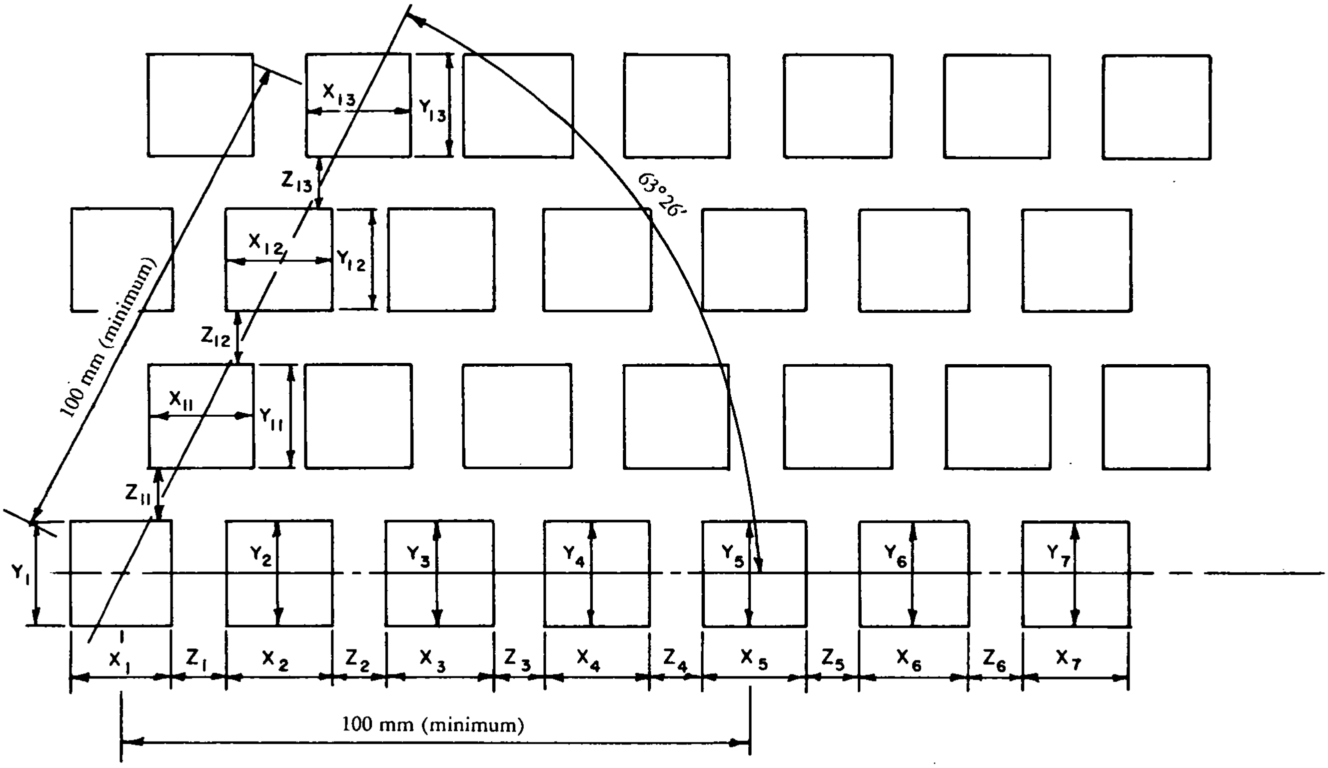
Accepted ☒
Rejected ☐

SHEET ____ OF ____

Figure 13. - Checking perforated plate sieve — example.

ALLOWABLE DIMENSIONS — PERFORATED PLATE SIEVES

Sieve size mm	Sieve size in	Aperture width range mm	Distance between aperture center (pitch) mm	Plate thickness mm	Minimum bridge width mm
75	3	74.3 - 75.4	86 - 109	2.5 - 4.0	10
37.5	1-½	37.1 - 37.9	43 - 55	1.5 - 2.5	5.25
19.0	¾	18.7 - 19.3	22 - 29	1.5 - 2.5	3
9.5	⅜	9.3 - 9.7	11.3 - 14.9	1.0 - 2.0	1.75
4.75	No. 4	4.61 - 4.89	5.8 - 7.8	0.8 - 1.5	1.03



NOTE: This drawing denotes the two straight lines when seperated by 63 degrees 26 minutes.

Figure 14. - Allowable dimensions — perforated plate sieves. Measuring sequence for perforated plate sieves.

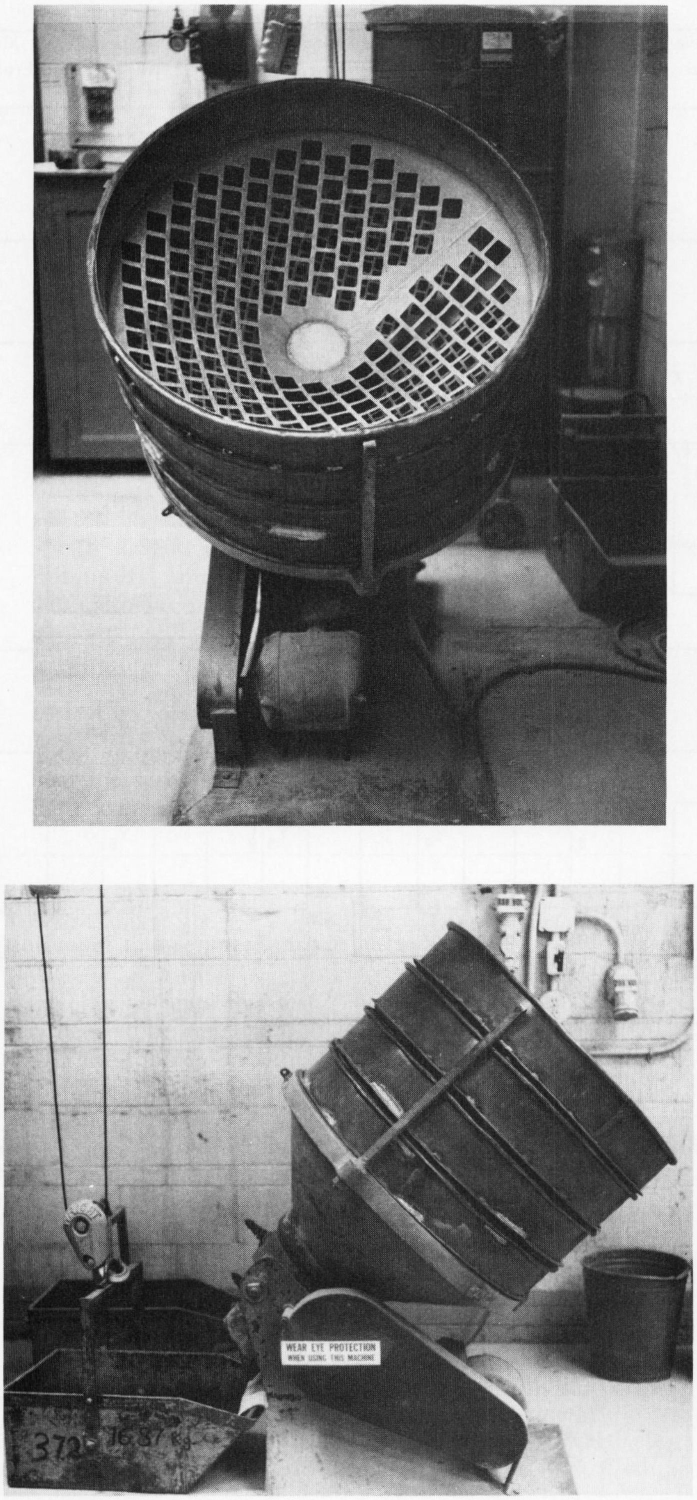


Figure 15. – Perforated plate sieves with orbital separating device.

Appendix X1

Table X1.1 – Nominal dimensions, permissible variations for wire cloth of standard test sieves (U.S.A. Standard Series) [ASTM E 11].

Sieve Designation		Nominal Sieve Opening, in.[c]	Permissible Variation of Average Opening from the Standard Sieve Designation	Maximum Opening Size for Not More than 5 % of Openings	Maximum Individual Opening	Nominal Wire Diameter, mm[a]
Standard[b]	Alternative					
(1)	(2)	(3)	(4)	(5)	(6)	(7)
125 mm	5 in.	5	±3.7 mm	130.0 mm	130.9 mm	8.0
106 mm	4.24 in.	4.24	±3.2 mm	110.2 mm	111.1 mm	6.40
100 mm[d]	4 in.[d]	4	±3.0 mm	104.0 mm	104.8 mm	6.30
90 mm	3½ in.	3.5	±2.7 mm	93.6 mm	94.4 mm	6.08
75 mm	3 in.	3	±2.2 mm	78.1 mm	78.7 mm	5.80
63 mm	2½ in.	2.5	±1.9 mm	65.6 mm	66.2 mm	5.50
53 mm	2.12 in.	2.12	±1.6 mm	55.2 mm	55.7 mm	5.15
50 mm[d]	2 in.[d]	2	±1.5 mm	52.1 mm	52.6 mm	5.05
45 mm	1¾ in.	1.75	±1.4 mm	46.9 mm	47.4 mm	4.85
37.5 mm	1½ in.	1.5	±1.1 mm	39.1 mm	39.5 mm	4.59
31.5 mm	1¼ in.	1.25	±1.0 mm	32.9 mm	33.2 mm	4.23
26.5 mm	1.06 in.	1.06	±0.8 mm	27.7 mm	28.0 mm	3.90
25.0 mm[d]	1 in.[d]	1	±0.8 mm	26.1 mm	26.4 mm	3.80
22.4 mm	⅞ in.	0.875	±0.7 mm	23.4 mm	23.7 mm	3.50
19.0 mm	¾ in.	0.750	±0.6 mm	19.9 mm	20.1 mm	3.30
16.0 mm	⅝ in.	0.625	±0.5 mm	16.7 mm	17.0 mm	3.00
13.2 mm	0.530 in.	0.530	±0.41 mm	13.83 mm	14.05 mm	2.75
12.5 mm[d]	½ in.[d]	0.500	±0.39 mm	13.10 mm	13.31 mm	2.67
11.2 mm	7/16 in.	0.438	±0.35 mm	11.75 mm	11.94 mm	2.45
9.5 mm	⅜ in.	0.375	±0.30 mm	9.97 mm	10.16 mm	2.27
8.0 mm	5/16 in.	0.312	±0.25 mm	8.41 mm	8.58 mm	2.07
6.7 mm	0.265 in.	0.265	±0.21 mm	7.05 mm	7.20 mm	1.87
6.3 mm[d]	¼ in.[a]	0.250	±0.20 mm	6.64 mm	6.78 mm	1.82
5.6 mm	No. 3½	0.223	±0.18 mm	5.90 mm	6.04 mm	1.68
4.75 mm	No. 4	0.187	±0.15 mm	5.02 mm	5.14 mm	1.54
4.00 mm	No. 5	0.157	±0.13 mm	4.23 mm	4.35 mm	1.37
3.35 mm	No. 6	0.132	±0.11 mm	3.55 mm	3.66 mm	1.23
2.80 mm	No. 7	0.111	±0.095 mm	2.975 mm	3.070 mm	1.10
2.36 mm	No. 8	0.0937	±0.080 mm	2.515 mm	2.600 mm	1.00
2.00 mm	No. 10	0.0787	±0.070 mm	2.135 mm	2.215 mm	0.900
1.70 mm	No. 12[e]	0.0661	±0.060 mm	1.820 mm	1.890 mm	0.810
1.40 mm	No. 14	0.0555	±0.050 mm	1.505 mm	1.565 mm	0.725
1.18 mm	No. 16	0.0469	±0.045 mm	1.270 mm	1.330 mm	0.650
1.00 mm	No. 18	0.0394	±0.040 mm	1.080 mm	1.135 mm	0.580
850 µm[f]	No. 20	0.0331	±35 µm	925 µm	970 µm	0.510
710 µm	No. 25	0.0278	±30 µm	775 µm	815 µm	0.450
600 µm	No. 30	0.0234	±25 µm	660 µm	695 µm	0.390
500 µm	No. 35	0.0197	±20 µm	550 µm	585 µm	0.340
425 µm	No. 40	0.0165	±19 µm	471 µm	502 µm	0.290
355 µm	No. 45	0.0139	±16 µm	396 µm	425 µm	0.247
300 µm	No. 50	0.0117	±14 µm	337 µm	363 µm	0.215
250 µm	No. 60	0.0098	±12 µm	283 µm	306 µm	0.180
212 µm	No. 70	0.0083	±10 µm	242 µm	263 µm	0.152
180 µm	No. 80	0.0070	±9 µm	207 µm	227 µm	0.131
150 µm	No. 100	0.0059	±8 µm	174 µm	192 µm	0.110
125 µm	No. 120	0.0049	±7 µm	147 µm	163 µm	0.091
106 µm	No. 140	0.0041	±6 µm	126 µm	141 µm	0.076
90 µm	No. 170	0.0035	±5 µm	108 µm	122 µm	0.064
75 µm	No. 200	0.0029	±5 µm	91 µm	103 µm	0.053
63 µm	No. 230	0.0025	±4 µm	77 µm	89 µm	0.044
53 µm	No. 270	0.0021	±4 µm	66 µm	76 µm	0.037
45 µm	No. 325	0.0017	±3 µm	57 µm	66 µm	0.030
38 µm	No. 400	0.0015	±3 µm	48 µm	57 µm	0.025

[a] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following:

Sieves coarser than 600 µm	5 %
Sieves 600 to 125 µm	7½ %
Sieves finer than 125 µm	10 %

[b] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[c] Only approximately equivalent to the metric values in Column 1.

[d] These sieves are not in the standard series but they have been included because they are in common usage.

[e] These numbers (3½ to 400) are the approximate number of openings per linear inch but it is preferred that the sieve be identified by the standard designation in millimeters or µm.

[f] 1000 µm = 1 mm.

Table X1.2. - Nominal dimensions, permissible variations, and ranges for perforated plate in standard sieves [ASTM E 323].

Sieve Designation and Aperture Size^{A}		Maximum Variation of Aperture Size^{C}	Centers			Plate Thickness			
			Preferred		Permissible Range^{D}	Preferred			Permissible Range
Standard^{B}	Alternative		Standard	Alternative		Standard	Alternative		
mm	in.^{E}	mm	mm	in.^{E}	mm	mm	in.^{E}	gage^{F}	mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
125	5	±1.0	160	6¼	144 to 184	3.4	0.1345	10	2.5 to 4.0
106	4¼	±0.9	135	5¼	122 to 155	3.4	0.1345	10	2.5 to 4.0
100^{G}	4	±0.9	128	5	115 to 147	3.4	0.1345	10	2.5 to 4.0
90	3½	±0.8	111	4⅜	100 to 128	2.7	0.1046	12	2.5 to 4.0
75	3	±0.7	95	3¾	86 to 109	2.7	0.1046	12	2.5 to 4.0
63	2½	±0.6	80	3⅛	72 to 92	2.7	0.1046	12	2.5 to 4.0
53	2⅛	±0.6	68	2⅝	61 to 78	2.7	0.1046	12	2.5 to 4.0
50^{G}	2	±0.5	64	2½	58 to 73	2.7	0.1046	12	2.5 to 4.0
45	1¾	±0.5	57	2¼	51 to 65	1.9	0.0747	14	1.5 to 2.5
37.5	1½	±0.4	48	1⅞	43 to 55	1.9	0.0747	14	1.5 to 2.5
31.5	1¼	±0.4	41	1⅝	37 to 47	1.9	0.0747	14	1.5 to 2.5
26.5	1 1/16	±0.4	35	1 5/16	31 to 40	1.9	0.0747	14	1.5 to 2.5
25.0^{G}	1	±0.4	32	1¼	29 to 37	1.9	0.0747	14	1.5 to 2.5
22.4	⅞	±0.3	29	1⅛	26 to 33	1.9	0.0747	14	1.5 to 2.5
19.0	¾	±0.3	25	1	22 to 29	1.9	0.0747	14	1.5 to 2.5
16.0	⅝	±0.27	21	13/16	19 to 24	1.9	0.0747	14	1.5 to 2.5
13.2	17/32	±0.25	18	¾	16 to 20	1.9	0.0747	14	1.0 to 2.0
12.5^{G}	½	±0.24	17	11/16	15 to 20	1.9	0.0747	14	1.0 to 2.0
11.2	7/16	±0.23	15	⅝	13 to 17	1.9	0.0747	14	1.0 to 2.0
9.5	⅜	±0.20	13.0	½	11.3 to 14.9	1.9	0.0747	14	1.0 to 2.0
8.0	5/16	±0.19	11.0	7/16	9.5 to 12.6	1.9	0.0747	14	1.0 to 2.0
6.7	17/64	±0.17	9.9	25/64	8.3 to 11.4	1.5	0.0598	16	0.8 to 1.5
6.3^{G}	¼	±0.16	9.5	⅜	8.0 to 10.9	1.5	0.0598	16	0.8 to 1.5
5.6	7/32	±0.15	8.7	11/32	7.2 to 10.0	1.5	0.0598	16	0.8 to 1.5
4.75	3/16	±0.14	6.8	¼	5.8 to 7.8	1.5	0.0598	16	0.8 to 1.5
4.00	5/32	±0.13	5.9	7/32	5.0 to 6.8	1.5	0.0598	16	0.8 to 1.5
3.35	0.127(⅛)	±0.12	4.9	3/16	4.2 to 5.7	1.5	0.0598	16	0.8 to 1.5
2.80	7/64	±0.11	4.4	11/64	3.7 to 5.1	1.5	0.0598	16	0.8 to 1.5
2.36	3/62	±0.10	3.8	5/32	3.2 to 4.4	1.5	0.0598	16	0.8 to 1.5
2.00	0.078	±0.09	3.3	⅛	2.8 to 3.8	1.5	0.0598	16	0.8 to 1.5
1.70	0.066	±0.08	2.9	7/64	2.5 to 3.3	0.8	0.0299	22	0.4 to 0.8
1.40	0.055	±0.08	2.6	0.100	2.2 to 3.0	0.8	0.0299	22	0.4 to 0.8
1.18	0.045	±0.07	2.2	0.090	1.9 to 2.5	0.8	0.0299	22	0.4 to 0.8
1.00	0.039	±0.07	2.0	0.077	1.7 to 2.3	0.8	0.0299	22	0.4 to 0.8

[A] The values shown in this table refer to both round and square apertures. In general, square-aperture perforated-sieve plates are available only in 3.35 mm and larger.

[B] These standard designations, progressing from a base of 1 mm in the ratio of approximately $\sqrt[4]{2}$ to 1, correspond to the values for test sieve apertures recommended by the International Organization for Standardization, Geneva, Switzerland.

[C] This permissible variation applies to both the standard aperture sizes and the alternative aperture sizes.

[D] A range of ±15 % is allowed except that in no case shall the minimum bridge (bar between apertures) be less than one half of the difference between the nominal aperture and the preferred center.

[E] Only approximately equivalent to the standard values.

[F] The gage values are for carbon steel. For other materials, the gage used should be the nearest decimal equivalent of the U.S. standard gage for steel.

[G] These sieves are not in the standard series but they have been included because they are in common usage.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1030-89

PROCEDURE FOR

CALIBRATING SPECIFIC GRAVITY FLASKS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The calibration procedure is issued under the fixed designation USBR 1030. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating specific gravity flasks used for determining the specific gravity of soils as performed in accordance with USBR 5320 (method A).

2. Applicable Documents

2.1 *USBR Procedures*:
USBR 1012 Calibrating Balances or Scales
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5320 Determining Specific Gravity of Soils
2.2 *ASTM Standards*:
D 854 Standard Method for Specific Gravity of Soils
E1 ASTM Thermometers

3. Summary of Method

3.1 The mass of a dry, clean specific gravity flask is determined and recorded. The flask is filled with distilled water to the graduation line on the neck of the flask. A vacuum is applied to the flask until all entrapped air is removed. The mass of the flask and water, temperature of the water, and volume of the flask are determined and recorded.

4. Significance and Use

4.1 Specific gravity (volumetric) flasks are used to determine the apparent specific gravity of soils composed of material passing the U.S.A. Standard series No. 4 (4.75-mm) sieve. Accurate calibration of the mass and volume of the flask is necessary to obtain a reliable value of soil specific gravity.

4.2 The procedure described results in a flask calibration that may be used to determine the specific gravity of a specimen of any suitable mass.

4.3 The calibration procedure is to be performed upon receipt of the flask.

5. Terminology

5.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

5.1.1 *Apparent Specific Gravity.*–G_a, ratio of: (1) the mass in air of a given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature, to (2) the mass in air of an equal volume of distilled water at a stated temperature (ASTM definition).

5.1.2 *Specific Gravity of Solids.*–G_s, ratio of: (1) the mass in air of a given volume of solids at a stated temperature, to (2) the mass in air of an equal volume of distilled water at a stated temperature (ASTM).

6. Apparatus

6.1 *Balance or Scale.*–A typical balance or scale used for this designation must be readable to 0.01 g and have a capacity of about 500 g.

6.2 *Specific Gravity Flask* (fig. 1).–A flask having a capacity of 250 mL or larger.

6.3 *Vacuum Pump.*–A vacuum pump (motorized or hand-held) capable of applying a vacuum of at least 10 inches (250 mm) of mercury to the specific gravity flask.

6.4 *Flexible Tubing.*–Noncollapsible flexible tubing sufficient for connecting the vacuum pump to a rubber stopper which fits the specific gravity flask.

6.5 *Thermometer.*– 0.5 °C divisions conforming to the requirements of ASTM E 1.

6.6 Water bulb with stem.

6.7 *Water Bath.*–A water bath for maintaining the specific gravity flask and contents at a constant temperature during the calibration procedure. The water bath is not mandatory but is recommended to minimize effects of density variations of the water from room temperature fluctuations.

6.8 Cotton swabs.

7. Reagents and Materials

7.1 Distilled water is to be used for determining the volume of the specific gravity flask.

8. Precautions

8.1 *Safety Precautions*:

8.1.1 Ensure that the water bath and vacuum pump power cords are in good condition and are properly grounded.

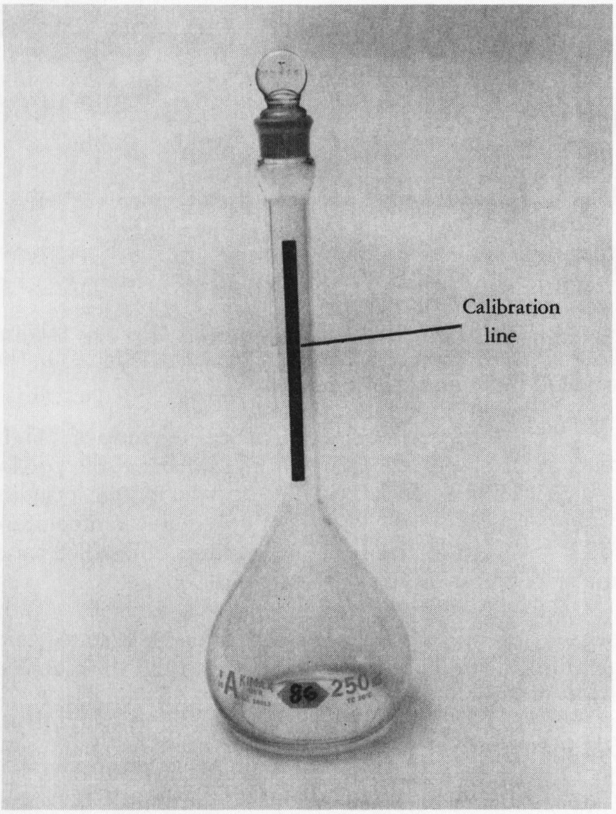


Figure 1. - Specific gravity flask.

8.1.2 Check the condition of the specific gravity flasks to ensure there are no chipped or sharp edges or cracks.

8.2 *Technical Precautions.*–Ensure that the graduation line on the flask is clearly inscribed on the flask neck.

9. Calibration and Standardization

9.1 Verify that the balance or scale used is currently calibrated in accordance with USBR 1012. If the calibration is not current, perform the calibration before using the balance or scale for this procedure.

10. Conditioning

10.1 Perform this calibration in an area isolated from excessive heat sources or air currents and is maintained at or near room temperature of 68 °F (20 °C).

10.2 The specific gravity flasks and water bath should be placed in the environment in which they are to be calibrated for a period of at least 24 hours before calibration.

11. Procedure

11.1 All data are to be recorded on the "Specific Gravity Flask Calibration (Volume Method)" form as shown on figure 2.

11.2 Record the identification number of the specific gravity flask to be calibrated.

11.3 Determine the mass of the clean, dry specific gravity flask to the nearest 0.01 gram and record.

11.4 Fill the flask with distilled water until the bottom of the meniscus is even with the reference mark (calibration line) on the neck of the flask as shown on figure 1.

11.5 Place the water-filled flask in the constant temperature water bath and securely place a rubber stopper on the top of the flask.

11.6 Apply a vacuum by connecting the vacuum source with appropriate tubing to the flask to remove all entrapped air.

11.7 Gently roll the flask occasionally to aid in removal of air.

11.8 Leave the flask in the water bath, with the vacuum applied, until there are no visible air bubbles.

11.9 Release the vacuum and remove the flask from the water bath. If the water level has fallen below the reference mark, the water bulb with stem is to be used to replace the distilled water precisely up to the mark.

11.10 With a towel, dry the outside of the flask and use a cotton swab to dry the inside neck of the flask above the reference mark.

11.11 Determine and record the mass of the water-filled flask to the nearest 0.01 gram.

11.12 Immediately after determining the mass of the water-filled flask, gently shake the flask and insert the thermometer to middepth.

11.13 Determine and record the temperature of the water to the nearest 0.5 °C.

11.14 Calculate and record the volume of the specific gravity flask to the nearest 0.01 cm^3.

11.15 Repeat subparagraphs 11.3 through 11.14 to obtain a second trial.

11.16 The difference between the two trials must be 0.1 cm^3 or less. If this is not the case, the procedure is to be repeated until two consecutive values are within 0.1 cm^3 of each other.

11.17 Calculate and record the average flask volume to the nearest 0.01 cm^3.

12. Calculations

12.1 Calculate the volume of the specific gravity flask using the expression:

$$(7) = \frac{(5)}{(6)}$$

where:

(7) = volume of flask, cm^3
(5) = (3) - (2) is the mass of water, g
(3) = mass of flask filled with water, g
(2) = mass of flask, g
(6) = absolute density of water at temperature (table 1), g/cm^3

13. Report

13.1 The report is to consist of a completed and checked "Specific Gravity Flask Calibration (Volume Method)" form (fig. 2).

13.2 All calculations are to show a checkmark.

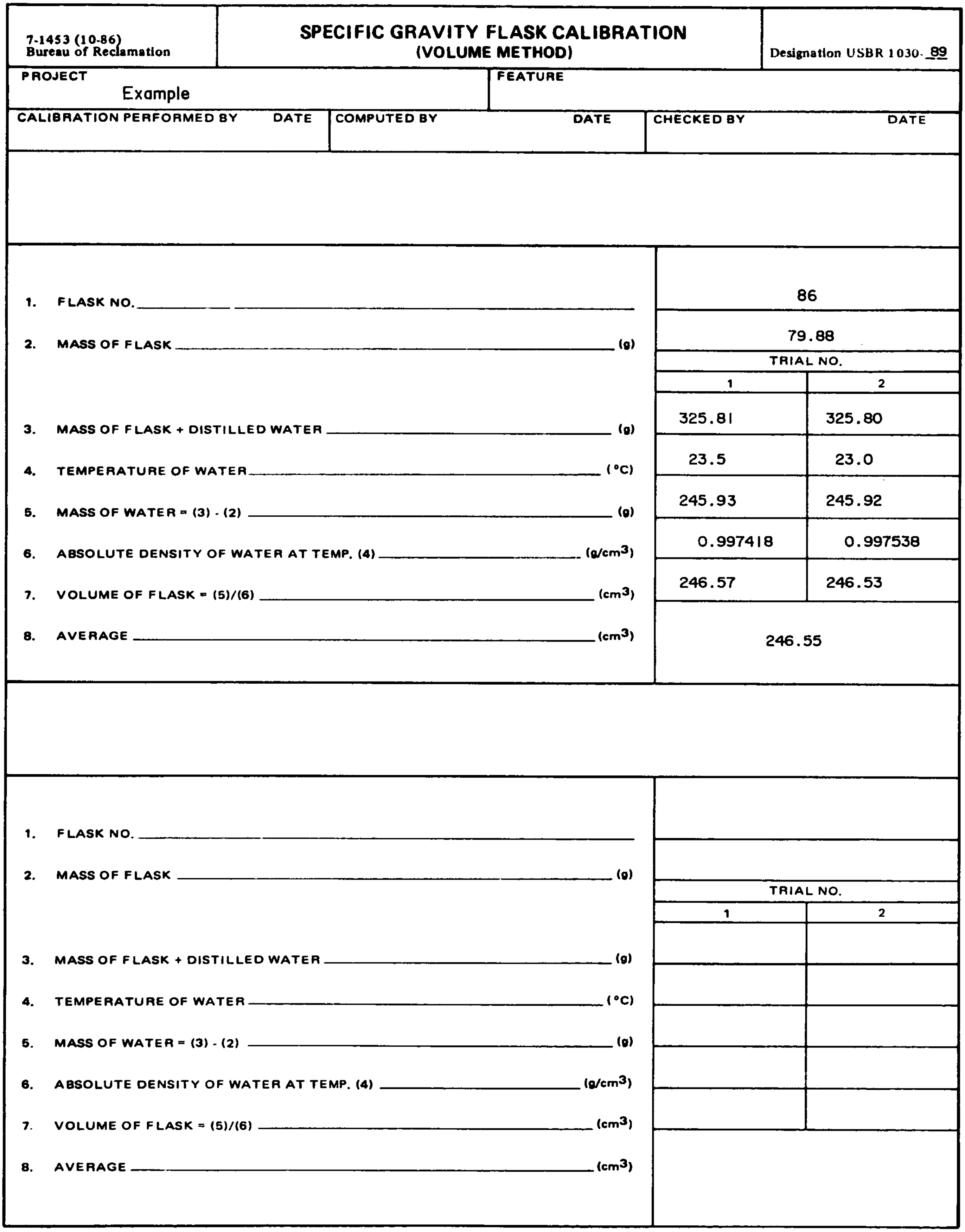
13.3 A permanent record should be made for each specific gravity flask used in the laboratory.

Table 1. – Absolute density of water in grams per cubic centimeter.†

Degrees C	0	1	2	3	4	5	6	7	8	9
0	0.999841	847	854	860	866	872	878	884	889	895
1	900	905	909	914	918	923	927	930	934	938
2	941	944	947	950	953	955	958	960	962	964
3	965	967	968	969	970	971	972	972	973	973
4	973	973	973	972	972	972	970	969	968	966
5	965	963	961	959	957	955	952	950	947	944
6	941	938	935	931	927	924	920	916	911	907
7	902	898	893	888	883	877	872	866	861	855
8	849	843	837	830	824	817	810	803	796	789
9	781	774	766	758	751	742	734	726	717	709
10	700	691	682	673	664	654	645	635	625	615
11	605	595	585	574	564	553	542	531	520	509
12	498	486	475	463	451	439	427	415	402	390
13	377	364	352	339	326	312	299	285	272	258
14	244	230	216	202	188	173	159	144	129	114
15	099	084	069	054	038	023	007	*991	*975	*959
16	0.998943	926	910	893	877	860	843	826	809	792
17	774	757	739	722	704	686	668	650	632	613
18	595	576	558	539	520	501	482	463	444	424
19	405	385	365	345	325	305	285	265	244	224
20	203	183	162	141	120	099	078	056	035	013
21	0.997992	970	948	926	904	882	860	837	815	792
22	770	747	724	701	678	655	632	608	585	561
23	538	514	490	466	442	418	394	369	345	320
24	296	271	246	221	196	171	146	120	095	069
25	044	018	*992	*967	*941	*914	*888	*862	*836	*809
26	0.996783	756	729	703	676	649	621	594	567	540
27	512	485	457	429	401	373	345	317	289	261
28	232	204	175	147	118	089	060	031	002	*973
29	0.995944	914	885	855	826	796	766	736	706	676
30	646	616	586	555	525	494	464	433	402	371

† For inch-pound applications, multiply the values in this table by 62.4280 to convert to lbm/ft^3.

* First three significant figures shown in line below.



7-1453 (10-86)
Bureau of Reclamation

SPECIFIC GRAVITY FLASK CALIBRATION
(VOLUME METHOD)

Designation USBR 1030-89

PROJECT Example	FEATURE

CALIBRATION PERFORMED BY DATE	COMPUTED BY DATE	CHECKED BY DATE

1. FLASK NO.	86	
2. MASS OF FLASK (g)	79.88	
	TRIAL NO.	
	1	2
3. MASS OF FLASK + DISTILLED WATER (g)	325.81	325.80
4. TEMPERATURE OF WATER (°C)	23.5	23.0
5. MASS OF WATER = (3) - (2) (g)	245.93	245.92
6. ABSOLUTE DENSITY OF WATER AT TEMP. (4) (g/cm^3)	0.997418	0.997538
7. VOLUME OF FLASK = (5)/(6) (cm^3)	246.57	246.53
8. AVERAGE (cm^3)	246.55	

1. FLASK NO.		
2. MASS OF FLASK (g)		
	TRIAL NO.	
	1	2
3. MASS OF FLASK + DISTILLED WATER (g)		
4. TEMPERATURE OF WATER (°C)		
5. MASS OF WATER = (3) - (2) (g)		
6. ABSOLUTE DENSITY OF WATER AT TEMP. (4) (g/cm^3)		
7. VOLUME OF FLASK = (5)/(6) (cm^3)		
8. AVERAGE (cm^3)		

GPO 854 - 192

Figure 2. – Specific gravity flask calibration (volume method) — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1040-89

PROCEDURE FOR
CALIBRATING PRESSURE GAUGES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1040. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating pressure gauges used for standard laboratory testing. It is recommended that any adjustments to a pressure gauge be made only by experienced personnel or the manufacturer.

1.2 This calibration procedure is limited to pressure gauges as classified in Federal Specification GG-G-76E.

2. Applicable Documents

2.1 American National Standard, ANSI B40.1-1980, Gauges-Pressure Indicating Dial Type — Elastic Element

2.2 Federal Specification GG-G-76E, Gauges, Pressure, and Vacuum, Dial Indicating, 1981

3. Summary of Method

3.1 A master gauge is calibrated using a primary pressure standard (see subpar. 9.2, figs. 1 and 3a). The pressure gauge to be calibrated is connected to the master gauge as shown on figure 3b. Pressure is applied to the pressure gauge at predetermined pressure increments over its full operating range. The value indicated by the pressure gauge is compared to the corresponding value indicated by the master gauge at each pressure increment. The percent error between the two values is calculated and the gauge is adjusted as necessary.

4. Significance and Use

4.1 Pressure gauges used in the laboratory must be calibrated to ensure reliable test results.

4.2 This calibration procedure is to be performed upon receipt of a pressure gauge and annually thereafter.

5. Apparatus

5.1 *Pressure Gauge.*-A pressure gauge meeting requirements of Federal Specification GG-G-76E and the American National Standard ANSI B40.1-1980.

5.2 *Primary Pressure Standard* (fig. 1).-A high accuracy, deadweight tester designed for precision measurement of applied gas pressure. The device consists of a weighted piston which becomes suspended in static equilibrium when a prescribed gas pressure is introduced. Calibrated masses are used for a range of pressures.

5.3 *Tubing.*-High-pressure tubing of appropriate size and length to connect pressure gauges and the primary pressure standard to the pressure source.

5.4 *Pressure Regulator.*-A pressure regulator capable of maintaining the desired pressure to the gauges and primary pressure standard.

5.5 *Valves.*-Appropriate size valves, two required; bleed and pressure cutoff.

6. Precautions

6.1 *Safety Precautions.*-Safety glasses are to be worn when applying pressure to the gauges.

7. Calibration and Standardization

7.1 Verify that the primary pressure standard has been currently calibrated in accordance with manufacturer specifications. If the calibration is not current, it is to be performed before using the primary pressure standard for this calibration procedure.

8. Conditioning

8.1 Not applicable; special conditioning requirements are not needed for this procedure.

9. Procedure

9.1 All data are to be recorded on the "Pressure Gauge Calibration" form as shown on figure 2.

9.2 *Master Gauge Calibration*:

9.2.1 Connect the master gauge to the primary pressure standard and pressure source as shown on figure 3a.

9.2.2 Apply pressure to the master gauge in increments (a minimum of five) over the full range of the master gauge.

9.2.3 Record the value of pressure indicated by the primary pressure standard and the corresponding value of pressure indicated by the master gauge for each pressure increment.

9.2.4 Compute the percent error for each pressure increment and compare the values obtained with permissible error values in table 1.

9.2.5 Adjust the master gauge if necessary (see subpar. 1.1) and repeat subparagraphs 9.2.2 through 9.2.4

Figure 1. – Primary pressure standard.

until the calculated percent error is within the permissible range specified in table 1.

9.2.6 After three trials, if the percent error values calculated for the master gauge are not within those shown in table 1, a new master gauge should be obtained and calibrated in accordance with subparagraph 9.2.

9.3 *Gauge Calibration*:

9.3.1 Connect the gauge to be calibrated to the master gauge and pressure source as shown on figure 3b.

9.3.2 Apply pressure to the gauge to be calibrated in increments (a minimum of five) over the full range of the gauge.

9.3.3 Record the value of pressure indicated by the master gauge and the corresponding value of pressure indicated by the gauge being calibrated for each pressure increment.

9.3.4 Compute the percent error for each pressure increment and compare the values obtained with permissible error values in table 1.

9.3.5 Adjust the gauge if necessary (see subpar. 1.1) and repeat subparagraphs 9.3.2 through 9.3.4 until the calculated percent error values are within the permissible ranges specified in table 1.

9.3.6 After three trials, if the percent error values calculated for the gauge are not within those shown in table 1, the gauge should be rejected for laboratory use.

Table 1. – Pressure gauge accuracy grades.[1]

Accuracy grade[2]	Permissible error, percent of span Lower one-fourth of scale	 Middle one-half of scale	 Upper one-fourth of scale
4A	0.1	0.1	0.1
3A	0.25	0.25	0.25
2A	0.5	0.5	0.5
A	2.0	1.0	2.0
B	3.0	2.0	3.0
C	4.0	3.0	4.0
D	5.0	5.0	5.0

[1] Table taken from ANSI B40.1-1980.

[2] Accuracy grade is specified by the manufacturer. An accuracy grade of 3A generally is suitable for most geotechnical laboratory testing applications.

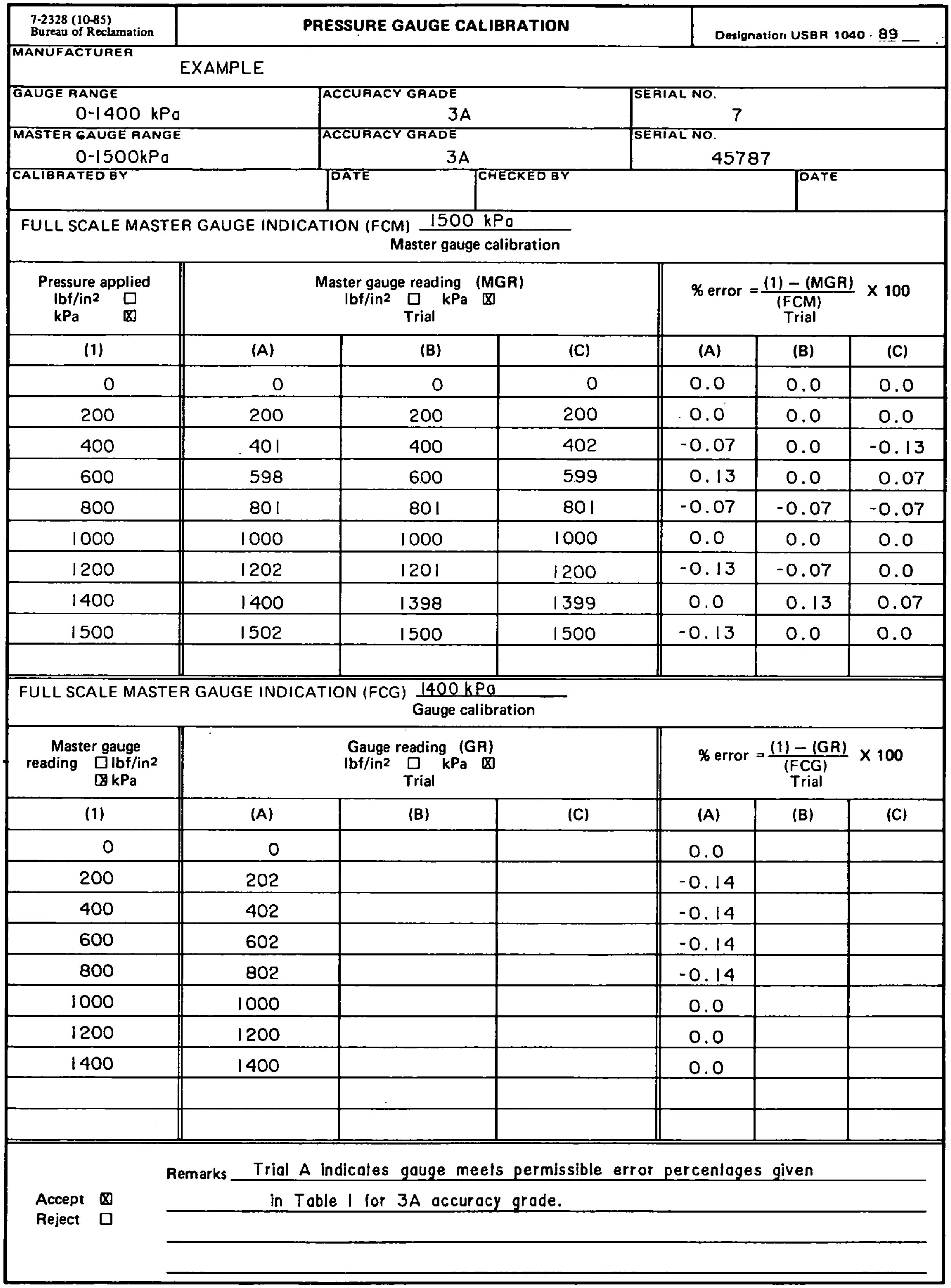
10. Calculations

10.1 Calculations required are as shown on figure 2.

11. Report

11.1 The report is to consist of a completed and checked "Pressure Gauge Calibration" form (fig. 2).

11.2 All calculations are to show a checkmark.



7-2328 (10-85) Bureau of Reclamation	**PRESSURE GAUGE CALIBRATION**	Designation USBR 1040 - 89

MANUFACTURER EXAMPLE

GAUGE RANGE 0-1400 kPa	ACCURACY GRADE 3A	SERIAL NO. 7
MASTER GAUGE RANGE 0-1500kPa	ACCURACY GRADE 3A	SERIAL NO. 45787

CALIBRATED BY	DATE	CHECKED BY	DATE

FULL SCALE MASTER GAUGE INDICATION (FCM) 1500 kPa

Master gauge calibration

Pressure applied lbf/in² ☐ kPa ☒	Master gauge reading (MGR) lbf/in² ☐ kPa ☒ Trial			% error = $\frac{(1)-(MGR)}{(FCM)}$ X 100 Trial		
(1)	(A)	(B)	(C)	(A)	(B)	(C)
0	0	0	0	0.0	0.0	0.0
200	200	200	200	0.0	0.0	0.0
400	401	400	402	-0.07	0.0	-0.13
600	598	600	599	0.13	0.0	0.07
800	801	801	801	-0.07	-0.07	-0.07
1000	1000	1000	1000	0.0	0.0	0.0
1200	1202	1201	1200	-0.13	-0.07	0.0
1400	1400	1398	1399	0.0	0.13	0.07
1500	1502	1500	1500	-0.13	0.0	0.0

FULL SCALE MASTER GAUGE INDICATION (FCG) 1400 kPa

Gauge calibration

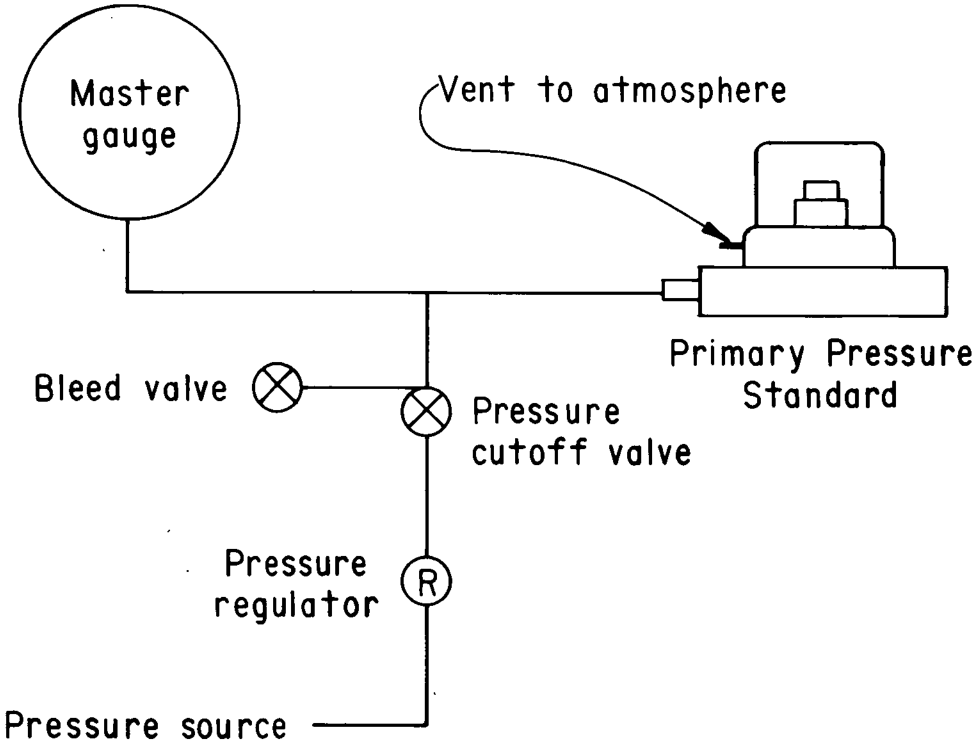
Master gauge reading ☐ lbf/in² ☒ kPa	Gauge reading (GR) lbf/in² ☐ kPa ☒ Trial			% error = $\frac{(1)-(GR)}{(FCG)}$ X 100 Trial		
(1)	(A)	(B)	(C)	(A)	(B)	(C)
0	0			0.0		
200	202			-0.14		
400	402			-0.14		
600	602			-0.14		
800	802			-0.14		
1000	1000			0.0		
1200	1200			0.0		
1400	1400			0.0		

Accept ☒
Reject ☐

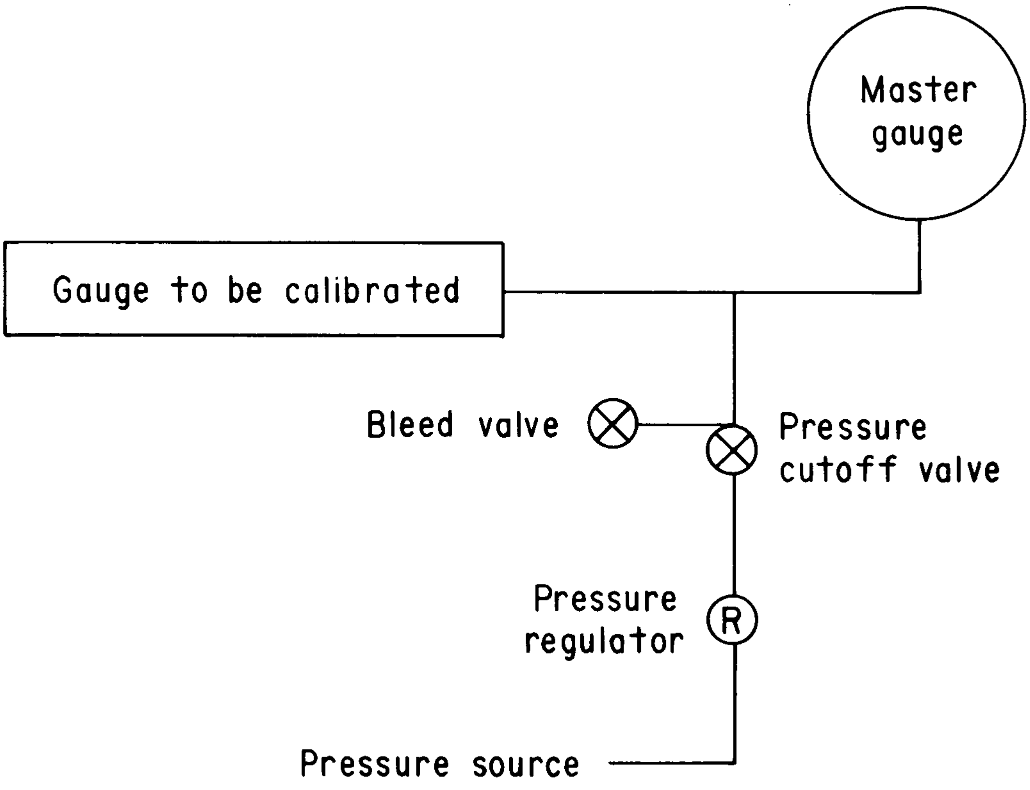
Remarks Trial A indicates gauge meets permissible error percentages given in Table 1 for 3A accuracy grade.

GPO 849-232

Figure 2. - Pressure gauge calibration — example.



(a) Schematic of master gauge calibration



(b) Schematic of gauge calibration

Figure 3. – Schematics of calibration assemblies.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1405-89

PROCEDURE FOR
CALIBRATING HYDROMETERS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1405. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating the hydrometer used for gradation analysis of soils as performed in accordance with USBR 5330.

1.2 This calibration procedure is used to determine the hydrometer correction to compensate for the temperature of the water and the type of dispersing agent used.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR 1012 Calibrating Balances or Scales
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5330 Performing Gradation Analysis of Fines and Sand Size Fraction of Soils, Including Hydrometer Analysis

2.2 *ASTM Standards*:

E 1 ASTM Thermometers
E 100 Specification for ASTM Hydrometers

3. Summary of Method

3.1 A hydrometer cylinder is filled with either distilled water or a sodium hexametaphosphate solution of given concentration and is placed in a water bath. A hydrometer is placed into the cylinder and sufficient time is allowed for the hydrometer, hydrometer cylinder, cylinder fluid, and water bath to reach a temperature equilibrium. Hydrometer readings are taken at temperatures spanning the range of expected test temperatures, and corrections for intermediate temperatures are calculated.

4. Significance and Use

4.1 Soil hydrometers are used in gradation analysis of soils to determine the distribution of particles smaller than the U.S.A. Standard series No. 200 (75-μm) sieve. The ASTM soil hydrometers used by the Bureau are marked to read in grams of soil in suspension per liter of mixture of soil and distilled water at 20 °C. Since the temperature of the water used in the test may not be exactly 20 °C and because either distilled water or a solution of distilled water and dispersing agent is used, it is necessary to prepare hydrometer correction charts to compensate for the effects of temperature variation and dispersing agent. The hydrometer corrections are subtracted from the hydrometer readings obtained during the gradation analysis test to give a corrected hydrometer reading.

4.2 The hydrometer correction values obtained from this procedure are unique to the individual hydrometer, dispersing agent, percent solution of the agent, and temperature range in which the calibration procedure is performed. If any one of these is changed, new individual hydrometer correction values must be obtained.

4.3 This calibration procedure is to be performed upon receipt of the hydrometer as an acceptance check.

4.4 The hydrometer zero reading (see subpar. 10.2) must be checked upon receipt of the hydrometer and annually thereafter or anytime hydrometer readings are suspect.

5. Terminology

5.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

5.1.1 *Dispersing Agent*.–An agent used to assist in separating individual fine soil particles and to prevent them from flocculating when in suspension.

5.1.2 *Gradation Analysis*.–The process of determining gradation (ASTM definition).

6. Apparatus

6.1 *Soil Hydrometer*.–An ASTM soil hydrometer, graduated to read in grams per liter of suspension and conforming to the requirements for hydrometer 152H in ASTM E 100.

6.2 *Hydrometer Cylinder*.–A glass cylinder essentially 18 inches in height and 2-1/2 inches in diameter (457 by 64 mm) and marked for a volume of 1000 mL. The inside diameter is to be such that the 1000-mL mark is 14±1 inch (355±25 mm) from the bottom on the inside.

6.3 *Stirring Apparatus* (malt mixer).–A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 revolutions per minute without load. The shaft should be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber. The shaft is to be of such a length that the stirring paddle will operate not less than 1-1/2 inches (38 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown on figure 1 should be provided.

6.4 *Thermometer.*-0 to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

6.5 *Balance or Scale.*-A typical balance or scale used for this designation must be readable to 0.1 g and have a capacity of about 500 g.

6.6 *Rubber Stopper.*-An appropriate size rubber stopper to adequately seal the hydrometer cylinder.

6.7 *Water Bath.*-An automatic temperature-controlled water tank or an insulated container large enough to hold the hydrometer cylinder is required. It is important that the water bath, hydrometer, and the hydrometer cylinder and its contents be maintained at a constant temperature for each hydrometer reading.

6.8 *Sodium Hexametaphosphate.*-A chemical agent in powder, crystal, or granular form, used as a dispersing agent.

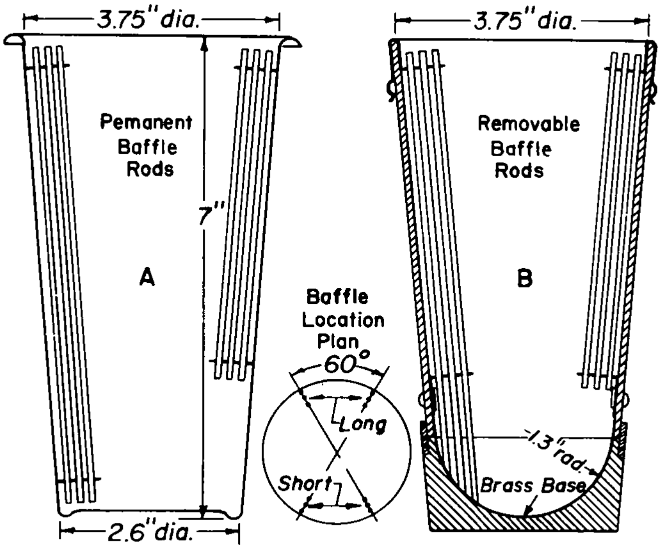
6.9 *Graduated Cylinder.*-1000 mL capacity, graduated to 10 mL.

6.10 *Graduated Cylinder.*-250 mL capacity, graduated to 2 mL or other suitable container or method to measure 125 mL of the dispersing agent solution.

7. Reagents and Materials

7.1 Distilled water is to be used for obtaining hydrometer corrections for gradation analysis that will be performed using distilled water as the fluid medium.

7.2 A sodium hexametaphosphate and distilled water solution is to be used for obtaining hydrometer corrections for gradation analysis that will be performed using sodium hexametaphosphate as a dispersing agent.



Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

Figure 1. - Dispersion cup designs [ASTM D 422].

7.3 In general, a 4-percent solution of sodium hexametaphosphate is used in performing the calibration procedure stated in subparagraph 7.2 (see subpar. 7.4 for preparing 8 and 12 percent solutions). To prepare a 4-percent solution, the following procedure is to be followed:

7.3.1 Fill a 1000-mL graduated cylinder with distilled water to approximately 750 mL.

7.3.2 Obtain 40 grams of reagent grade or better sodium hexametaphosphate and place it into the dispersion cup. Add approximately 100 mL of distilled water to the sodium hexametaphosphate. Mix the sodium hexametaphosphate and water using the malt mixer until the sodium hexametaphosphate is dissolved. To dissolve the sodium hexametaphosphate into solution typically requires approximately 5 minutes of mixing in the malt mixer.

7.3.3 Add the solution from the dispersion cup to the graduated cylinder. Fill the graduated cylinder to the 1000-mL line with distilled water. Take the rubber stopper and securely place it on top of the graduated cylinder. With one hand over the top of the graduated cylinder and the other on the bottom, shake the graduated cylinder to thoroughly mix the solution.

7.4 In some circumstances, an 8- or 12-percent solution may be desired as a dispersing agent. The following amounts of sodium hexametaphosphate are to be used for the desired percent solution of sodium hexametaphosphate:

Solution desired, %	*Sodium hexametaphosphate required, g*
4	40
8	80
12	120

7.5 If an 8- or 12-percent solution is desired, the procedure outlined in subparagraph 7.3 is to be used along with the appropriate amount of sodium hexametaphosphate as given in subparagraph 7.4.

7.6 A prepared sodium hexametaphosphate dispersing solution may be stored for no more than 21 days if the storage temperature remains near room temperature (73 °F), and for no more than 7 days if the temperature of the storage area consistently exceeds 73 °F.

7.7 All containers of the dispersing solution must have the date of preparation and percent solution marked on them.

8. Precautions

8.1 *Technical Precautions*:

8.1.1 Sufficient time should be allowed for the hydrometer and liquids to reach a temperature equilibrium. Usually 30 minutes are required for the hydrometer to each equilibrium after the liquids have attained the desired temperature.

8.1.2 Because sodium hexametaphosphate in powder, granular, or crystalline form absorbs moisture, the material must be stored in airtight containers.

9. Preparation of Apparatus

9.1 The hydrometer is to be cleaned, especially the reading portion of the stem, by washing the hydrometer with soapy water and then rinsing it with alcohol and again in clean water.

10. Calibration and Standardization

10.1 Verify that the balance or scale used is currently calibrated in accordance with USBR 1012. If the calibration is not current, perform the calibration before using the balance or scale for this procedure.

10.2 *Hydrometer Zero Reading Check*.-The zero reading must be checked upon receipt of the hydrometer and annually thereafter or anytime hydrometer readings are suspect.

10.2.1 Fill a clean hydrometer cylinder to the calibration mark with 1 liter of distilled water.

10.2.2 Prepare a water bath at 20 °C and place the hydrometer cylinder and distilled water in the bath. Stir the water in the cylinder occasionally and allow sufficient time for the temperature of the water in the cylinder to come to equilibrium with the bath temperature.

10.2.3 Wash the hydrometer to be calibrated with soap and distilled water and clean the neck with alcohol. Rinse the hydrometer in distilled water and dry it with a clean towel.

10.2.4 Place the hydrometer in the cylinder and allow adequate time for the temperature of the hydrometer and water to stabilize.

10.2.5 Take the reading of the hydrometer at the top of the meniscus (see note 1) to the nearest 0.5 unit and record as shown on figure 2. This reading should be between +0.5 and -1.5. Insert the thermometer so that the tip is about 8 inches (200 mm) into the hydrometer cylinder, and check that the water temperature has remained at 20 °C. The thermometer should be read to the nearest 0.5 °C.

NOTE 1.-Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top. By calibrating the hydrometer, using the top of the meniscus, this correction is automatically accounted.

10.2.6 If the hydrometer reading does not fall within the required range, the hydrometer is to be rejected for laboratory use.

11. Conditioning

11.1 Perform this calibration procedure in an area where there will not be a large temperature fluctuation while performing the procedure.

12. Procedure

12.1 All data are to be recorded on the "Hydrometer Calibration for Gradation Analysis" form as shown on figure 2.

12.2 Locate and record the hydrometer number.

12.3 Record the type of and percent solution of dispersing agent to be used for the calibration procedure. This will either be distilled water or a solution of sodium hexametaphosphate, as described in subparagraph 7.3 or 7.4.

12.4 The hydrometer is calibrated by taking hydrometer readings at four different temperatures covering the range of expected test temperatures.

12.5 Adjust the temperature of the water bath to the lowest calibration temperature desired.

12.6 Place 125 mL of dispersing agent solution into the hydrometer cylinder.

12.7 Fill the hydrometer cylinder to 1000 mL with distilled water.

12.8 Apply a rubber stopper and securely place it on top of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the hydrometer cylinder bottom, shake the hydrometer cylinder until the dispersing agent and distilled water are thoroughly mixed.

12.9 Place the hydrometer cylinder into the water bath.

12.10 Dry the hydrometer, if necessary; carefully place the hydrometer into the hydrometer cylinder and wait at least 30 minutes to allow the temperature of the hydrometer, hydrometer cylinder, and liquids to equalize.

12.11 Record the temperature of the liquid in the hydrometer cylinder to the nearest 0.5 °C.

12.12 Determine and record the water level at the top of the meniscus on the hydrometer to the nearest 0.5 unit. If the water level is above the zero mark on the hydrometer, then the hydrometer correction is recorded as a negative value of that reading. If the water level is below the zero marking on the hydrometer, then the hydrometer correction is recorded as a positive value of that reading (see fig. 3).

12.13 Verify the hydrometer reading by removing the hydrometer, drying it, and replacing the hydrometer into the hydrometer cylinder. If the hydrometer readings are not the same, remove the hydrometer and repeat subparagraphs 12.10 through 12.12 until a reading can be verified.

12.14 Remove the hydrometer and elevate the temperature of the water bath to the next desired calibration temperature. Allow the temperatures of the water bath, the hydrometer cylinder, and the dispersing agent solution to equalize.

12.15 Repeat subparagraphs 12.10 through 12.14 until hydrometer readings at four different temperatures covering the range of expected test temperatures have been obtained and verified.

12.16 Determine the calibration equation.

12.16.1 Plot the temperature versus hydrometer reading data pairs on a graph similar to that shown on figure 4.

12.16.2 Draw a best-fit straight line through the plotted points (or perform a linear regression analysis and construct the resulting best-fit straight line on the graph).

12.16.3 Compare the data points to the straight line for acceptability.

12.16.3.1 All data points should plot within ±0.5 hydrometer unit of the straight line (or the correlation coefficient for the linear regression should be equal to or greater than ±0.95).

7-2309 (12-86) Bureau of Reclamation	**HYDROMETER CALIBRATION FOR GRADATION ANALYSIS**	Designation USBR 1405-89

HYDROMETER NO. 189	ZERO READING 0.5
DISPERSING AGENT Sodium Hexametaphosphate	PERCENT SOLUTION 4 %
CALIBRATION PERFORMED BY DATE	CHECKED BY DATE

CALIBRATION DATA

TEMPERATURE °C	HYDROMETER READING
18.0	6.5
21.0	5.5
25.0	4.0
28.0	3.0

DETERMINATION OF CALIBRATION EQUATION

SELECTED POINTS

TEMPERATURE °C	HYDROMETER READING
(1) 18.0	(3) 6.5
(2) 28.0	(4) 3.0

HYDROMETER CALIBRATION EQUATION

$\boxed{y = mx + b}$

(2) - (1) = 10.0 (A)
(4) - (3) = -3.5 (B)

$m = \frac{(B)}{(A)} = -0.35$

b = y - mx   b = (3) - (m)(1) = 12.8

CALIBRATION EQUATION y = -0.35(x)+12.8

GPO 852 - 933

Figure 2. – Hydrometer calibration for gradation analysis — example.

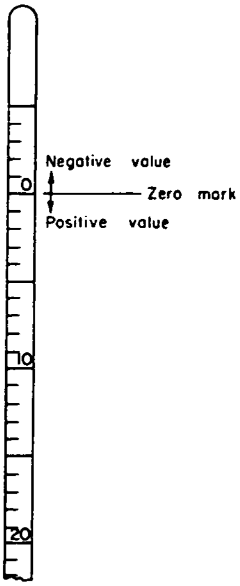


Figure 3. - Soil hydrometer stem sketch.

12.16.3.2 If the criteria in subparagraph 12.16.3.1 are not met, discard the data point that appears to be farthest from the straight line and repeat subparagraphs 12.16.1 through 12.16.3. If the criteria still cannot be met, the calibration procedure must be repeated until the criteria have been satisfied.

12.16.4 Determine and record the equation of the calibration line.

12.17 Use the calibration equation to obtain a table of temperature-hydrometer corrections as shown in table 1.

13. Calculations

13.1 Determine the linear equation of the hydrometer calibration line and calculate the hydrometer corrections for the temperature range calibrated.

13.2 Select the two data pairs closest to the straight line and calculate the equation of the straight line. The equation of the calibration line is determined in the form:

$$y = mx + b$$

where:

y = hydrometer correction
m = slope of line
x = temperature, °C
b = hydrometer correction intercept

13.3 The "Hydrometer Calibration for Gradation Analysis" form illustrates an example calculation of the slope of the calibration line, m, and the intercept, b.

13.4 Calculate hydrometer corrections using the calibration equation in subparagraph 13.2 and substituting the appropriate temperatures. The temperature range is generally between 18 and 28 °C, using 0.5 °C increments. These hydrometer corrections are to be rounded to the nearest 0.5 unit as shown in table 1 for the example calibration equation.

13.5 Calculation of the hydrometer corrections shown in table 1 is performed as follows:

$$y = -0.35\,x + 12.8 \quad \text{(Calibration equation, fig. 2)}$$

substitute 18 °C into the calibration equation:

$$y = -0.35\,(18.0) + 12.8$$
$$y = 6.5$$

Therefore, the hydrometer correction, y, (for the temperature of 18 °C) is recorded in the table as 6.5. This substitution procedure is continued for the entire temperature range calibrated.

14. Report

14.1 The report is to consist of the following completed and checked form, plot, and table:

"Hydrometer Calibration for Gradation Analysis" form (fig. 2).
Plot of calibration equation (fig. 4).
Table of hydrometer corrections (table 1).

14.2 All calculations are to show a checkmark and all plotting must be checked.

Table 1. - Hydrometer corrections.

Hydrometer number *189*
Dispersing agent *Sodium hexametaphosphate*
Percent solution *4%*
Calibration date
Computed by
Checked by

Temperature, °C	Hydrometer correction
18.0	6.5
18.5	6.5
19.0	6.0
19.5	6.0
20.0	6.0
20.5	5.5
21.0	5.5
21.5	5.5
22.0	5.0
22.5	5.0
23.0	5.0
23.5	4.5
24.0	4.5
24.5	4.0
25.0	4.0
25.5	4.0
26.0	3.5
26.5	3.5
27.0	3.5
27.5	3.0
28.0	3.0

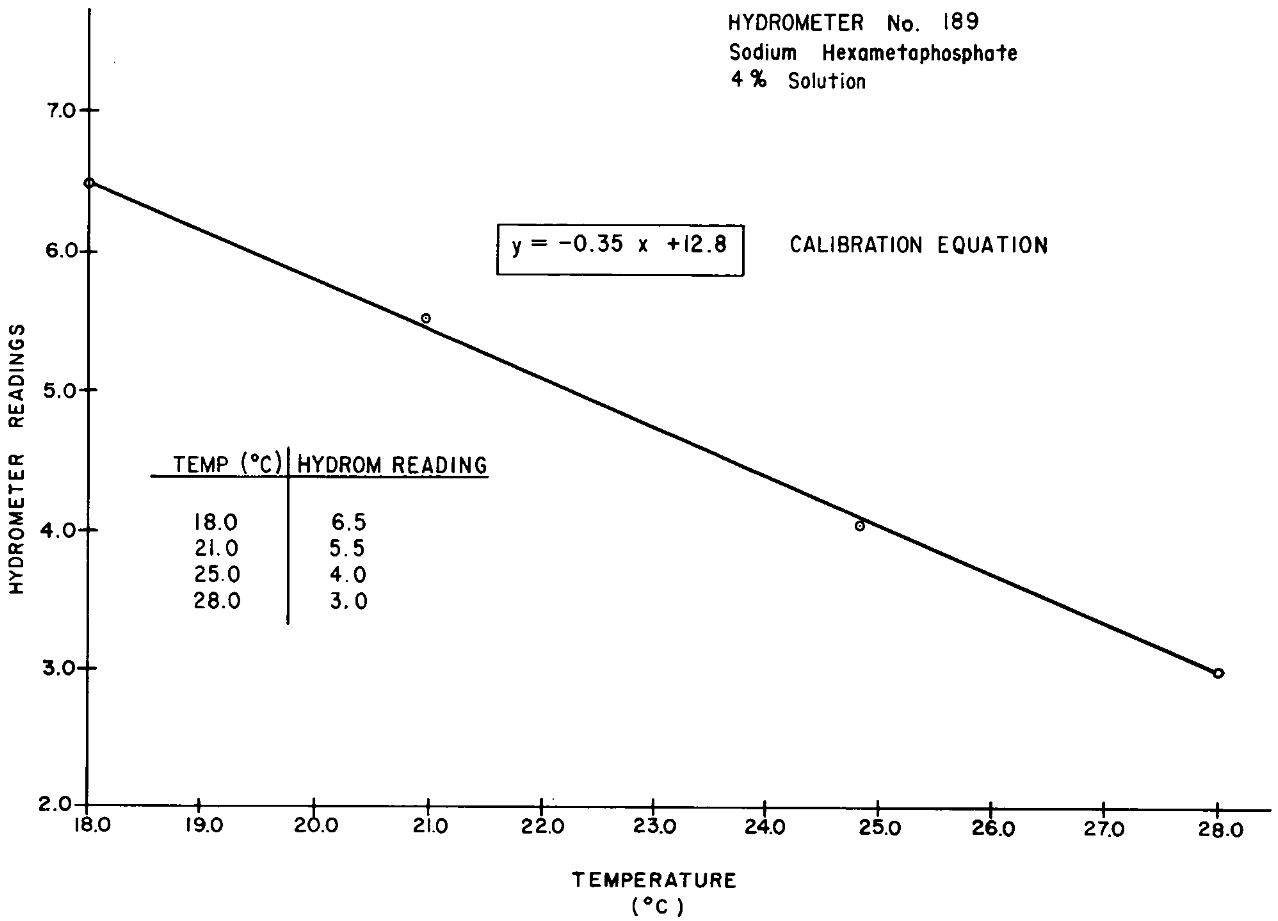


Figure 4. – Hydrometer calibration equation.

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1430-89

PROCEDURE FOR

CALIBRATING THE LOADING DEVICE FOR PERMEABILITY TESTS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Division Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1430. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating the loading device used for permeability tests as performed in accordance with USBR 5600 or 5605.

1.2 This calibration procedure is used to determine the acceptability of the loading device.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR *1104 Load Verification of Testing Machines
USBR 5600 Determining Permeability and Settlement of Soils [8-in (203-mm) Diameter Cylinder]
USBR 5605 Determining Permeability and Settlement of Soils Containing Gravel

3. Summary of Method

3.1 The loading device is placed in a testing machine and is loaded incrementally to the maximum capacity of the ram. The reading on the pressure gauge of the loading device is compared to the testing machine load reading at each loading increment.

3.2 The repeatability of the loading device at several loads is checked, and the loading device is adjusted or repaired as necessary.

3.3 A calibration plot defining the relationship between pressure gauge readings and testing machine load readings is used to determine which pressure gauge readings to use for a particular load when performing permeability tests in accordance with USBR 5600 or 5605.

4. Significance and Use

4.1 A calibrated loading device must be used in the laboratory to ensure that correct loads are placed on the permeability specimen when the specimen is tested in accordance with USBR 5600 or 5605.

4.2 This calibration procedure is to be performed upon receipt of the loading device and biennially thereafter.

5. Apparatus

5.1 *Testing Machine.*–Any type having sufficient load capacity. The testing machine should be equipped with two steel bearing blocks with hardened faces; the upper one of which is a spherically seated headblock and the lower of a plain rigid block. The faces of the bearing blocks when new should not depart from plane by more than 0.0005 inch (0.013 mm) at any point and should be maintained within 0.001 inch (0.02 mm). The bearing faces should be perpendicular to the axis of loading of each bearing block. The center of the bearing face of the spherically seated block should coincide with the center of the sphere. The moving portion of this block should be held closely in the spherical seat, but the design should be such that the bearing face can be rotated freely and tilted through small angles in any direction to prevent eccentric loading conditions.

5.2 *Loading Device.*–A hand-operated hydraulic pump loading device, fitted with a pressure gauge of sufficient capacity to safely load the ram to at least 75 to 80 percent of its load rating, including flexible hose with quick-connect couplings for attaching to rams.

5.3 *Steel Plate.*–A steel plate equivalent to the top plate of the permeability apparatus to be placed between the loading device and the upper bearing block of the testing machine.

6. Precautions

6.1 *Technical Precautions*:

6.1.1 Visually check the condition of the loading device each time it is used. Be sure that all hydraulic hoses and fittings are connected to the proper inlet and outlet connections of the pump cylinder.

6.1.2 During loading and when the maximum capacity of the ram has been reached, visually check the system for leaks and malfunctions which could affect test results.

6.1.3 Use a steel plate between the loading device and the upper bearing plate of the testing machine. Do not allow the saddle of the ram to come into contact with the upper bearing plate of the testing machine while it is being loaded because the apparatus may be damaged.

6.2 *Safety Precautions.*–Extreme care should be exercised when working with hydraulic hoses and loading devices. Safety devices, such as safety glasses and safety shoes, must be used while performing the calibration.

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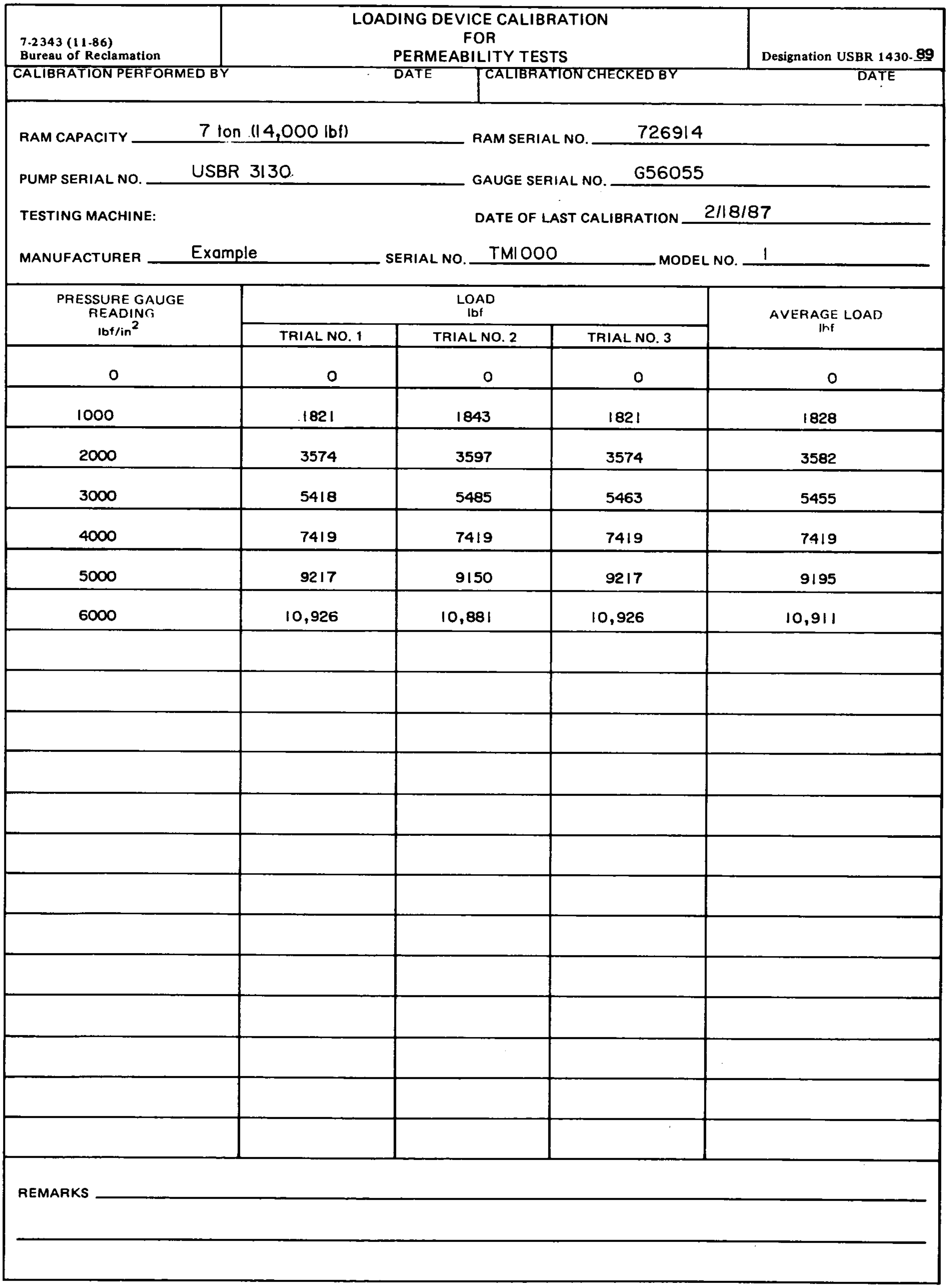
* *Concrete Manual,* Bureau of Reclamation, part 2, in press.



7-2343 (11-86) Bureau of Reclamation	LOADING DEVICE CALIBRATION FOR PERMEABILITY TESTS	Designation USBR 1430-89

CALIBRATION PERFORMED BY	DATE	CALIBRATION CHECKED BY	DATE

RAM CAPACITY 7 ton (14,000 lbf) RAM SERIAL NO. 726914

PUMP SERIAL NO. USBR 3130 GAUGE SERIAL NO. G56055

TESTING MACHINE: DATE OF LAST CALIBRATION 2/18/87

MANUFACTURER Example SERIAL NO. TM1000 MODEL NO. 1

PRESSURE GAUGE READING lbf/in^2	LOAD lbf			AVERAGE LOAD lbf
	TRIAL NO. 1	TRIAL NO. 2	TRIAL NO. 3	
0	0	0	0	0
1000	1821	1843	1821	1828
2000	3574	3597	3574	3582
3000	5418	5485	5463	5455
4000	7419	7419	7419	7419
5000	9217	9150	9217	9195
6000	10,926	10,881	10,926	10,911

REMARKS

Figure 1. – Loading device calibration for permeability tests — example.

7. Calibration and Standardization

7.1 Verify that the testing machine has been recently calibrated in accordance with USBR 1104. If the calibration is not current, perform the calibration before using the testing machine.

8. Conditioning

8.1 The room temperature should not vary more than ±5 °C during the calibration.

8.2 Place the loading device and other apparatus in the environment in which it is to be calibrated for at least 24 hours before performing the calibration procedure.

9. Procedure

9.1 All data are to be recorded on the "Loading Device Calibration for Permeability Tests" form as shown on figure 1.

9.2 Refer to the manufacturer's instructions for guidelines on operating the testing maching.

9.3 Assemble the ram, hydraulic line, pressure gauge, and pump. Ensure that all air is removed from the system. See manufacturer's instructions for the recommended method to remove air from the loading device.

9.4 Place the ram in the load frame of the testing machine. Be sure there is sufficient clearance between the upper and lower bearing plates of the testing machine.

9.5 Place the steel plate between the loading device and the upper bearing plate of the testing machine.

9.6 Pump the loading device until a pressure gauge reading equal to about 10 percent of the maximum capacity of the pressure gauge is reached. Read and record the pressure gauge reading as shown on figure 1.

9.7 Using the most sensitive range possible of the testing machine, read and record the corresponding load due to the pressure applied in subparagraph 9.6.

9.8 Repeat subparagraphs 9.6 and 9.7 increasing the pressure gauge reading in 10 percent increments. Continue increasing the pressure until a load equal to at least 75 to 80 percent of the load rating of the ram is reached.

9.9 Release the pressure in the pump (refer to the manufacturer's instructions).

9.10 Perform subparagraphs 9.6 through 9.9 a total of three times. The three load readings should not vary from each other by more than 1 percent of the maximum capacity of the ram; if they do, inspect the loading device for defects and adjust or repair as necessary. Repeat the procedure until the readings meet the criteria.

9.11 Compute the average of the three load readings for each pressure increment.

9.12 Prepare a plot of average load versus pressure gauge reading, and draw a best fit line from the origin through the data points as shown on figure 2.

10. Calculations

10.1 Determine the average of the three load readings.

$$A = \frac{R_1 + R_2 + R_3}{3}$$

where:

A = average load

R_1, R_2, R_3 = individual load readings

11. Report

11.1 The report is to consist of the following completed and checked form and plot:

"Loading Device Calibration for Permeability Tests" form (fig. 1).

A plot of the calibration results (fig. 2).

11.2 All calculations are to show a checkmark and all plotting must be checked.

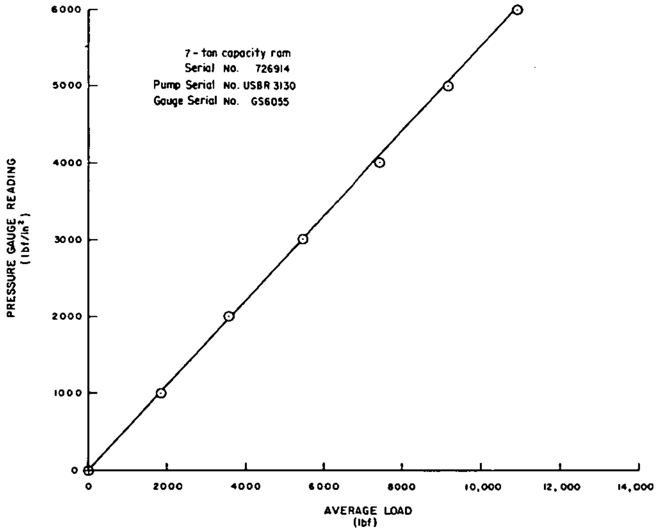


Figure 2. – Loading device — calibration plot example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1440-89

PROCEDURE FOR

CALIBRATING THE VIBRATORY TABLE FOR MAXIMUM INDEX UNIT WEIGHT TESTING

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. This procedure is issued under the fixed designation USBR 1440. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating the vibratory table used for determining the maximum index unit weight of cohesionless soils in the laboratory as performed in accordance with USBR 5530.

1.2 This procedure is limited to the Syntron Model V-80 cushioned vibratory table manufactered before 1965, and the Syntron Model V-75 solid impact vibratory table which is currently the only model accepted by USBR that can be purchased new.

1.3 This calibration procedure is used to determine the vertical amplitude of the vibrating tables described in subparagraph 1.2 and to adjust the table—if necessary—to an average double amplitude (peak-to-peak) displacement of 0.013±0.002 inch (0.33±0.05 mm) at 60-hertz frequency.

2. Auxiliary Tests

2.1 The LVDTs (linear variable differential transformers) used to measure the vertical amplitude of the vibratory table must be calibrated in accordance with USBR 1008 prior to performing this procedure.

3. Applicable Documents

3.1 *USBR Procedures*:
USBR 1008 Calibrating Linear Variable Differential Transformers
USBR 5530 Determining the Maximum Index Unit Weight of Cohesionless Soils

3.2 *ASTM Standard*:
D 4253 Maximum Index Density of Soils Using a Vibratory Table

3.3 *Journal*:
Geotechnical Testing Journal, Suggested Method for the Calibration of Vibrating Tables for Maximum Index Density Testing, vol. 2, No. 2, pp. 152-157, Sept., 1979.

4. Summary of Method

4.1 Calibration masses of 300 and 95 lbm (136 and 43 kg) are securely anchored to the vibratory table deck. The amplitude of vibration produced by the vibratory table is measured using LVDTs which are attached to the calibration masses. The amplitude of vibration of the vibratory table is checked at rheostat control settings of 100, 80, 60, 40, 20, and 0. The measured amplitude is compared to that which is required, and adjustments are made to the table if necessary.

5. Significance and Use

5.1 For many cohesionless, free-draining soils, maximum index unit weight is a key element in evaluating the state of compactness of a given soil mass which occurs either naturally or is placed during construction (fill).

5.2 The double amplitude of vertical vibration has been found to have a significant effect on the soil index unit weight obtained in the laboratory. Vibratory tables that subject a unit weight mold with soil to a double amplitude vertical vibration of something other than 0.013±0.002 inch (0.33±0.05 mm), at 60 Hz, produce inconsistent maximum index unit weight values using USBR 5530.

5.3 This calibration procedure is to be performed upon receipt of the table, biennially thereafter, before reuse after any event such as relocation or repairs which might affect its operation, and whenever test results are questionable.

6. Apparatus (see schematic fig. X2.1)

6.1 *Vibrating Table* (fig. 1).–A vibratory table securely mounted to a concrete floor or mass of sufficient size and configuration that excess vibrations are not transmitted to other testing areas. The vertically vibrating deck of the table is to be of sufficient size and rigidity that the mass assembly being used can be attached and rigidly supported during the calibration. The table is to be capable of vertically vibrating the mold assembly with a sinusoidal time-vertical displacement relationship at an average double amplitude (peak-to-peak displacement) of 0.013±0.002 inch (0.33±0.05 mm) at 60-Hz frequency. The table should have the capability for adjustment of the double amplitude of vibration between about 0.005 inch (0.15 mm) and 0.013 inch (0.33 mm) at 60 Hz.

6.2 *Linear Variable Differential Transformer* (LVDT).–LVDT, a.c., capable of accurately measuring linear

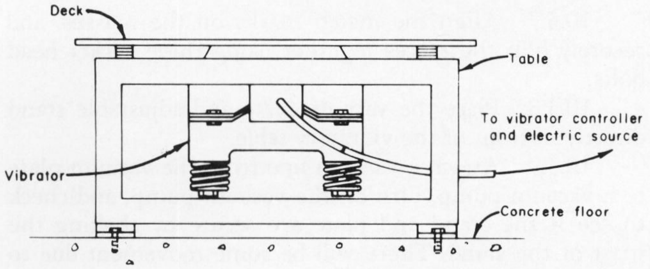


Figure 1. - Schematic of vibratory table.

displacement within 0.0005 inch. Minimum nominal displacement range ±0.050 inch, maximum nominal displacement range ±1.00 inch. The LVDTs are to have a No. 6-40 UNF threaded core. The two LVDTs needed should meet these requirements.

6.2.1 *LVDT Core Extension Rods.*-1/8-inch diameter, nonmagnetic (preferably brass) rods, threaded on both ends, No. 6-40 UNF thread, for a minimum length of 1 inch at each end; having an approximate length of 2-1/2 inches; two rods required.

6.2.2 *LVDT Guides.*-LVDT Teflon guides which can be purchased from the LVDT manufacturer; four guides required. The purpose of Teflon guides is to ensure no horizontal movement of the LVDT core during use.

6.3 *Calibration Masses*:

6.3.1 A three-piece calibration mass having a combined mass of 300 lbm (136 kg) used to simulate the mass of the loaded 0.5-ft^3 (14 200-cm^3) measure. Flat surfaces on the calibration masses must be ground flat, parallel, and to at least a 63 finish to ensure proper contact.

NOTE 1.-A 63 finish refers to the average peak-to-valley distance in microinches on the surface of the calibration masses.

6.3.2 A one-piece calibration mass of 95 lbm (43 kg) used to simulate the mass of the loaded 0.1-ft^3 (2830-cm^3) measure.

6.4 *Signal Conditioner.*-A signal conditioner to provide a constant a-c input to the LVDT and convert the output from a.c. to a proportional d-c signal.

6.5 *Storage Oscilloscope.*-A storage oscilloscope used to record the output of the LVDT. A dual-beam, cathode-ray oscilloscope is required to check the vibrating table for rocking motion. The oscilloscope is to be fitted with a suitable camera to make a permanent record of the table vibration wave form.

6.6 *Digital Voltmeter.*-A digital voltmeter with a measuring range of 1 mV to 250 volts with both a-c and d-c functions used for both the initial calibration of the LVDT and for centering the LVDT core in the body before each measurement of the vibration amplitude. The voltmeter is used also to check the value and variation of a-c power onsite.

6.7 *Stationary Frame* (fig. 2).-A stationary frame used to hold the LVDT body in place and in isolation from external vibrations. The stationary frame consists of an adjustable stand and vacuum plate to provide a solid base for the stand.

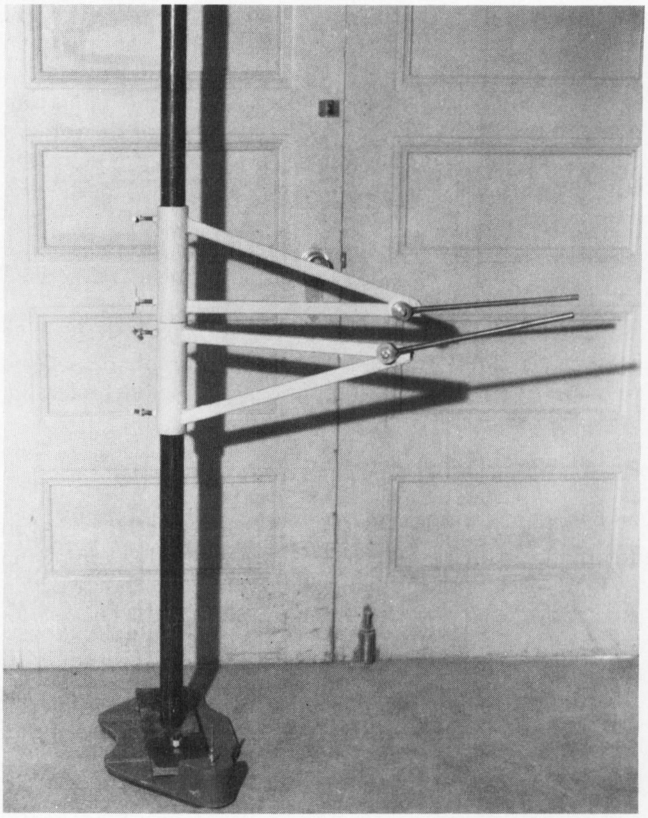


Figure 2. - Stationary calibration frame.,

6.8 *Feeler Gauge.*-A feeler gauge having a thickness of 0.020 inch (0.51 mm) used for periodic calibration checks of the LVDT between vibration measurements.

6.9 *Ear Protectors* (required).-Ear protectors are to be worn by all personnel performing the calibration. The vibratory table produces a noise level in excess of 140 dB.

6.10 *Miscellaneous Equipment.* - Combination wrenches, one end box and one end open; to include 1-1/4-, 15/16-, and 9/16-inch size; adjustable wrenches, one 8- and one 10-inch; 8-ounce ball peen hammer.

7. Precautions

7.1 *Safety Precautions*:

7.1.1 Ensure that the vibratory table and controller are properly grounded to avoid possible electrical shock.

7.1.2 Ear protectors are to be worn by all personnel while working in the vicinity of the vibratory table during operation.

7.2 *Technical Precautions*:

7.2.1 Check all mounts on the vibratory table for cracks and loose bolts; repair or replace if necessary.

7.2.2 Ensure that the vibratory table is mounted level and securely to a solid concrete slab or foundation.

7.2.3 Ensure that the mounting holes for the index unit weight measures are drilled in the locations as shown on figure X2.3. If the holes are not in the locations as shown, the vibratory table can exhibit out-of-phase oscillation. The resulting amplitude at the center of the out-of-phase table can be considerably less than that on either side.

7.2.4 Examine the condition of all the mounting holes on the vibratory table deck to ensure that the threads are not stripped. If the threads are stripped, rotate the bolt pattern 180 degrees, if possible, and redrill the mounting holes.

7.2.5 Ensure that the flat surfaces of the three-piece calibration mass are ground to a smooth finish as described in subparagraph 6.3.1.

7.2.6 Ensure that the LVDT extension rods have been made in accordance with subparagraph 6.2.1. The rods are to be made of a nonmagnetic metal, preferably brass.

8. Calibration and Standardization

8.1 Ensure that the LVDTs are currently calibrated in accordance with USBR 1008. Verify the calibration of the LVDTs each time a vibratory table is calibrated in accordance with procedure in subparagraph 10.4.

8.2 Verify that the oscilloscope and voltmeter have been calibrated within the last year. If the calibrations are not current, the oscilloscope and voltmeter should be sent to a qualified calibration agency for calibration prior to use.

9. Conditioning

9.1 Allow all electronic equipment to warm up for a minimum of 30 minutes prior to use to ensure stability.

9.2 Calibrate the vibratory table in its permanently mounted location.

10. Procedure

10.1 All data are to be recorded on the "Vibratory Table Calibration Sheet" as shown on figure 3.

10.2 Locate and record all pertinent information as shown on figure 3. Be sure to include *Remarks* with regard to voltage source characteristics as well as table mount location and condition.

10.3 *Calibration Using the 300-lbm Calibration Mass*:

10.3.1 Place the bottom one-third of the 300-lbm (136-kg) calibration mass on the vibratory table deck.

10.3.2 Align the bolt down tabs with the appropriate mounting holes, being sure that the front mark on the calibration mass is to the front of the table.

10.3.3 Secure the calibration mass to the table using three 3/8-inch-diameter bolts having a minimum length of 1-1/4 inches.

10.3.4 Place the second one-third of the 300-lbm calibration mass on top of the bottom calibration mass.

10.3.5 Align the match marks on the masses, then securely bolt the two pieces together using three socket head bolts.

10.3.6 Place the top one-third of the 300-lbm calibration mass onto the two calibration masses already bolted in place.

10.3.7 Align the match marks on the masses, and securely bolt the pieces together using three socket head bolts.

10.3.8 Place the vacuum plate and adjustable stand directly in front of the vibratory table.

10.3.9 Attach a vacuum line from the vacuum plate to a vacuum pump, turn on the vacuum pump, and check to see if the stand and plate are secure by shaking the mast of the stand. There will be some movement due to flexing of the steel pipe; however, the vacuum plate should not move.

10.3.10 Slide the two calibration stand brackets over the mast, and attach and secure the bracket extension arms.

10.3.11 Position the lower bracket over the right side of the calibration mass and the upper bracket over the left side of the calibration mass, and secure each using the locking bolts on the calibration stand bracket.

10.3.12 Ensure that all personnel in the vicinity of the vibratory table are wearing ear protectors.

10.3.13 Turn the rheostat located on the control box to the 100-percent setting, and activate the vibrator by moving the on/off switch to the "on" position.

10.3.14 Allow the vibratory table to operate at this setting for a minimum of 5 minutes, and then deactivate the vibrator by moving the on/off switch to the "off" position.

10.4 *Verification of LVDT Calibration*:

10.4.1 Connect the oscilloscope and amplifier to a power supply in accordance with the manufacturer's specifications.

10.4.2 Attach LVDT No. 1 cable to channel No. 1 of the amplifier. Similarly, attach the LVDT No. 2 cable to channel No. 2 of the amplifier.

10.4.3 Attach the output cable from channel No. 1 of the amplifier to channel No. 1 of the oscilloscope. Similarly, attach the output cable from channel No. 2 of the amplifier to channel No. 2 of the oscilloscope.

10.4.4 Connect the voltmeter to the terminal of the amplifier such that the voltage output of the LVDTs can be constantly monitored.

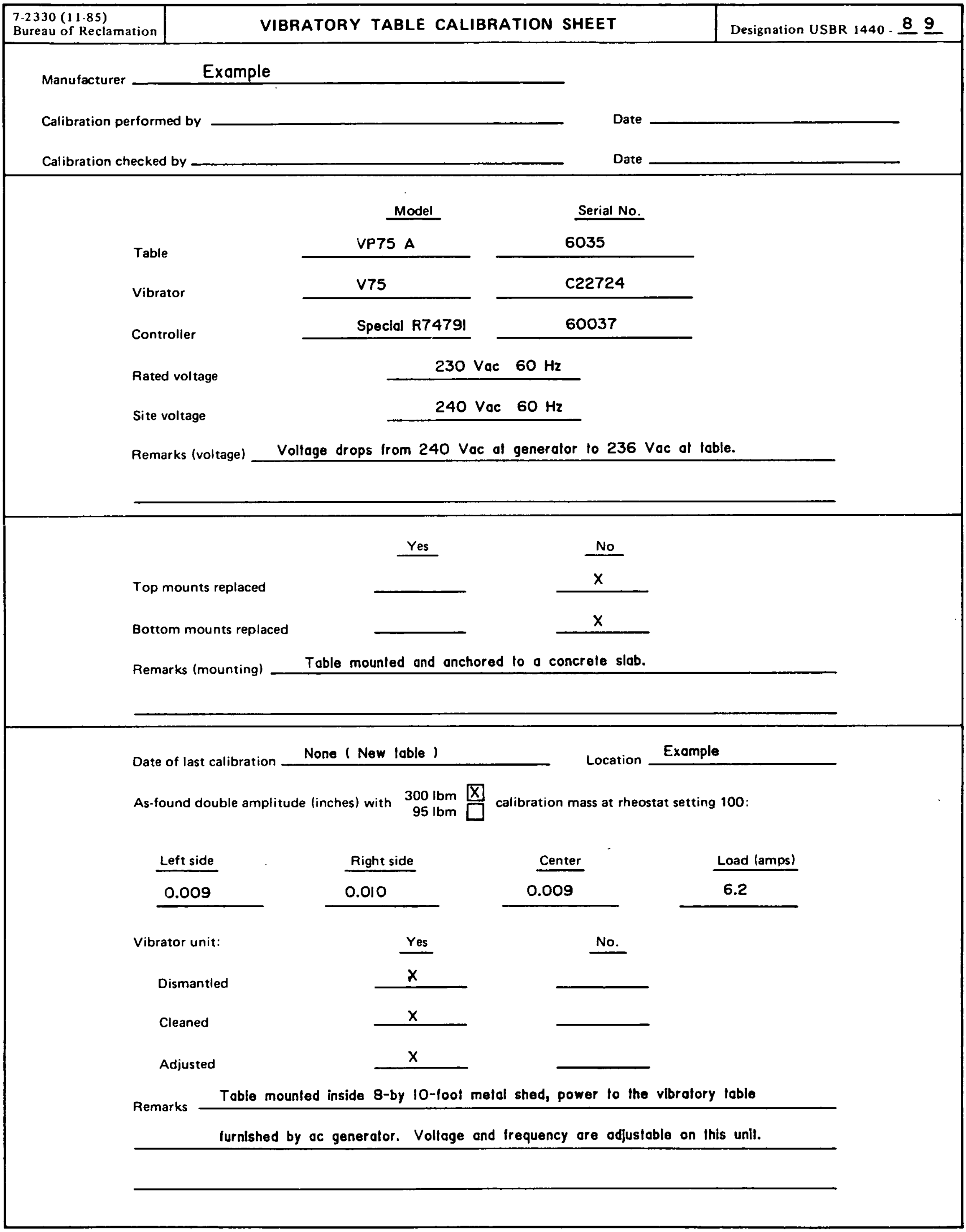
10.4.5 Attach the LVDT mounting block to the LVDT mounting block carrier as shown on figure X2.2.

10.4.6 Slide the LVDT mounting block assembly onto the bracket extension arm, and loosely secure it in place by slightly turning the thumb screw.

10.4.7 Attach the Teflon guides and LVDT core extension rod to the core of LVDT No. 1 as shown on figure 4a. The purpose of the Teflon guides is to ensure that, when the LVDT core is being displaced for calibration verification, there is no horizontal movement which could affect the calibration.

10.4.8 Slide the body of LVDT No. 1 into the mounting block assembly attached to the bracket extension arm located over the right side of the calibration mass, and secure the LVDT body in place by tightening the mounting block screw.

10.4.9 Position the LVDT core with the extension rod attached (fig. 4a) into the body of the LVDT.



7-2330 (11-85) Bureau of Reclamation	VIBRATORY TABLE CALIBRATION SHEET	Designation USBR 1440 - 89

Manufacturer Example

Calibration performed by ______ Date ______

Calibration checked by ______ Date ______

	Model	Serial No.
Table	VP75 A	6035
Vibrator	V75	C22724
Controller	Special R74791	60037

Rated voltage 230 Vac 60 Hz

Site voltage 240 Vac 60 Hz

Remarks (voltage) Voltage drops from 240 Vac at generator to 236 Vac at table.

	Yes	No
Top mounts replaced		X
Bottom mounts replaced		X

Remarks (mounting) Table mounted and anchored to a concrete slab.

Date of last calibration None (New table) Location Example

As-found double amplitude (inches) with 300 lbm ☒ 95 lbm ☐ calibration mass at rheostat setting 100:

Left side	Right side	Center	Load (amps)
0.009	0.010	0.009	6.2

Vibrator unit:	Yes	No.
Dismantled	X	
Cleaned	X	
Adjusted	X	

Remarks Table mounted inside 8-by 10-foot metal shed, power to the vibratory table furnished by ac generator. Voltage and frequency are adjustable on this unit.

Figure 3. – Vibratory table calibration sheet — example.

300 lbm calibration mass

Simulates 0.5-ft^3 test apparatus and soil mass

Rheostat setting (%)	Double amplitude left side (inches)	Double amplitude right side (inches)	Double amplitude center (inches)	Load (amps)
100	0.012	0.012	0.012	6.2
80			0.012	6.1
60			0.007	5.3
40			0.004	4.4
20			0.003	3.8
0			0.002	3.5

Recommended Rheostat Setting 100%

Remarks

95 lbm calibration mass

Simulates 0.1-ft^3 test apparatus and soil mass

Rheostat setting (%)	Double amplitude left side (inches)	Double amplitude right side (inches)	Double amplitude center (inches)	Load (amps)
100*	0.014	0.014	0.014	6.1
80	0.014	0.014	0.014	6.0
60			0.012	5.7
40			0.008	4.6
20			0.003	4.4
0			0.002	3.5

Recommended Rheostat Setting 80%

Remarks * Striking of pole faces observed at this setting, DO NOT OPERATE VIBRATOR AT 100 %.

GPO 849-230

Figure 3. - Vibratory table calibration sheet — example — Continued.

10.4.10 Position the LVDT body by sliding the mounting block assembly along the bracket extension arm and/or by moving the bracket arm itself if necessary, such that the core extension rod firmly rests near the No. 6-40 UNF threaded hole located on the top surface of the calibration mass, and securely tighten it in place.

10.4.11 Adjust the calibration stand bracket and/or the height of the LVDT body within the mounting block so that, when the LVDT core extension rod rests firmly on the top surface of the calibration mass, the output on the voltmeter is at or near 0.0 volt. Ensure that the toggle switch on the amplifier control box is set to the appropriate LVDT and that the voltmeter is set on the d-c function. The voltmeter range should be set at 20 volts d.c. or less to obtain the sensitivity required to measure 1 mV.

10.4.12 Position the output signal of the LVDT on the oscilloscope such that the horizontal line is set on the first major division from the bottom of the screen. Refer to the oscilloscope instruction manual for the correct oscilloscope setting.

10.4.13 Carefully slide the 0.020-inch (0.51-mm) thick feeler gauge between the LVDT core extension rod and the calibration mass as shown on figure 4b.

10.4.14 The voltmeter output should indicate a change of 0.200 volts d.c. Check the signal trace on the oscilloscope for proper placement. Remove the feeler gauge. The voltmeter should indicate the initial voltage as in subparagraph 10.4.11, and the output signal of the LVDT should return to the position set in subparagraph 10.4.12. If these results are not obtained, adjust the amplifier accordingly by turning the gain control and repeating subparagraphs 10.4.11 through 10.4.14 as often as required to ensure correct adjustment.

NOTE 2.–If an LVDT with a measuring range other than 2 inches (50 mm) is used the voltage output is computed using the following equation:

$$D_v = \frac{D_k D_T}{M_r}$$

where:

D_v = voltage output of the transducer, V
D_k = known displacement, in or mm
D_T = total voltage output of the LVDT, V; (typically a 20-volt range, ±10 volts as per manufacturer's specifications)
M_r = total measuring range of the LVDT, in or mm

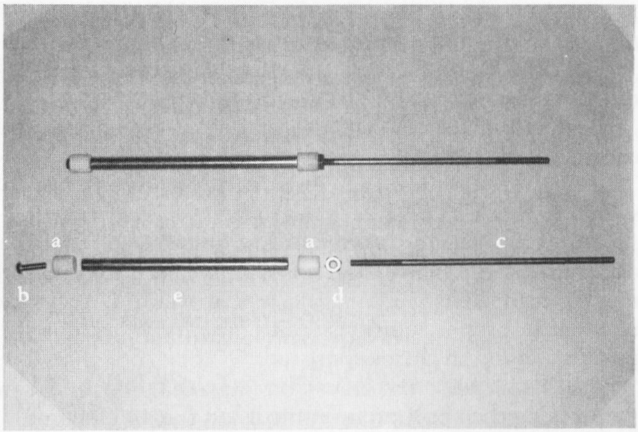
10.4.15 Remove the core and core extension rod from the LVDT, and remove the Teflon guides.

10.4.16 Reattach the core extension rod to the LDVT core.

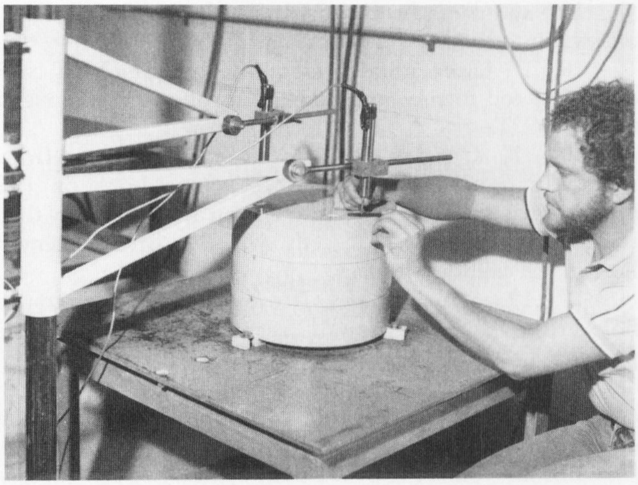
10.4.17 Repeat subparagraphs 10.4.5 through 10.4.16 for LVDT No. 2 located over the left side of the calibration mass.

CAUTION: Do not lean, stand, or rest on the vibratory table while the LVDT calibrations are being verified. The slightest amount of movement can affect the calibration.

10.5 *Double Amplitude and Frequency Measurement* ("as found condition"):



(a) LVDT core/core extension rod assembly. a) teflon guide, b) No. 6-40 UNF threaded screw, c) LVDT core extension rod, d) lock nut, and e) LVDT core.



(b) Feeler gauge placement.

Figure 4. – Verifying the LVDT calibration.

10.5.1 Position LVDT No. 1 directly over the No. 6-40 UNF threaded hole on the right side of the calibration mass.

10.5.2 Place the LVDT core with extension rod attached into the LVDT body, and screw the LVDT core extension rod into the threaded hole in the calibration mass.

10.5.3 Lock the extension rod in place on the calibration mass using two locknuts.

10.5.4 Set the toggle switch on the amplifier control box to the appropriate LVDT.

10.5.5 Carefully adjust the calibration brackets and LVDT holder so that the core is in the center of the LVDT.

10.5.6 Slide the LVDT body up or down accordingly until the voltmeter reads at or near 0.0 volt.

10.5.7 Position LVDT No. 2 directly over the No. 6-40 UNF threaded hole on the left side of the calibration mass, and repeat subparagraphs 10.5.2 through 10.5.6.

10.5.8 Check the voltage output of LVDT No. 1 and readjust to 0.0 volt, if necessary.

10.5.9 Ensure that all personnel in the vicinity of the vibratory table are wearing ear protectors.

10.5.10 Ensure that the rheostat located on the control box is at the 100-percent setting.

10.5.11 Activate the vibrator by moving the on/off switch to the "on" position.

10.5.12 Check the oscilloscope trace to see that the traces are in the proper locations; i.e., right LVDT is the top trace and left LVDT is the bottom trace. If they are not in the proper locations, adjust them by turning the position knobs on the oscilloscope.

10.5.13 Lock the traces on the oscilloscope screen by pressing the appropriate controls on the oscilloscope.

10.5.14 Obtain a photograph of the oscilloscope traces for permanent record as shown on figure 5.

10.5.15 If the control box for the vibratory table is equipped with an ammeter, read and record the amperage value as shown on figure 3.

10.5.16 Deactivate the vibrator by turning the on/off switch to the "off" position.

10.5.17 Loosen the locknuts holding the LVDT core extension rod to the calibration mass on either the right or left LVDT.

10.5.18 Unscrew the LVDT core extension rod from the calibration mass, loosen the locking bolts on the calibration stand bracket, and swing the bracket so that the LVDT is positioned directly over the threaded center hole in the calibration mass.

10.5.19 Screw the LVDT core extension rod into the hole in the center of the calibration mass, and lock it in position.

10.5.20 Carefully adjust the calibration stand bracket and LVDT holder so that the LVDT core is in the center of the LVDT body.

10.5.21 Slide the LVDT body up or down accordingly until the voltmeter reads at or near 0.0 volt.

10.5.22 Repeat subparagraph 10.5.9 through 10.5.16.

10.6 Examine the oscilloscope trace photographs obtained in subparagraph 10.5.14 for the sides and center of the calibration mass.

10.7 If the sides and center oscilloscope photographs indicate the vibratory table is producing the correct amplitude values; i.e., 0.013±0.002 inch (0.33±0.05 mm), repeat subparagraphs 10.5.9 through 10.5.22 with rheostat settings of 80, 60, 40, 20, and 0.

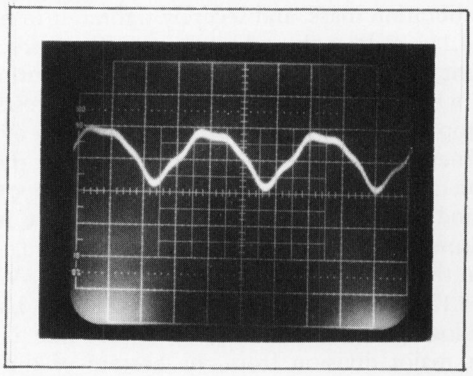
NOTE 3.–The vibratory table is calibrated at rheostat settings less than 100 percent so that a proper rheostat setting can be determined for performing the maximum index unit weight of cohesionless soils using the wet method, as outlined in USBR 5530.

10.7.1 Return the LVDT located in the center of the calibration mass to either the right or left position from which it was moved in subparagraph 10.5.18. Repeat subparagraphs 10.5.20 and 10.5.21.

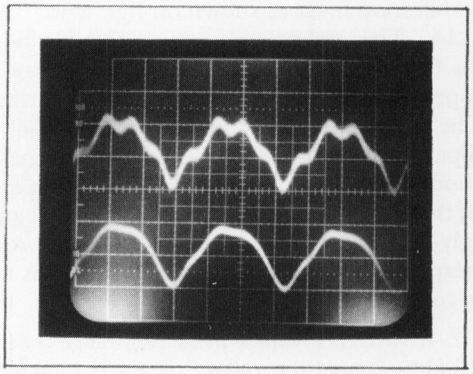
10.8 If the sides or center oscilloscope photographs indicate that the vibratory table is producing incorrect values of amplitude, the necessary repairs and/or adjustments must be made to the vibratory unit in order to obtain the correct amplitude.

RELATIVE DENSITY TABLE CALIBRATION

Location: Denver Office Geotechnical Services Branch
Date: February 22, 1989
Model: No. VP-75A Unit 2 Serial No. 601036 (Controller)



Controller Setting (%) 100 Mass on Unit: 300 AMPS: 7.2
Remarks: Center as found Photo #1



Controller Setting (%) 100 Mass on Unit: 300 AMPS: 7.2
Remarks: Left and Right as Found LT = Bottom, RT = Top Photo #2

Figure 5. – Relative density table calibration—as found oscilloscope traces.

NOTE 4.–For a new vibratory table, it is recommended that the vibratory unit be dismantled and all paint be removed from the ends of the coil springs since gradual wearing of the paint can cause changes in calibration values obtained. This should be accomplished before using the vibratory table.

10.9 *Vibrator Adjustments*:

10.9.1 Check the distance between the top of the locknut nearest the leaf spring clamp to the bottom of the leaf spring clamp, item D, figure X1.2. The distance should be approximately 7/8 inch (22 mm). If it is not, loosen the locknuts. Set the correct distance and repeat subparagraphs 10.5.9 through 10.5.16.

10.9.2 If the double amplitude values are equal to 0.013±0.002 inch (0.33±0.05 mm), proceed as per subparagraphs 10.5.17 through 10.7; if not, additional vibrator adjustments need to be made. This may be done by further adjusting the locknuts, item B, figure X1.2.

10.9.3 Ensure that all personnel in the vicinity of the vibratory table are wearing ear protectors.

10.9.4 Ensure that the rheostat is at 100-percent setting, and turn the vibrator controller on.

10.9.5 With one person at each stud (item 9, fig. X1.2), simultaneously turn the bottom lock nuts. If the amplitude of the vibrator is too low, the bottom locknuts are to be tightened. If the amplitude of the vibrator is too high, the bottom locknuts are to be loosened. If the desired values of amplitude cannot be obtained by adjusting the bottom locknuts, it may be necessary to either tighten or loosen the top locknuts to obtain the desired values.

10.9.6 Secure the locknuts against one another when the desired amplitude values are obtained and turn the vibrator controller off.

10.9.7 Ensure that the stopnut (item 15, fig. X1.2) which holds the armature casting to the coil assembly is secure. If the stopnut needs to be replaced, it is to be replaced with a new one. Never reuse a worn stopnut.

10.10 *Check Clearance Between Pole Faces With Calibration Mass in Place* (model V-80 only, fig. X1.1, item A):

10.10.1 Obtain two strips of paper approximately 3/8 inch (10 mm) wide at least 6 inches (150 mm) long, and insert one strip between each of the pole faces of the vibrator.

10.10.2 Ensure that the rheostat is set at 100 percent and that all personnel in the vicinity are wearing ear protectors; turn the vibratory table on for about 5 seconds.

10.10.3 Turn the vibratory table off and check the paper. Markings on the paper indicate that the pole faces are making contact.

10.10.4 Adjust the vibrator in accordance with subparagaph 10.9, and repeat subparagraphs 10.10.1 through 10.10.3 until markings are not seen on the paper.

10.10.5 Repeat subparagraphs 10.10.2 through 10.10.4 inserting the second paper strip on the opposite side of the vibratory table as before.

10.10.6 Examine the oscilloscope trace. If the amplitude is not correct, follow the manufacturer's instruction for inserting shims between the vibration dampener and the core mounting assembly (items 14 and C, fig. X1.1).

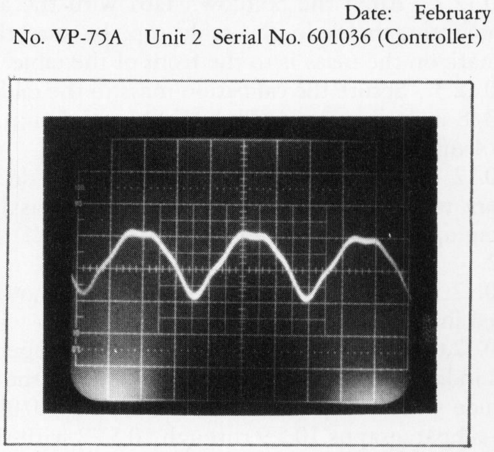
10.10.7 Repeat the procedure as outlined in subparagraphs 10.5.9 through 10.5.22, and label the photographs as shown on figure 6.

10.11 *Check the Air Gap* (model V-75 only, item A, fig. X1.2):

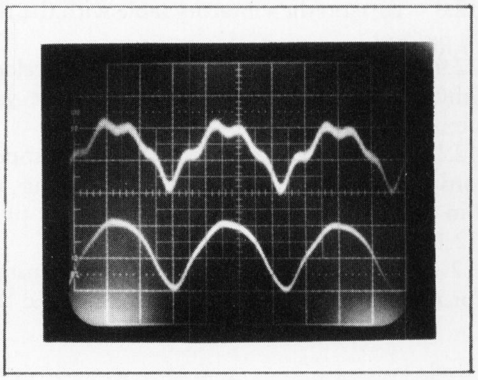
NOTE: 5.–If the control box for the vibratory table is equipped with an ammeter, the air gap for the V-75 is to be checked in accordance with subparagraph 10.11. If the control box is not equipped with an ammeter, the air gap can be checked as per subparagraph 10.10.

RELATIVE DENSITY TABLE CALIBRATION

Location: Denver Office Geotechnical Services Branch
Date: February 22, 1989
Model: No. VP-75A Unit 2 Serial No. 601036 (Controller)



Controller Setting (%) 100 Mass on Unit: 300 AMPS: 7.4
Remarks: After adj. recommended setting for 1/2 ft^3 measure
Photo #3 Center



Controller Setting (%) 100 Mass on Unit: 300 AMPS: 7.4
Remarks: After adj. recommended setting for 1/2 ft^3 measure
Photo #4 Lt = Bottom, RT = Top

Figure 6. – Relative density table calibration — after adjusting oscilloscope traces.

10.11.1 With the 300-lbm (136-kg) mass in place, ensure that the rheostat is set at 100 percent and that all personnel in the vicinity of the vibratory table are wearing ear protectors; turn the vibrator on.

10.11.2 Read the amperage value and compare the value obtained with the rated value for the vibrator; i.e., a table rated for 230 volts a.c., 8 amps, will draw approximately 7 amps when it is properly adjusted.

10.11.3 Repeat the procedure outlined in subparagraphs 10.9.4 through 10.9.7 if the amperage value obtained in subparagraph 10.11.2 is incorrect.

10.11.4 Loosen the locknuts holding the LVDT core extension rods to the calibration mass, and unscrew the rods from the mass.

10.11.5 Move the adjustable stand as required, and remove the 300-lbm (136-kg) calibration masses from the table deck.

10.12 *Calibration Using the 95-lbm Calibration Mass*:

10.12.1 Place the 95-lbm (43-kg) calibration mass on the vibratory table.

10.12.2 Align the boltdown tabs with the appropriate mounting holes in the table top; be sure that the front mark on the mass is to the front of the table.

10.12.3 Secure the calibation mass to the table using three 3/8-inch-diameter bolts having a minimum length of 1-1/4-inches. Use washers if necessary.

10.12.4 To measure the double amplitude of the vibratory table with the 95-lbm calibration mass, repeat subparagraphs 10.3.8 through 10.3.11 and 10.5.1 through 10.5.22.

10.12.5 Examine the oscilloscope trace photographs obtained in subparagraph 10.5.14.

10.12.6 If the sides and center oscilloscope photographs indicate the vibratory table is producing the correct amplitude values; i.e., 0.013±0.002 inch (0.33±0.05 mm), repeat subparagraphs 10.5.9 through 10.5.22 with rheostat settings of 80, 60, 40, 20, and 0.

10.12.7 If the double amplitude exceed the prescribed value, the rheostat is to be adjusted until the correct double amplitude value is obtained.

10.12.8 Turn on the vibratory table with the rheostat set at 100 percent.

10.12.9 Slowly turn the rheostat counterclockwise, and monitor the oscilloscope until the correct value of amplitude is obtained.

10.12.10 Obtain a photograph of oscilloscope trace, and record the recommended rheostat setting that is required in order to obtain the correct double amplitude.

10.12.11 Turn off the vibratory table.

10.12.12 After determining the recommended setting for the vibratory table, it is recommended that the air gap be checked at this setting as prescribed in either subparagraph 10.10 or 10.11, whichever is appropriate.

10.12.13 Loosen the locknuts holding the LVDT core extension rods to the calibration mass, and unscrew the rods from the mass.

10.12.14 Move the adjustable stand as required, and remove the 95-lbm mass from the table deck.

10.12.15 Disconnect all electronic equipment, and carefully store the calibration masses in a suitable container.

11. Interpretation of Results

11.1 If the vibratory table fails to produce the required double amplitude as specified in this procedure, it should either be repaired or rejected.

11.2 Under no circumstances should the vibratory table be operated with a power source which provides 5 percent less than, or 10 percent greater than (approximately), the rated power requirements of the vibratory table. If the power source is insufficient, it is recommended that a step-up transformer be installed to obtain the desired voltage.

12. Report

12.1 The report is to consist of a completed and checked "Vibratory Table Calibration Sheet" (fig. 3) along with the photographs obtained at each rheostat setting.

12.2 See appendix X1 for sketches of vibratory table component parts.

12.3 See appendix X2 for drawings of vibratory table calibration equipment.

ANNEX A1. INSTALLATION AND MAINTENANCE OF VIBRATORY TABLES

A1.1 Scope

A1.1.1 Annex A1 outlines procedures for recommended installation and maintenance of FMC Corporation, Syntron electromagnetic vibratory tables, models VP-80 and VP-75A. These tables are used for determining the maximum index unit weight of cohesionless, free-draining soils.

A1.2 Installation

A1.2.1 The vibratory unit is designed for a specific line voltage and frequency. The power supply voltage and frequency must match the information stamped on the equipment name plate. If the power supply voltage is 5 percent less than, or 10 percent greater than (approximately) the rated voltage, installation of a transformer is required for proper operation.

A1.2.2 The nominal dimensions of the steel deck of the table should be 3/8 inch (10 mm) thick and 30 by 30 inches (760 by 760 mm).

A1.2.3 Verify that bolt holes, used to attach calibration masses to the steel deck, are drilled in the correct locations and that they are tapped to receive 3/8-inch NC bolts.

A1.2.4 Vibratory tables are extremely noisy during operation. If possible, select a site where the table can be isolated from personnel working in the immediate area. Some tables have been isolated by constructing a soundproof covering around the table. If such a cover is used, it must be easily removed or disassembled to calibrate the table.

A1.2.5 Select a site in the laboratory suitable for mounting the vibratory table. This site must be on a concrete slab in a protected area and close to the power supply. When selecting the site, allow about a 16-inch (400-mm) clearance between the back of the table and the wall and allow at least 3 feet (1 meter) clearance on either side. The front of the table (usually identified by the equipment name tag) should face open space in the laboratory. Position the vibratory table so that the power cord comes out of the back of the vibratory adjacent to the wall.

A1.2.6 Obtain four wood shims made of 2- by 4-inch lumber. Each shim should have a length of about 12 inches (300 mm). Place one shim under each side of the bottom portion of the table frame, with the smaller dimension of the shim in the vertical direction. The purpose of these shims is to relieve the weight the table may exert on the mounts while the anchor holes are marked and the table is fastened to the floor. If this precaution is not taken, undue stress will be placed on the mounts which could cause them to fail prematurely.

A1.2.7 Mark the anchor hole locations (2 per mount), then remove the table and determine the size of the hole that must be drilled in the concrete. The size of the hole required depends on the size and model of the lead anchor.

A1.2.8 Obtain a suitable masonry bit and power drill. A power drill, which drills by impact as well as rotation, usually works better than one that drills only by rotation.

A1.2.9 Drill each hole to the recommended depth. If the hole is drilled deeper than the recommended depth, the lead anchor will pull out when the bolt is inserted and tightened. A lead anchor, threaded for a minimum 3/8-inch-diameter bolt, is recommended. It is also recommended that threaded anchors be used instead of lag bolt anchors, since the latter sometimes strip when the lag bolt is tightened. Clean all of the dust out of each hole. Insert one lead anchor into each hole. If the lead anchor is the type that must be set by use of a drive tool, follow the manufacturer's recommendation for the correct setting procedure.

A1.2.10 Relocate the vibratory table directly over the mounting holes. Place the 2- by 4-inch shims under the bottom frame of the vibratory table. Insert the appropriate sized bolts into the holes on the mounts, and tighten each bolt 3 to 4 turns; then remove the 2- by 4-inch shims and allow the weight of the table to rest on the mounts. Tighten all bolts securely.

A1.2.11 The controller should be installed as close to the table as possible, preferably on the wall in a clean, dry location, free from excessive heat and vibration. The controller should be located where it may be easily seen and is accessible to the operator, approximately 4 to 5 feet (1.2 to 1.5 m) above the floor.

A1.2.12 Wire the vibrator to the controller and the controller to the power supply. The wiring connections must be securely made in accordance with the wiring diagram included in each control box. A ground connection to the controller and table is required to ensure maximum safety to the operator. Wiring should be connected by a qualified electrician.

A1.3 Maintenance of the Vibratory Table

A1.3.1 Dry the vibratory unit with compressed air after wet use and occasionally lubricate the leaf and coil springs with WD-40 or a similar rust preventive product; this keeps the components from rusting, thereby keeping the vibrator moving freely.

A1.3.2 Plug all holes on the table that are not in use with appropriate size bolts; this prevents water from running into the holes and down into the vibrator.

A1.3.3 Periodically clean the attaching holes for the maximum index unit weight measures that are located on the deck of the table.

A1.3.4 Repairing the stripped holes in the table top can be accomplished by using a Helicoil™ thread replacement device. The Helicoil™ set can be purchased at most hardware and automotive repair centers.

A1.3.5 Periodically check the vibratory table for broken or weathered top and bottom mounts.

A1.3.6 Periodically check the electrical wiring for frayed, cracked, or broken insulation.

A1.3.7 Periodically check the vibratory table for loose lock nuts, broken leaf springs, etc.

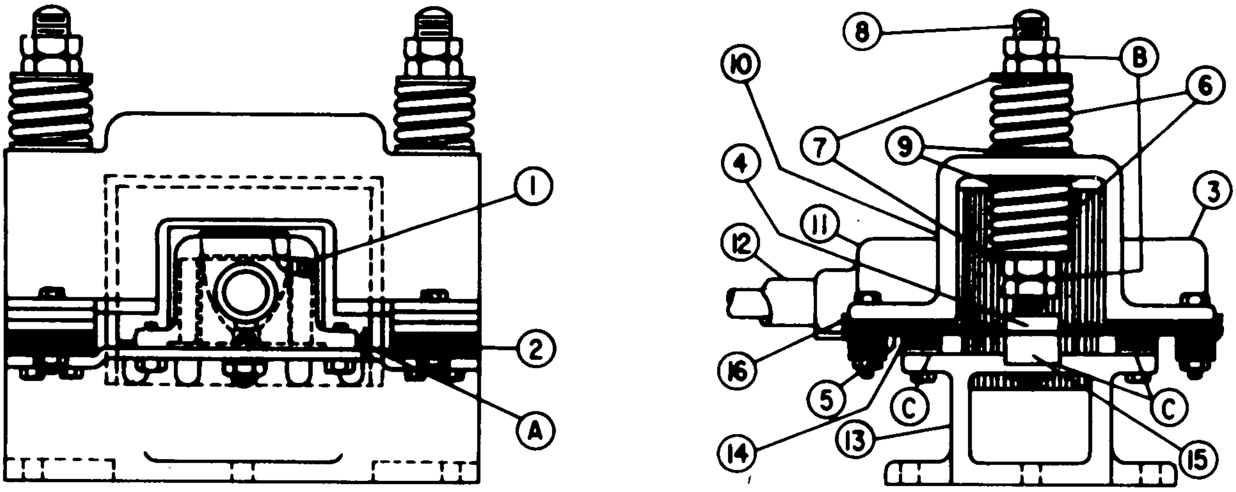
A1.3.6 Periodically check the electrical wiring for frayed, cracked, or broken insulation.

A1.3.7 Periodically check the vibratory table for loose lock nuts, broken leaf springs, etc.

CAUTION: Do not attempt repairs unless the unit can be recalibrated before use, since adjustment will be required.

APPENDIX X1

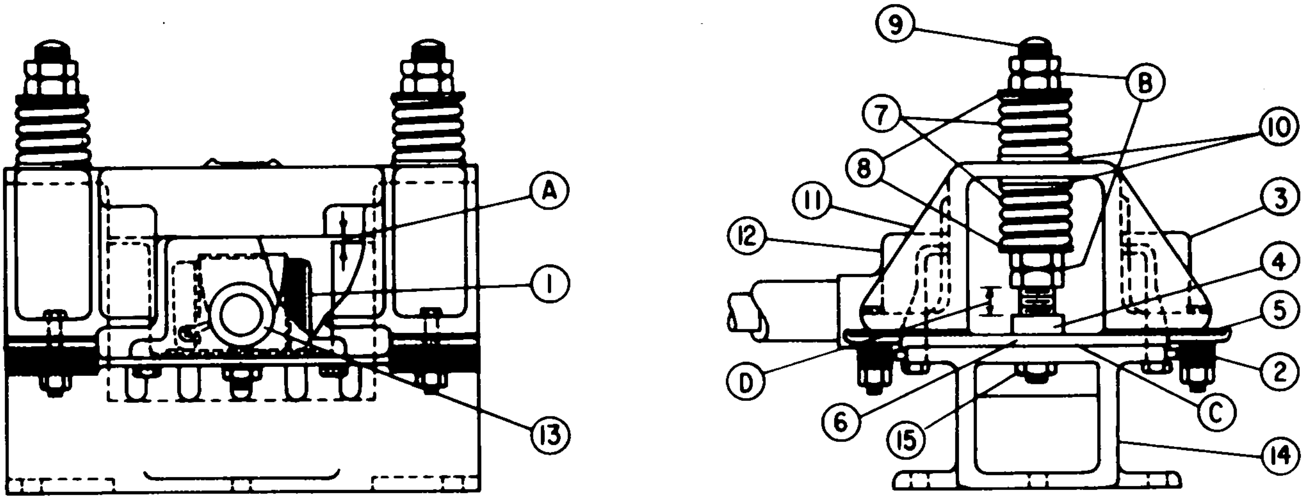
VIBRATORY TABLE COMPONENT PARTS



Item	Description
1	Coil rubber
2	Rubber transverse spring spacer
3	Coil cover (plain)
4	Spring clamp (center)
5	Leaf springs
6	Coil springs
7	Spring seats (outer)
8	Stud
9	Spring seats (inner)
10	Armature mounting assembly

Item	Description
11	Coil cover (cable support side)
12	Cable strain relief
13	Core mounting assembly
14	Vibration dampener
15	Leaf spring spacer (center)
16	Leaf spring spacer (end)
A	Clearance between pole faces
B	Lock nuts
C	Location of shims

Figure X1.1. – Vibratory table component parts (model No. V-80).



Item	Description
1	Coil assembly
2	Rubber transverse spring
3	Coil cover (plain)
4	Leaf spring clamp
5	Leaf spring
6	Striking plate assembly
7	Coil spring
8	Outside spring seat
9	Stud

Item	Description
10	Inside spring seat
11	Armature costing
12	Coil cover (cable side)
13	Cable bushing
14	Core assembly
15	Stop nut (5/8 inch-11)
A	Air gap
B	Lock nuts
C	Location of shim
D	Lock nuts/leaf spring clamp gap

Figure X1.2. - Vibratory table component parts (model No. V-75).

APPENDIX X2

VIBRATORY TABLE CALIBRATION EQUIPMENT

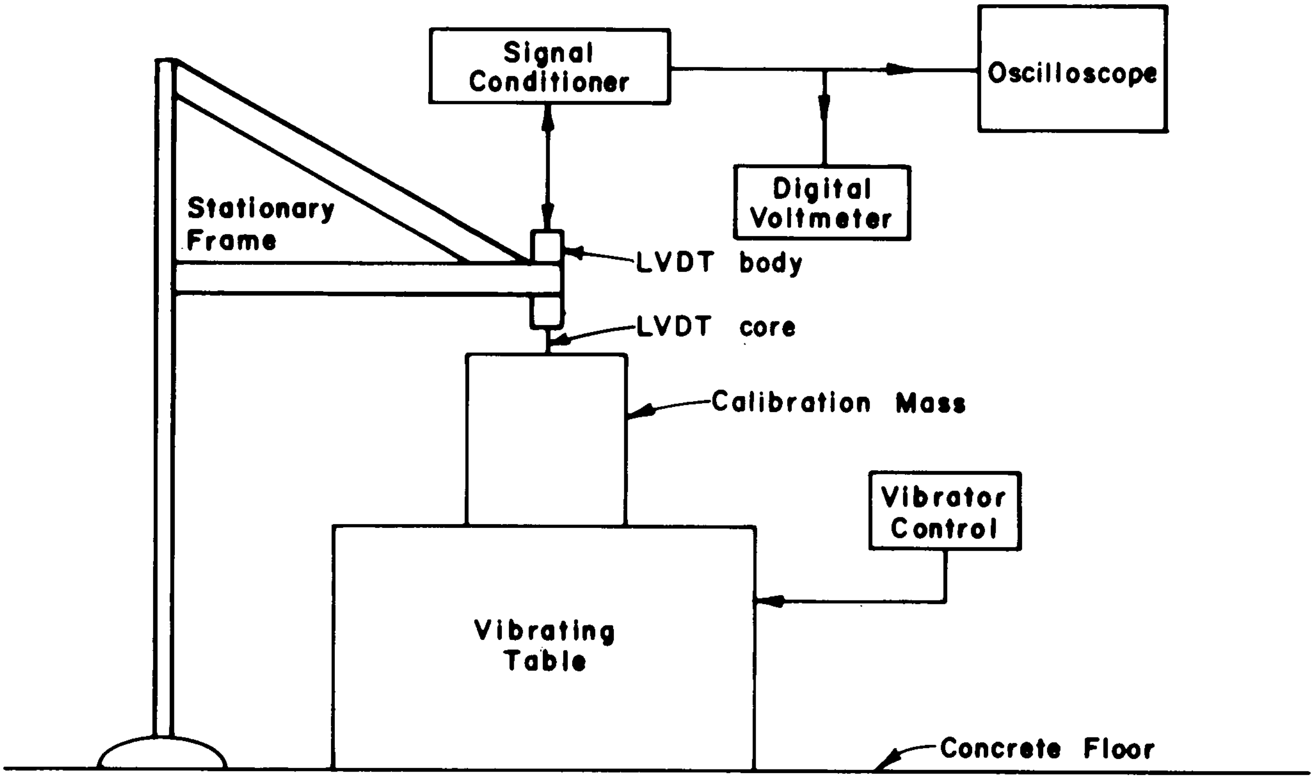
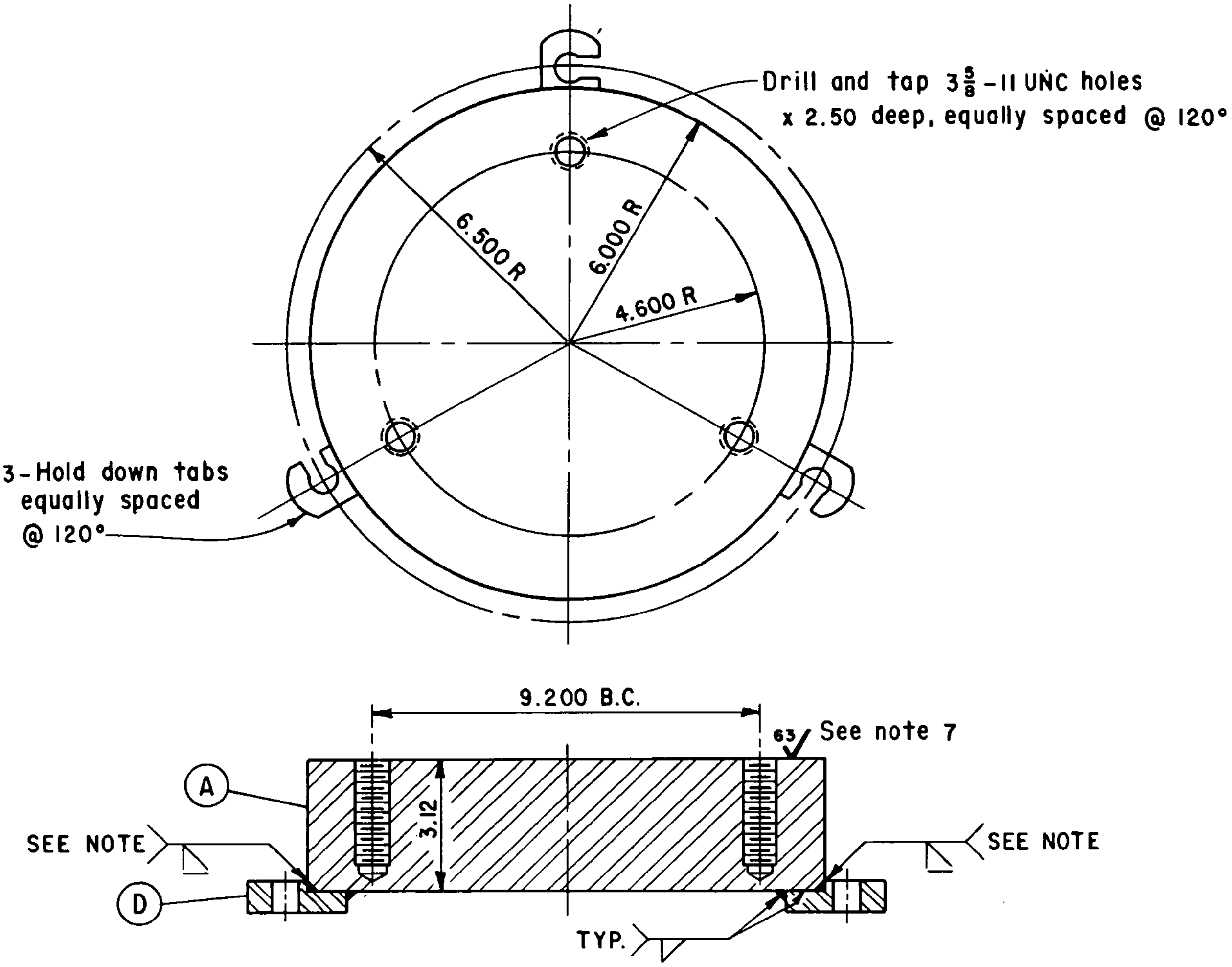


Figure X2.1 – Vibratory table calibration equipment — schematic.



PART A – BOTTOM MASS

ONE REQ'D

SHOP NOTES

NOTE: Manufacture these parts in the following sequence:

1. Manufacture Hold Down Tabs Part D.
2. Obtain 6 cap screws.
3. Manufacture Bottom Mass Part A welding of Tabs Part D.
4. Manufacture Center Mass Part B.
5. Obtain the mass of the bottom Mass Part A and Center Mass Part B; include 3 cap screws.
6. Subtract the mass obtained in No.5 from $300^{\#}$ this will be the mass required for the Top Mass Part C including the additional 3 cap screws.
7. Surface texture $\overset{63}{\checkmark}$ flat and parallel to adjoining surfaces.

NOTE: Prior to welding the Hold Down Tabs to the Calibration Mass, bevel edge of Hold Down Tabs and grind or machine excess weld spatter so that the weld is flush with the outside of Calibration Mass.

All material manufactured from cold rolled steel.

NOTE

All dimensions are in inches unless otherwise shown.

Figure X2.2. – Vibratory table calibration equipment. 101-D-647

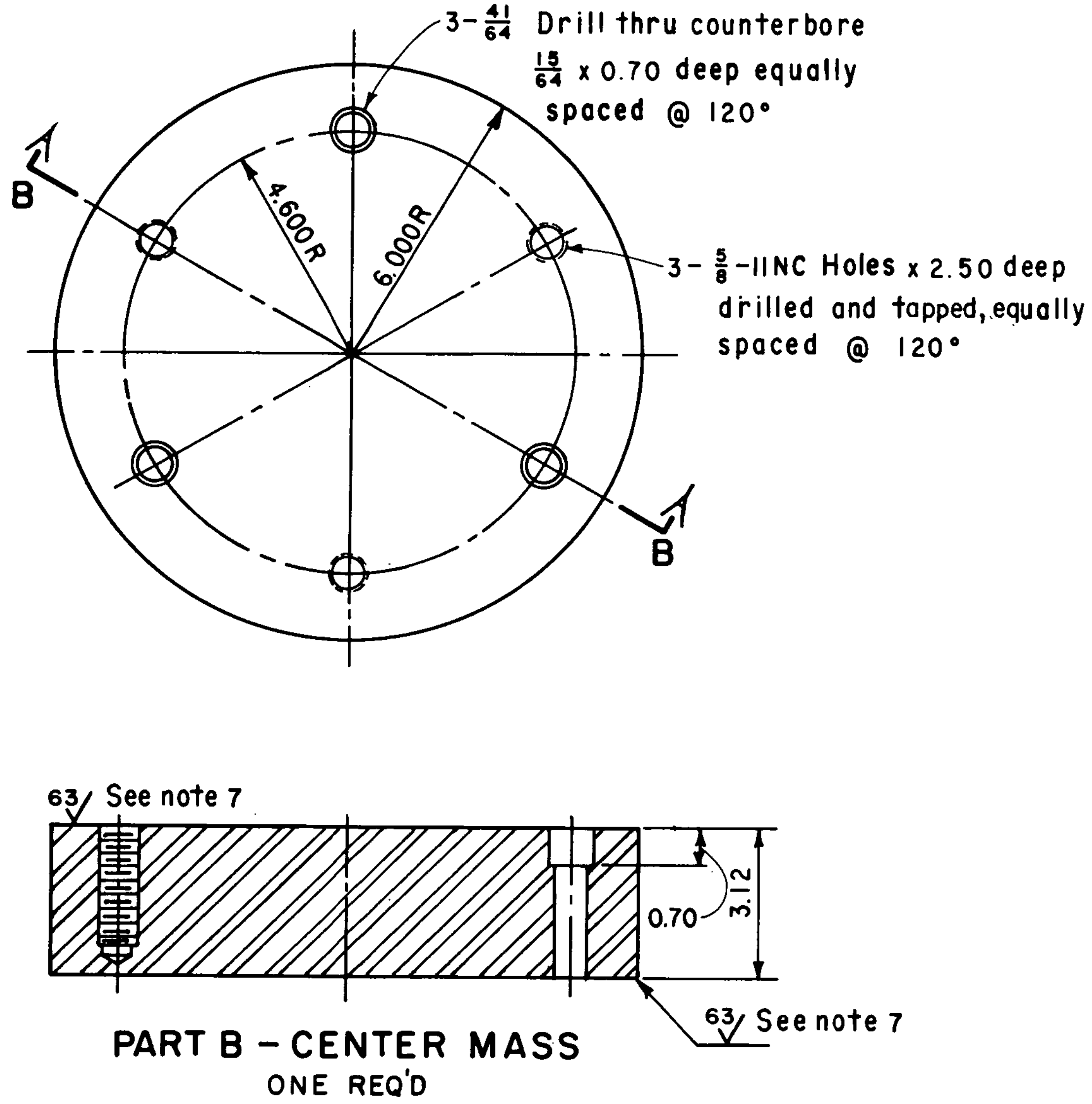


Figure X2.2. - Vibratory table calibration equipment — Continued. 101-D-647

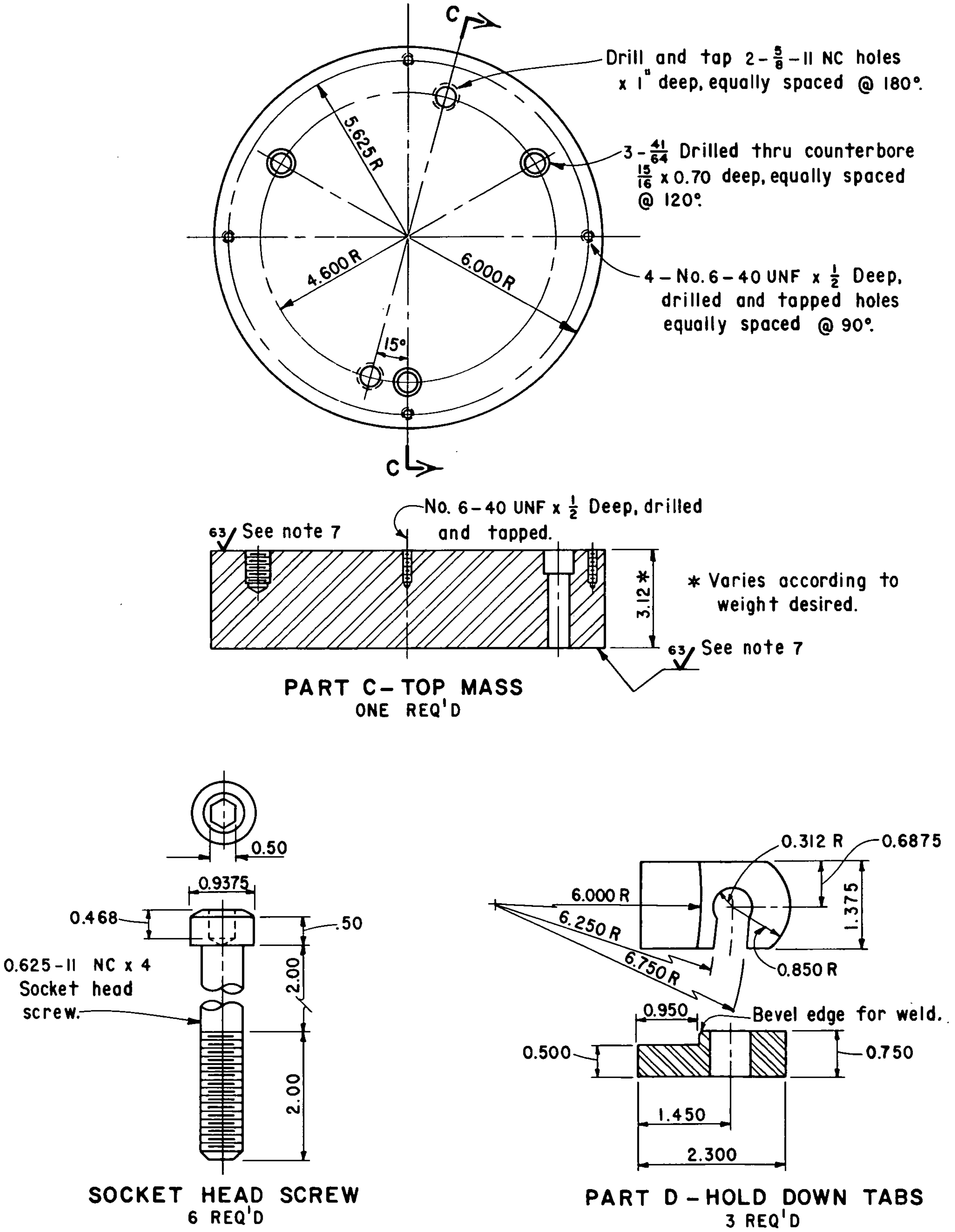
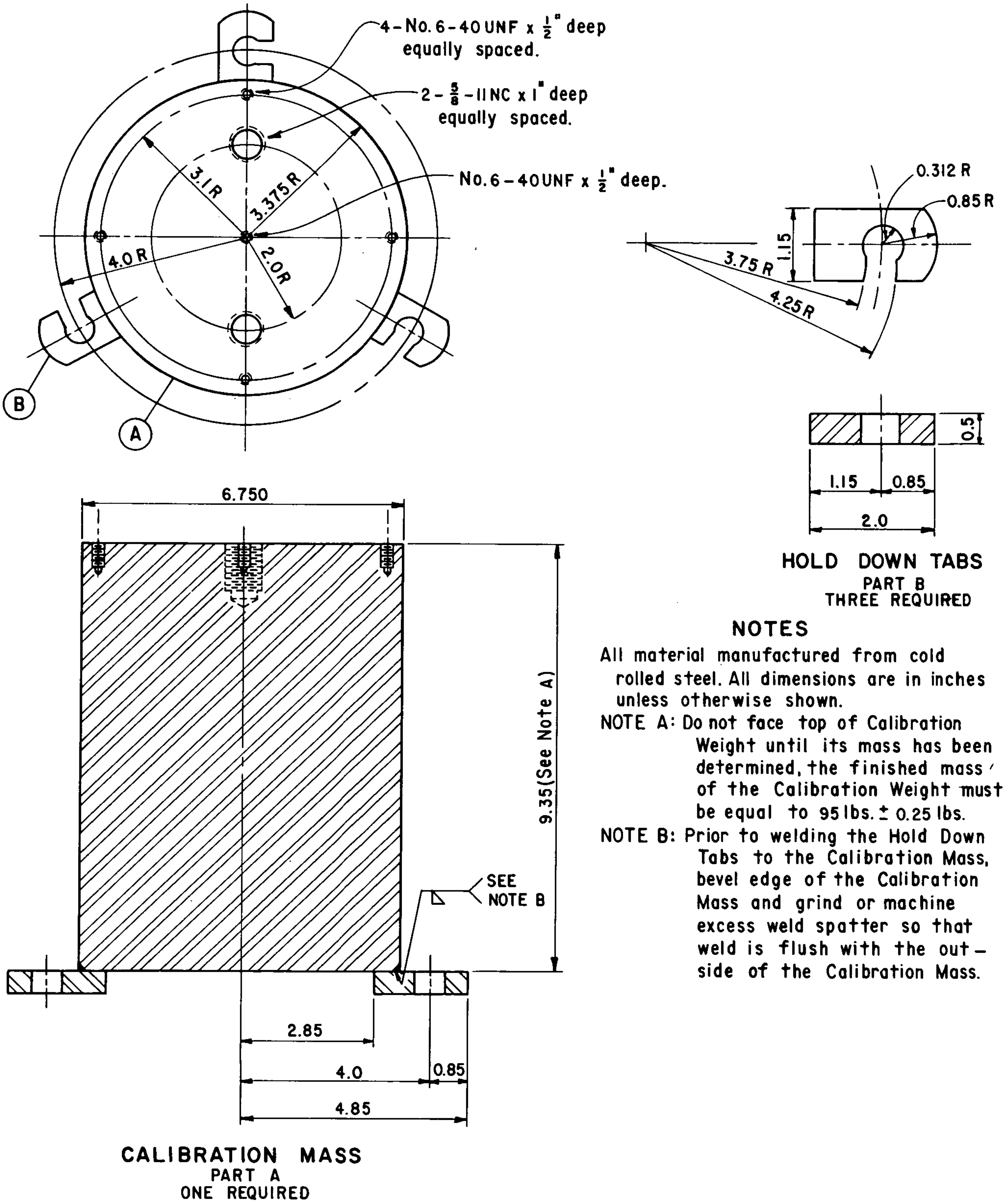


Figure X2.2. – Vibratory table calibration equipment — Continued. 101-D-647



NOTES

All material manufactured from cold rolled steel. All dimensions are in inches unless otherwise shown.

NOTE A: Do not face top of Calibration Weight until its mass has been determined, the finished mass of the Calibration Weight must be equal to 95 lbs. ± 0.25 lbs.

NOTE B: Prior to welding the Hold Down Tabs to the Calibration Mass, bevel edge of the Calibration Mass and grind or machine excess weld spatter so that weld is flush with the outside of the Calibration Mass.

Figure X2.2. – Vibratory table calibration equipment. 101-D-648

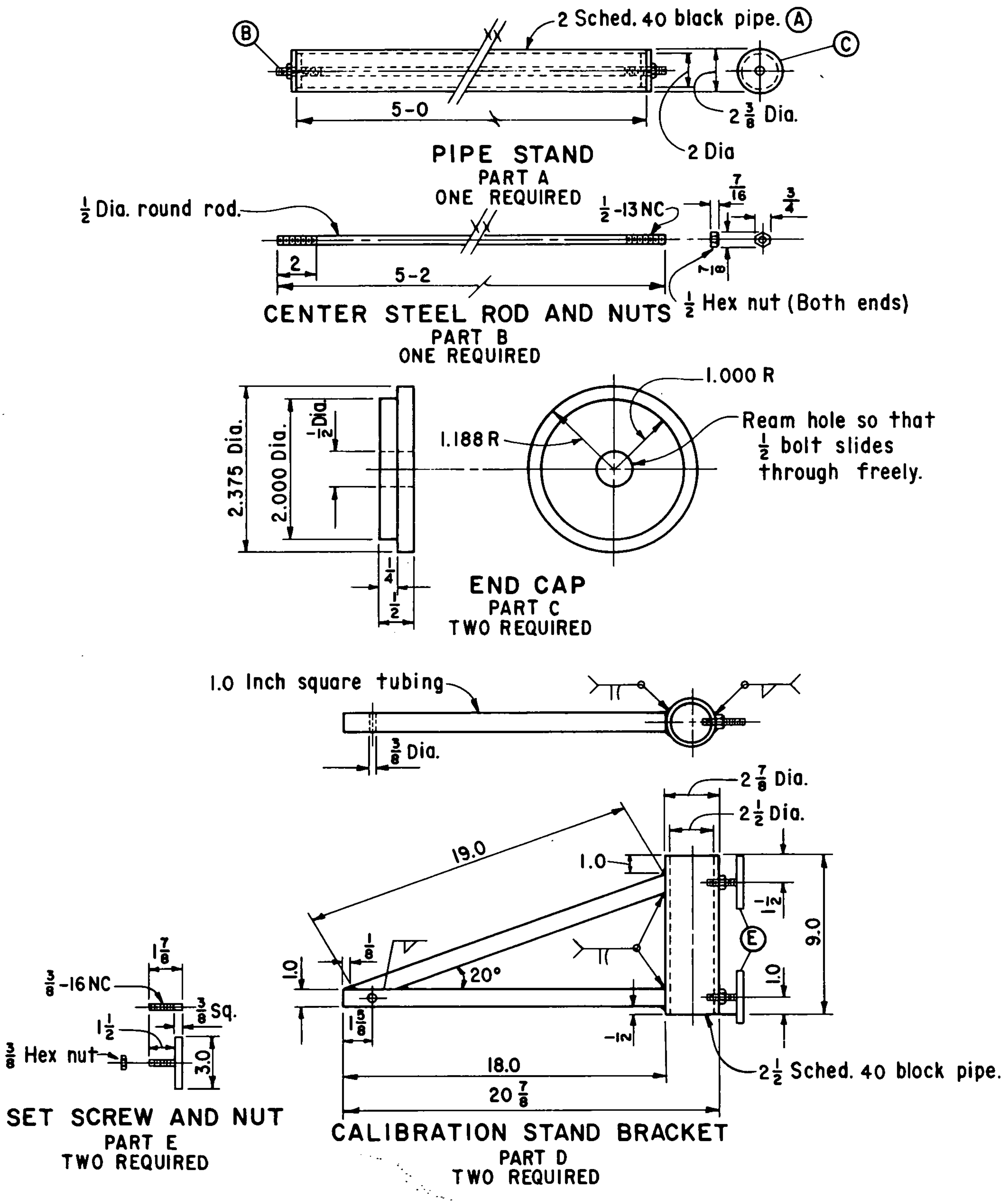
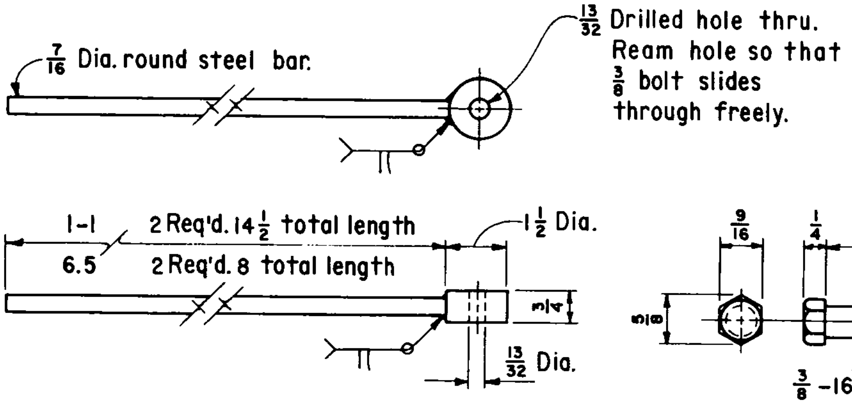
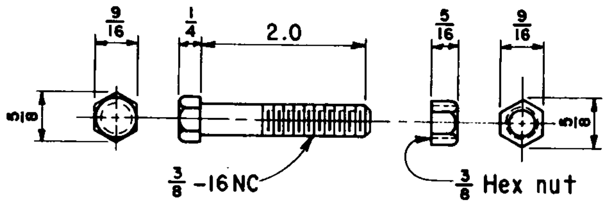


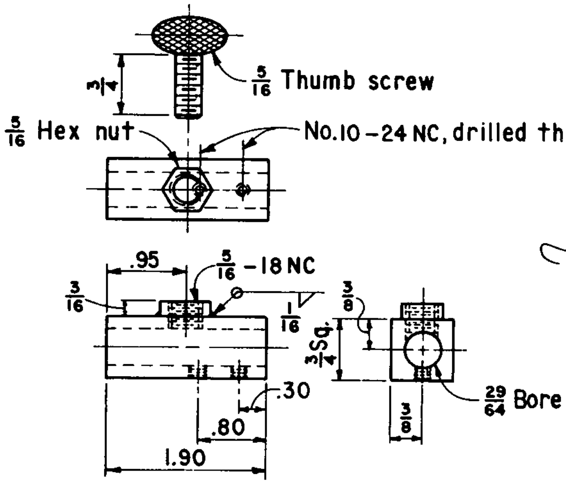
Figure X2.2. - Vibratory table calibration equipment — 101-D-649

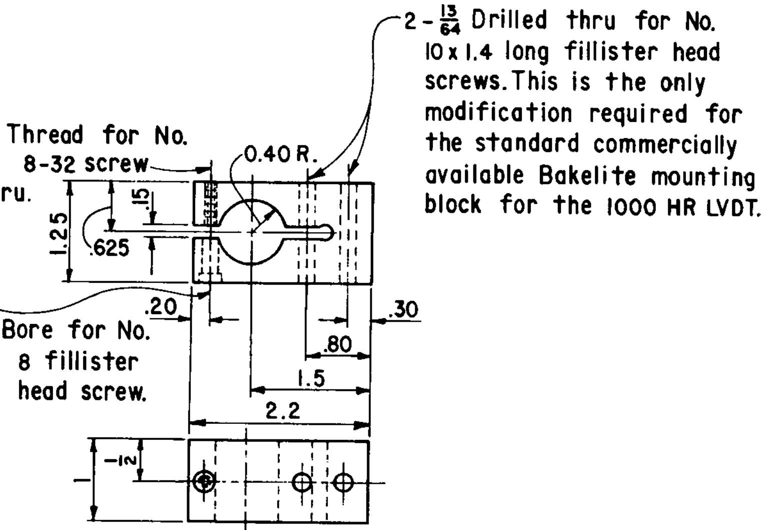


EXTENSION ARMS
PART F
TWO OF EACH REQUIRED



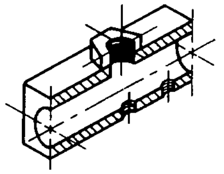
STANDARD 3/8 NC BOLT AND NUT
PART G
TWO REQUIRED





LVDT MOUNTING BLOCK CARRIER
PART H
TWO REQUIRED

BAKELITE MOUNTING BLOCK
PART I
TWO REQUIRED



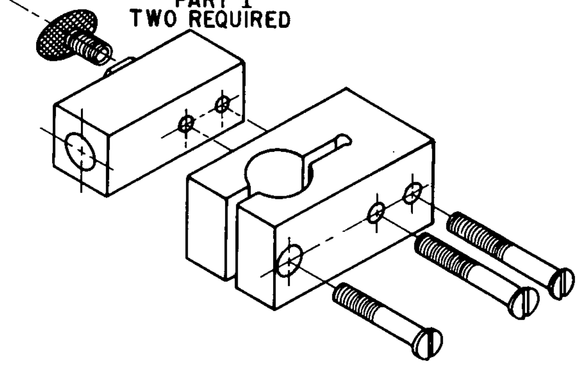
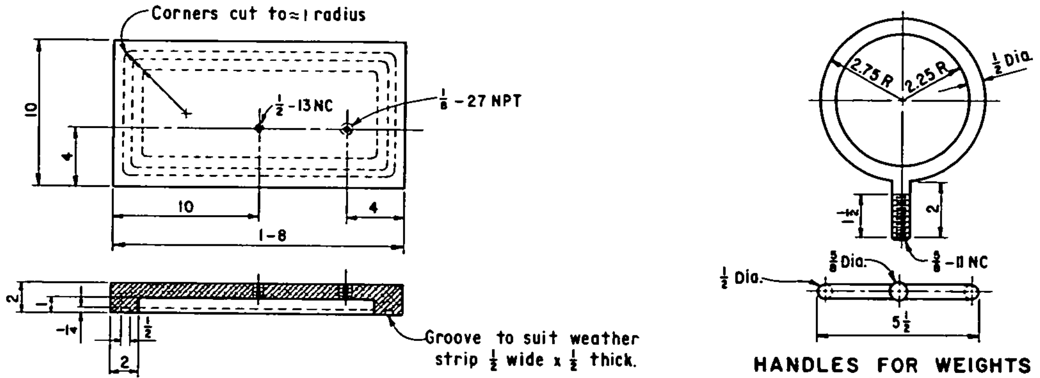


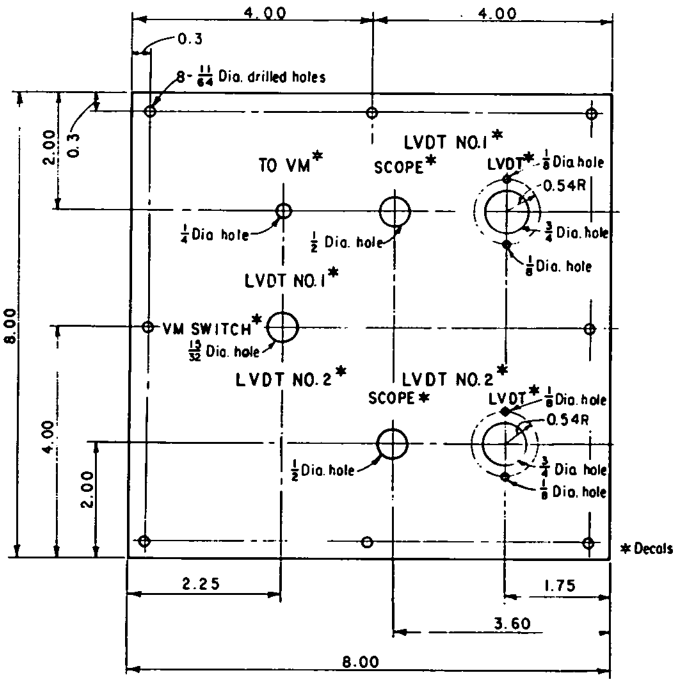
Figure X2.2. – Vibratory table calibration equipment — Continued. 101-D-649



ALUMINUM VACUUM PLATE
PART J

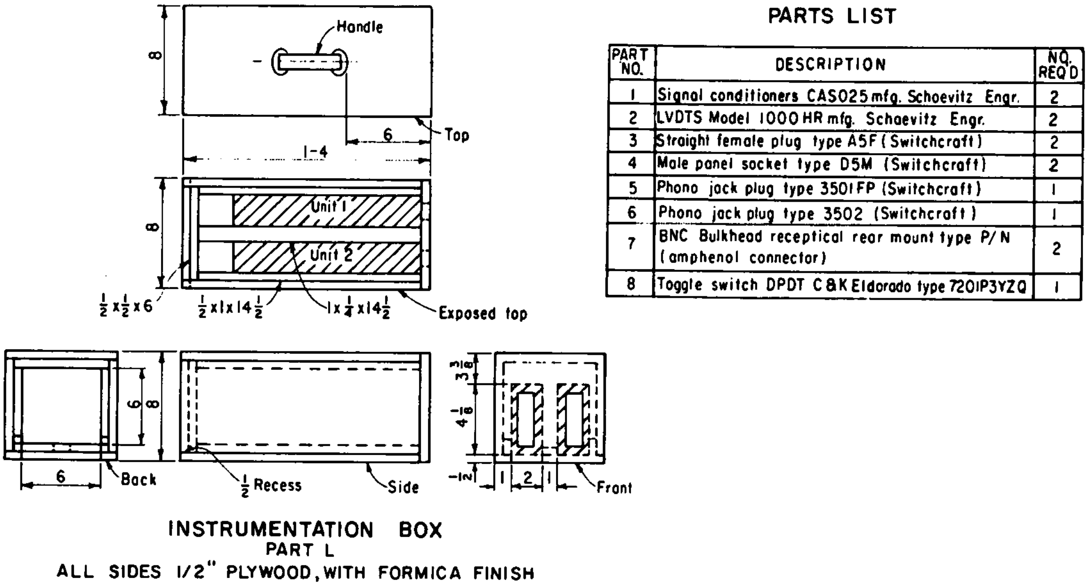
HANDLES FOR WEIGHTS
PART K
TWO REQUIRED

Figure X2.2. - Vibratory table calibration equipment. — Continued. 101-D-649



COVER PLATE FOR THE AMPLIFIER CARRYING CASE
PART K
0.062 THICK STAINLESS STEEL PLATE
ONE REQUIRED

Figure X2.2. - Vibratory table calibration equipment. 101-D-650.



PARTS LIST

PART NO.	DESCRIPTION	NO. REQ'D
1	Signal conditioners CAS025 mfg. Schoevitz Engr.	2
2	LVDTS Model 1000 HR mfg. Schaevitz Engr.	2
3	Straight female plug type A5F (Switchcraft)	2
4	Male panel socket type D5M (Switchcraft)	2
5	Phono jack plug type 3501FP (Switchcraft)	1
6	Phono jack plug type 3502 (Switchcraft)	1
7	BNC Bulkhead receptical rear mount type P/N (amphenol connector)	2
8	Toggle switch DPDT C&K Eldorado type 7201P3YZQ	1

Figure X2.2. – Vibratory table calibration equipment — Continued. 101-D-650

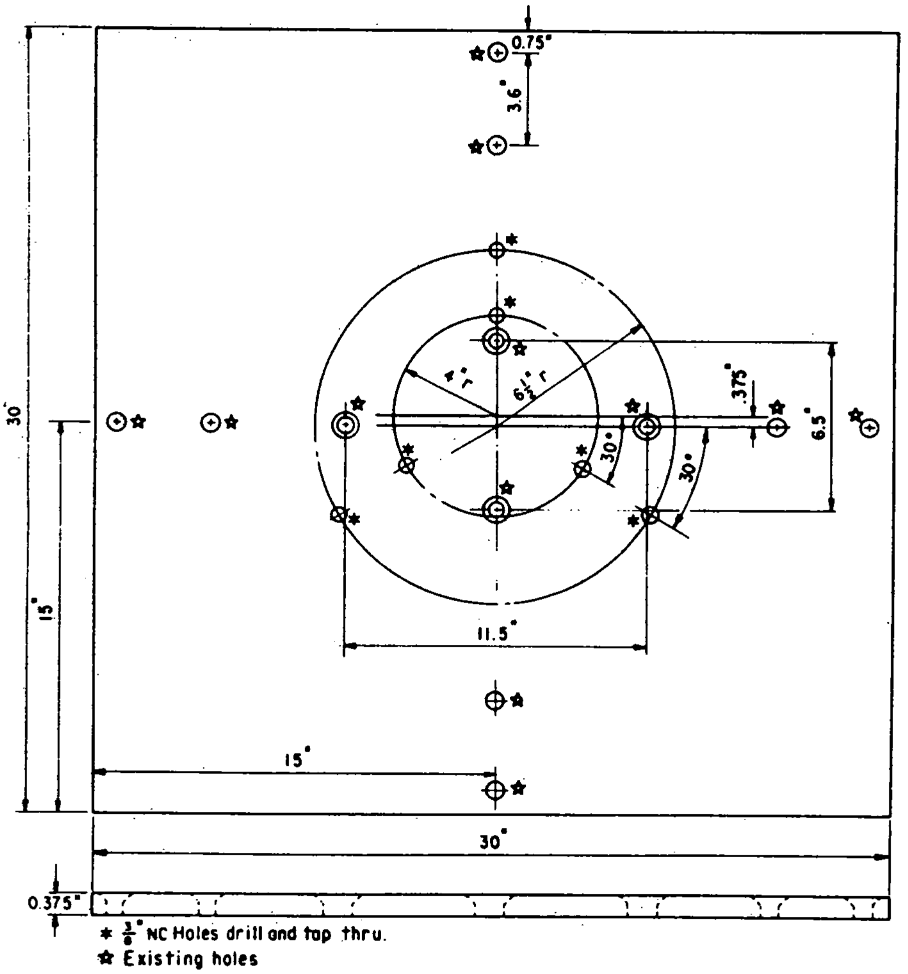


Figure X2.3. – Mounting hole locations.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5005-86

PROCEDURE FOR

DETERMINING UNIFIED SOIL CLASSIFICATION (VISUAL METHOD)

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5005. The number immediately following the designation indicates the year of acceptance or the year of last revision.

This procedure is similar to ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) except for the following: (1) change in title and format, (2) references to USBR procedures, (3) note 2 in ASTM D 2488 is required in this procedure, (4) note 4 in ASTM D 2488 is required in this procedure, (5) the maximum particle size is in millimeters with prescribed increments of measurement, (6) the specimens for the dry strength test are one-fourth inch (6 mm) in diameter rather than one-half inch (12 mm), (7) note 14 is not used, and (8) moisture content is used here instead of water content and mass is substituted for weight.

For circumstances where it may be required or expedient to use ASTM standards, ASTM D 2487 or D 2488 may be substituted for USBR 5000 or 5005, respectively. However, it must be clearly stated in written comments, tables, figures, and logs that the ASTM standards were used.

1. Scope

1.1 This designation outlines the procedures for the description of soils for engineering purposes.

1.2 This designation outlines procedures for visually identifying soils for engineering purposes based on the classification system described in USBR 5000. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on the visual-manual processes.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures required in USBR 5000 shall be used.

1.2.2 The identification portion of this procedure — in assigning a group symbol and name — is limited to soil particles smaller than 3 inches (75 mm); that is, passing a U.S.A. Standard series 3-inch sieve.

1.2.3 The identification portion of this procedure is limited to naturally occurring soils.

NOTE 1.-This procedure may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (see app. X2).

1.3 The descriptive information in this procedure may be used with other soil classification systems or for materials other than naturally occurring soils.

2. Applicable Documents

2.1 *USBR Procedures*:

USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

USBR 5000 Determining Unified Soil Classification (Laboratory Method)

2.2 *ASTM Standards*:

D 2487 Classification of Soils for Engineering Purposes

D 2488 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)

3. Summary of Method

3.1 Using visual examination and simple manual tests, this procedure gives standardized criteria and processes for describing and identifying soils.

3.2 Soil can be given an identification by assigning a group symbol(s) and name. The flow charts (figure 1 for fine-grained soils and figure 2 for coarse-grained soils) can be used to determine the appropriate group symbol(s) and name. If the soil has visually determined properties that do not distinctly place it into a specific group, borderline symbols may be used (see app. X3).

3.3 A distinction must be made between *dual symbols* and *borderline symbols*.

3.3.1 A *dual symbol* (two symbols separated by a hyphen, e.g., GP-GM, SW-SC, CL-ML) should be used to indicate the soil has been identified as having the properties of a classification as required by USBR 5000 where two symbols are required. Two symbols are required when the soil has between 5 and 12 percent fines and where the liquid limit and plasticity index values plot in the CL-ML (cross hatched) area of the plasticity chart.

3.3.2 A *borderline symbol* (two symbols separated by a slash, e.g., CL/CH, GM/SM, CL/ML) should be used to indicate the soil has been identified as having properties

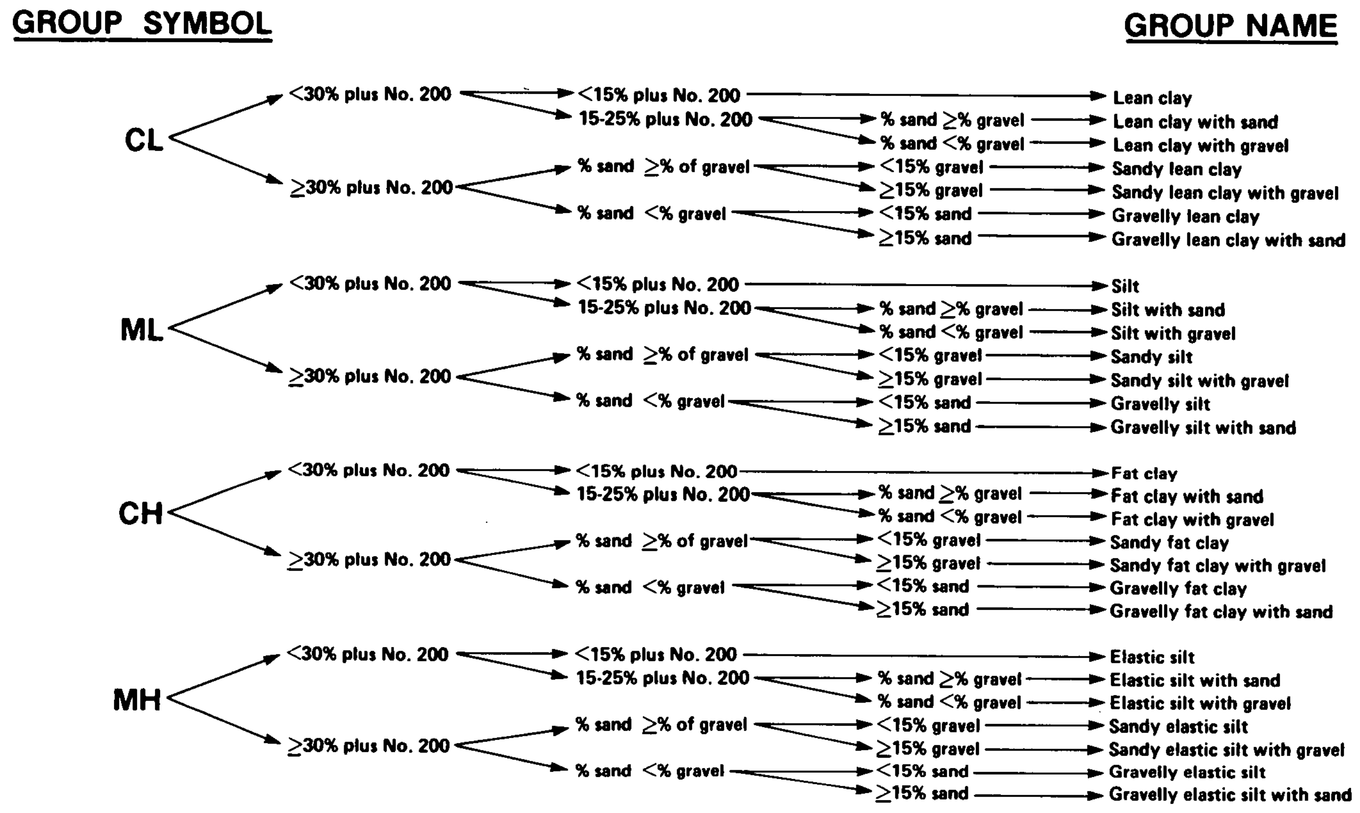


Figure 1a. – Flowchart for identifying inorganic fine-grained soil (50% or more fines) — visual-manual method.

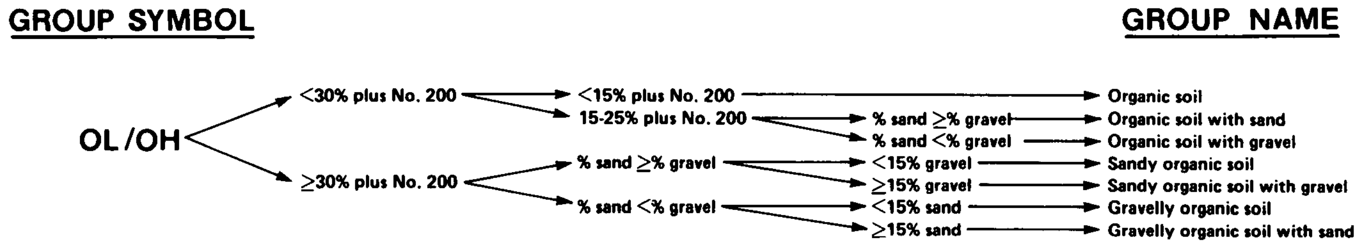


Figure 1b. – Flowchart for identifying organic fine-grained soil (50% or more fines) — visual-manual method.

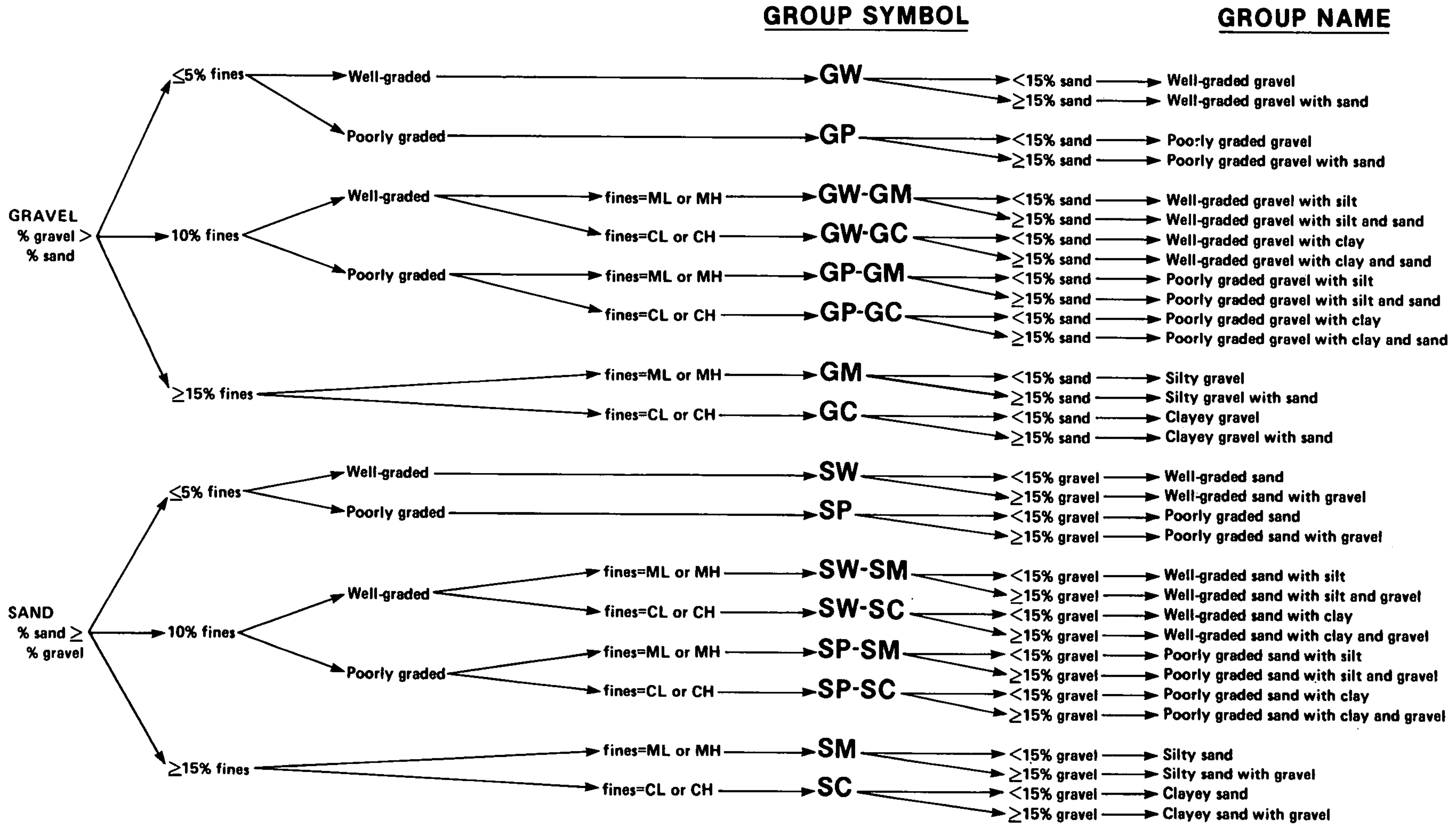


Figure 2. – Flowchart for identifying coarse-grained soils (less than 50% fines) — visual-manual method.

that do not distinctly place the soil into a specific group (see app. X3).

4. Significance and Use

4.1 The descriptive information required in this procedure can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

4.2 The descriptive information required in this procedure should be used to supplement the classification of a soil as determined in USBR 5000.

4.3 This procedure may be used in identifying soils using the classification group symbols and names as prescribed in USBR 5000. Since the names and symbols used in this procedure to identify the soils are the same as those used in USBR 5000, it shall be clearly stated in reports, etc., that the classification symbol and name are based on the visual-manual procedures.

4.4 This procedure is to be used not only for identification of soils in the field but also in the office, in the laboratory, or wherever soil samples are inspected and described.

4.5 The procedure has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 2.-The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it also may be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

4.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the processes in this procedure for every sample. Soils which appear to be similar can be grouped together. One sample from the group can be completely described and identified, with the others referred to "as similar" based on performing only a few of the descriptive and identification processes described in this procedure.

5. Terminology

5.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

5.1.1 *Boulder.*-A particle of rock that will not pass a 12-inch (300-mm) square opening.

5.1.2 *Cobble.*-A particle of rock that will pass a 12-inch (300-mm) square opening and be retained on a 3-inch (75-mm) U.S.A. Standard sieve.

5.1.3 *Peat.*-A soil composed primarily of vegetable tissue in various stages of decomposition with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous (ASTM D 2487-83).

5.2 *Terms Specific to This Designation*:

5.2.1 *Gravel.*-Particles of rock that will pass a 3-inch (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

Coarse	— Passes 3-inch (75-mm) sieve and retained on 3/4-inch (19.0-mm) sieve
Fine	— Passes 3/4-inch (19.0-mm) sieve and retained on No. 4 (4.75-mm) sieve

5.2.2 *Sand.*-Particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

Coarse	— Passes No. 4 (4.75-mm) sieve and retained on No. 10 (2.00-mm) sieve
Medium	— Passes No. 10 (2.00-mm) sieve and retained on No. 40 (425-μm) sieve
Fine	— Passes No. 40 (425-μm) sieve and retained on No. 200 (75-μm) sieve

5.2.3 *Clay.*-Soil passing the No. 200 (75-μm) U.S.A. Standard sieve that exhibits plasticity (putty-like properties) within a range of moisture contents, and which exhibits considerable strength when air-dried. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, having a plasticity index equal to or greater than 4 and the plot of plasticity index versus liquid limit falls on or above the "A"-line (see fig. 3, USBR 5000).

5.2.4 *Silt.*-Material passing the No. 200 (75-μm) U.S.A. Standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dried (ASTM). For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, having a plasticity index less than 4 or if the plot of plasticity index versus liquid limit falls below the "A"-line (see fig. 3, USBR 5000).

5.2.5 *Organic Clay.*-A clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay except that its liquid limit value after ovendrying is less than 75 percent of its liquid limit value before ovendrying.

5.2.6 *Organic Silt.*-A silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after ovendrying is less than 75 percent of its liquid limit value before ovendrying.

6. Apparatus

6.1 *Required Apparatus*:

6.1.1 Small supply of water.

6.1.2 Pocket knife or small spatula.

6.2 *Useful Auxiliary Apparatus*:

6.2.1 Small bottle of dilute hydrochloric acid, one part HCl (10 N) to three parts distilled water.

6.2.2 Small test tube and stopper, or jar with a lid.

6.2.3 Dish for wash test.

6.2.4 Small hand lens.

6.2.5 Ruler.

7. Precautions

7.1 When preparing the dilute HCl (hydrochloric acid) solution of one part concentrated HCl (10 N) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes in contact with skin, rinse thoroughly with water.

CAUTION.-Do not add water to acid.

8. Sampling

8.1 The sample shall be considered to be representative of the stratum, from where it was obtained, by an appropriate accepted or standard procedure.

NOTE 3.-The sampling procedure should be identified as having been conducted in accordance with a USBR procedure or an ASTM standard, or other appropriate standard or procedure.

8.2 The sample shall be carefully identified as to origin.

NOTE 4.-Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon, or a location description with respect to a permanent monument, grid system, or station number and offset with respect to a stated centerline, and a depth or elevation.

8.3 For accurate description and identification, the minimum amounts of the specimen to be examined shall be in accordance with the following schedule:

Maximum particle size, sieve opening		*Minimum specimen size, dry mass*	
mm	in	kg	lbm
4.75	No. 4	0.1	0.2
9.5	3/8	0.25	0.5
19.0	3/4	1.1	2.5
37.5	1-1/2	10	20
75.0	3	70	150

NOTE 5.-If random, isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the above schedule.

8.4 If the field sample or specimen being examined is smaller than the minimum amount, the report shall include an appropriate remark.

9. Descriptive Information

9.1 Describe the *angularity* of the sand (coarse sizes only), gravel, cobbles, and boulders as rounded, subrounded, subangular, or angular as indicated by the criteria in table 1 and on figure 3. A range of angularity may be stated such as subrounded to rounded.

9.2 Describe the *shape* of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in table 2 and on figure 4; otherwise, do not remark. Indicate the fraction of particles having that shape such as one-third of gravel particles are flat.

Table 1. - Criteria for describing angularity of coarse-grained particles (see fig. 3).

Rounded	- Particles have smoothly curved sides and no edges
Subrounded	- Particles have nearly plane sides but have well-rounded corners and edges
Subangular	- Particles are similar to angular description but have rounded edges
Angular	- Particles have sharp edges and relatively plane sides with unpolished surfaces

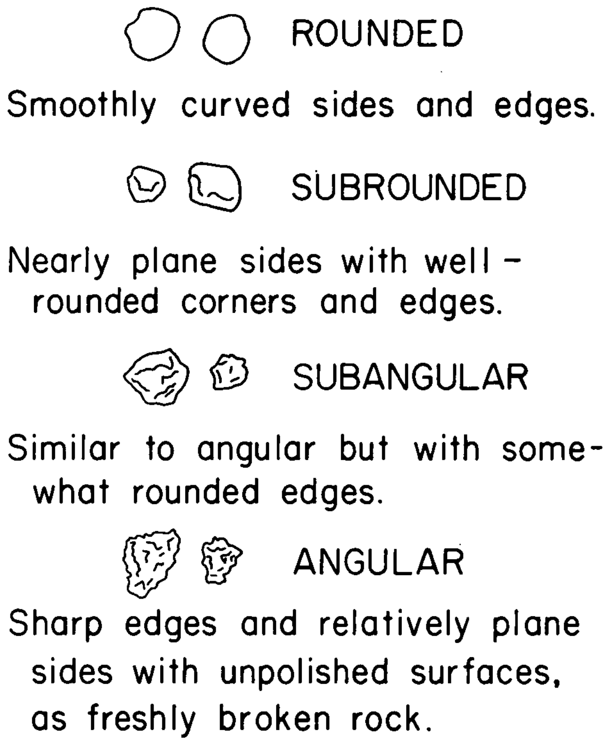


Figure 3. - Typical angularity of coarse-grained particles.

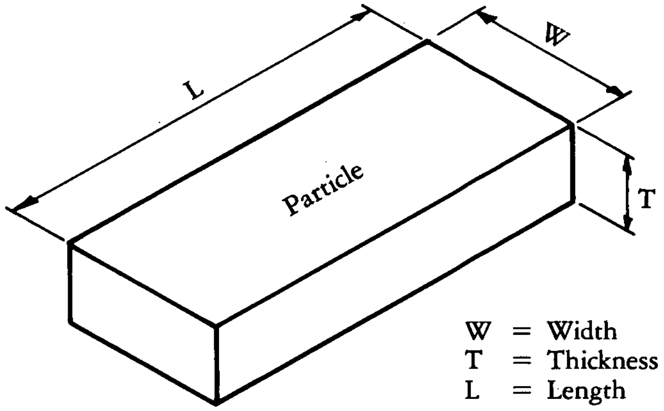
Table 2. - Criteria for describing particle shape (see fig. 4).

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	- Particles with $\frac{\text{width}}{\text{thickness}} > 3$
Elongated	- Particles with $\frac{\text{length}}{\text{width}} > 3$
Flat and elongated	- Particles meet criteria for both flat and elongated

9.3 Describe the *color*. Color is an important property in identifying organic soils and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this should be noted and all representative colors should be described. Color should be described for moist samples. If color represents a dry condition, this should be stated in the report.

9.4 Describe the *odor* if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples; but if the samples



Flat: W/T > 3
Elongated: L/W > 3
Flat and Elongated: meets both criteria

Figure 4. - Criteria for particle shape.

are dried, the odor may often be revived by heating a moistened sample. Describe the odor if unusual (petroleum product, chemical, etc.).

9.5 Describe the *moisture condition* as dry, moist, or wet as indicated by the criteria in table 3.

9.6 Describe the *reaction with HCl* as none, weak, or strong as indicated by the criteria in table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute HCl is important.

9.7 For intact fine-grained soil, describe the *consistency* as very soft, soft, firm, hard, or very hard as indicated by the criteria in table 5. This observation is inappropriate for disturbed soils or soils with significant amounts of gravel.

9.8 Describe the *cementation* of intact coarse-grained soils as weak, moderate, or strong as indicated by the criteria in table 6.

9.9 Describe the *structure* of intact soils according to the criteria in table 7.

9.10 For gravel and sand components, describe the range of particle sizes within each component as defined in subparagraphs 5.2.1 and 5.2.2 (for example: about 20 percent fine to coarse gravel, about 40 percent fine to coarse sand).

9.11 Describe the *maximum particle size* found in the sample.

9.11.1 If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in subparagraph 5.2.2 (for example: maximum size, medium sand).

9.11.2 If the maximum particle size is a gravel size, describe maximum particle size in millimeters as the smallest sieve opening that the particle would pass [for example: maximum size, 37.5 mm (would pass 37.5-mm-square opening but not a 19.0-mm-square opening)].

9.11.3 If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle (for example: maximum dimension, 400 mm). Use 25-mm increments from 75 to 300 mm (cobbles) and 100-mm increments for particles larger than 300 mm (boulders).

Table 3. - Criteria for describing moisture condition.

Dry	- Absence of moisture, dusty, dry to the touch
Moist	- Damp but no visible water
Wet	- Visible free water, usually soil is below water table

Table 4. - Criteria for describing the reaction with HCl.

None	- No visible reaction
Weak	- Some reaction, with bubbles forming slowly
Strong	- Violent reaction, with bubbles forming immediately

Table 5. - Criteria for describing consistency.

Very soft	- Thumb penetrates soil more than 1 inch (25 mm)
Soft	- Thumb penetrates soil about 1 inch (25 mm)
Firm	- Thumb indents soil about 1/4 inch (6 mm)
Hard	- Thumb cannot indent soil but readily indented with thumbnail
Very hard	- Thumbnail cannot indent soil

Table 6. - Criteria for describing cementation.

Weak	- Crumbles or breaks with handling or little finger pressure
Moderate	- Crumbles or breaks with considerable finger pressure
Strong	- Will not crumble or break with finger pressure

Table 7. - Criteria for describing structure.

Stratified	- Alternating layers of varying material or color with layers at least 1/4 inch (6 mm) thick; note thickness
Laminated	- Alternating layers of varying material or color with the layers less than 1/4 inch (6 mm) thick; note thickness
Fissured	- Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	- Fracture planes appear polished or glossy, sometimes striated
Blocky	- Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	- Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	- Same color and appearance throughout

9.12 Describe the *hardness* of coarse sand and larger particles as hard or state what happens when the particles are hit by a hammer (e.g., gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow). Hard means particles do not crack, fracture, or crumble under a hammer blow.

9.13 Additional comments should be noted such as:
Presence of roots or root holes
Difficulty in drilling or augering hole
Caving of trench or hole
Presence of mica

9.14 A local or commercial name and/or a geologic interpretation for the soil may be added if identified as such.

9.15 A classification or identification of the soil according to other classification systems may be added if identified as such.

10. Identification of Peat

10.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture—usually a dark brown to black color—and an organic odor should be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

11. Specimen Preparation for Identification

11.1 The soil identification portion of this procedure is based on the minus 3-inch (75-mm) particle sizes. The plus 3-inch (75-mm) particles must be removed, manually, for a loose sample, or mentally evaluated, for an intact sample before classifying the soil.

11.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 6.-Since the percentages of the particle-size distribution in USBR 5000 are by dry mass and the estimates of percentages for gravel, sand, and fines in this procedure are by dry mass, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

11.3 Of the fraction of the soil smaller than 3 inches (75 mm), estimate and note the percentage, by dry mass, of the gravel, sand, and fines. (See app. X4 for suggested procedures.)

NOTE 7.-Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry mass. Frequent comparisons with laboratory gradation analyses should be made.

11.3.1 The percentages shall be estimated to the nearest 5 percent. The percentages of gravel, sand, and fines must add up to 100 percent.

11.3.2 If one of the components is present, but not in sufficient quantity to be considered 5 percent of the minus 3-inch (75-mm) portion, indicate its presence by the term *trace* (for example: trace of fines). A trace is not to be considered in the total of 100 percent for the components.

12. Preliminary Identification Procedure

12.1 The soil is *fine grained* if it contains 50 percent or more fines; follow paragraph 13.

12.2 The soil is *coarse grained* if it contains less than 50 percent fines; follow paragraph 14.

13. Procedure for Identifying Fine-Grained Soils

13.1 *Selection.*-Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

13.2 *Dry Strength.*-From the specimen, select enough material to mold into a ball about 1 inch (25 mm) in diameter. Mold the material until it has the consistency of putty; add water if necessary.

13.2.1 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about 1/4 inch (6 mm) in diameter. Allow the test specimens to dry in air or sun or dry by artificial means as long as the temperature does not exceed 140 °F (60 °C).

13.2.2 If the test specimen contains natural dry lumps, those that are about 1/4 inch (6 mm) in diameter may be used in place of the molded balls.

NOTE 8.-The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

13.2.3 Test the strength of the dry balls or lumps by crushing between the fingers and note the strength as none, low, medium, high, or very high according to the criteria in table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

13.2.4 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate usually can be detected from the intensity of the reaction with dilute hydrochloric acid (see subpar. 9.6).

13.3 *Dilatancy.*-From the specimen, select enough material to mold into a ball about 1/2 inch (12 mm) in diameter. Mold the material; add water if necessary until it has a soft, but not sticky, consistency.

13.3.1 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample

Table 8. - Criteria for describing dry strength.

None	- The dry specimen crumbles into powder with mere pressure of handling.
Low	- The dry specimen crumbles into powder with some finger pressure.
Medium	- The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High	- The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	- The dry specimen cannot be broken between the thumb and a hard surface.

by closing the hand or pinching the soil between the fingers and note reaction as none, slow, or rapid according to the criteria in table 9. The reaction is the speed at which water appears while shaking and disappears while squeezing.

13.4 *Toughness*.–Following completion of the dilatancy test, shape the test specimen into an elongated pat and roll by hand on a smooth surface or between the palms into a thread about 1/8 inch (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread out into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 1/8 inch (3 mm). The thread will crumble at a diameter of 1/8 inch (3 mm) when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

13.4.1 Describe the toughness of the thread and lump as low, medium, or high according to the criteria in table 10.

13.5 *Plasticity*.–On the basis of observations made during the toughness test, describe the plasticity of the material according to the criteria given in table 11.

13.6 *Inorganic/Organic*.–Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see subpar. 13.8). If inorganic, follow subparagraph 13.7.

13.7 *Identification of Inorganic Fine-Grained Soils*:

13.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, none to slow dilatancy, and medium toughness and plasticity (see table 12).

13.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see table 12).

13.7.3 Identify the soil as a *silt*, ML, if the soil has none to low dry strength, slow to rapid dilatancy, and low toughness and plasticity or is nonplastic (see table 12).

Table 9. – Criteria for describing dilatancy.

None	– No visible change in the specimen
Slow	– Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	– Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Table 10. – Criteria for describing toughness.

Low	– Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
Medium	– Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.
High	– Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness.

Table 11. – Criteria for describing plasticity.

Nonplastic	– A 1/8-inch (3-mm) thread cannot be rolled at any moisture content.
Low	– The thread can be barely rolled and the lump cannot be formed when drier than the plastic limit.
Medium	– The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	– It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times close to the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Table 12. – Identification of inorganic fine-grained soils from manual tests.

Soil symbol	Dry strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

13.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, none to slow dilatancy, and low to medium toughness and plasticity (see table 12).

NOTE 9.–These properties for elastic silt are similar to those for a lean clay. However, the silt will dry much faster on the hand and have a smooth, silky feel when dry. Some soils which would classify as elastic silt, MH, according to the criteria in USBR 5000 are visually difficult to distinguish from lean clay, CL. It may be necessary to perform laboratory testing for proper identification.

13.8 *Identification of Organic Fine-Grained Soils*:

13.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, e.g., black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Normally, organic soils would not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 10.–In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, and toughness tests and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

13.9 If the soil is estimated to have 15 to 25 percent sand or gravel or both, the words "with sand" or "with gravel" shall be added to the group name (see figs. 1a and 1b) (for example: lean clay with sand, CL; silt with gravel, ML). If the percent of sand is equal to the percent of gravel, use "with sand."

13.10 If the soil is estimated to have 30 percent or more sand or gravel or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand (see figs. 1a and 1b) (for example: sandy lean clay, CL; gravelly fat clay, CH; sandy silt, ML). If the percent of sand is equal to the percent of gravel, use "sandy."

14. Procedure for Identifying Coarse-Grained Soils (contains less than 50 % fines)

14.1 The soil is a *gravel* if the percent gravel is estimated to be more than the percent sand.

14.2 The soil is a *sand* if the percent gravel is estimated to be equal to or less than the percent sand.

14.3 The soil is a *clean gravel* or *clean sand* if the percent fines is estimated to be 5 percent or less.

14.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

14.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded) or if it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

14.4 The soil is either a *gravel with fines* or a *sand with fines* if the percent fines is estimated to be 15 percent or more.

14.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in paragraph 13.

14.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in paragraph 13.

14.5 If the soil is estimated to contain 10 percent fines, give the soil a dual identification using two group symbols.

14.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

14.5.2 The group name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines (see fig. 2) (for example: well-graded gravel with clay, GW-GC; poorly graded sand with silt, SP-SM).

14.6 If the specimen is predominantly sand or gravel but contains an estimated 15 percent or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name (see fig. 2) (for example: poorly graded gravel with sand, GP; clayey sand with gravel, SC).

14.7 If the field sample contained any cobbles and/or boulders, the words "with cobbles," or "with cobbles and boulders" shall be added to the group name (for example: silty gravel with cobbles, GM).

15. Report

15.1 The report shall include information as to sample origin as well as the items indicated in table 13.

NOTE 11.–Example: CLAYEY GRAVEL WITH SAND AND COBBLES (GC): About 50 percent fine to coarse, subrounded to subangular gravel; about 30 percent fine to coarse, subrounded sand; about 20 percent fines with medium plasticity, high dry strength, no dilatancy, medium toughness; original field sample had trace of hard, subrounded cobbles; maximum size, 150 mm; weak reaction with HCl.

In-place conditions: firm, homogeneous, dry, brown
Geologic interpretation: alluvial fan

NOTE 12.–Other examples of soil descriptions and identifications are given in appendixes X1 and X2.

15.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in USBR 5000, it must be distinctly and clearly stated in log forms, summary tables, reports, etc., that the symbol and name are based on visual-manual procedures.

16. Precision and Accuracy

16.1 This method provides qualitative information only; therefore, a precision and accuracy statement is nonapplicable.

Table 13. - Checklist for description of soils.

1. Group name
2. Group symbol
3. Percent of cobbles and/or boulders (by volume)
4. Percent of gravel, sand and/or fines (by dry mass)
5. Particle-size range: Gravel - fine, coarse
   Sand - fine, medium, coarse
6. Particle angularity: angular subangular subrounded rounded
7. Particle shape (if appropriate): flat elongated flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic low medium high
11. Dry strength: none low medium high very high
12. Dilatancy: none slow rapid
13. Toughness: low medium high
14. Color (in moist condition)
15. Odor — mention only if organic or unusual
16. Moisture: dry moist wet
17. Reaction with HCl: none weak strong

For intact samples:

18. Consistency (fine-grained soils only): very soft soft firm hard very hard
19. Structure: stratified laminated fissured slickensided lensed homogeneous
20. Cementation: weak moderate strong
21. Local name
22. Geologic interpretation

Additional comments:

Presence of roots or root holes
Presence of mica, gypsum, etc.
Surface coatings on coarse-grained particles
Caving or sloughing of auger hole or trench sides
Difficulty in augering or excavation
Etc.

APPENDIX

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in subparagraph 15.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

Example 1: WELL-GRADED GRAVEL WITH SAND (GW): About 75 percent fine to coarse, hard, subangular gravel; about 25 percent fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm; dry, brown; no reaction with HCl.

Example 2: SILTY SAND WITH GRAVEL (SM): About 60 percent predominantly fine sand; about 25 percent fines with low plasticity, low dry strength, rapid dilatancy, low toughness; about 15 percent fine, hard, subrounded gravel (a few gravel-size particles fractured with hammer blow); maximum size, 20 mm; no reaction with HCl. Note: field sample size smaller than recommended.

In-place conditions — firm, stratified and contains lenses of silt 1 to 2 inches thick, moist, brown to gray; in-place dry unit weight was 106 lbf/ft^3 and in-place moisture was 9 percent.

Example 3: ORGANIC SOIL (OL/OH): About 100 percent fines with low plasticity, slow dilatancy, low dry strength, low toughness; wet, dark brown, organic odor; weak reaction with HCl.

Example 4: SILTY SAND WITH ORGANIC FINES (SM): About 75 percent fine to coarse, hard, subangular reddish sand; about 25 percent organic and dark brown nonplastic fines, no dry strength, slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

Example 5: POORLY GRADED GRAVEL WITH SILT, SAND, COBBLES AND BOULDERS (GP-GM): About 75 percent fine to coarse, hard, subrounded to subangular gravel; about 15 percent fine, hard, subrounded to subangular sand; about 10 percent nonplastic fines; moist, brown; no reaction with HCl. Original field sample had a trace of hard, subrounded cobbles and a trace of hard, subrounded boulders, having a maximum dimension of 500 mm.

X2. USING THE IDENTIFICATION METHOD AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, ETC.

X2.1 The identification method may be used as a descriptive system applied to materials that exist in situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, etc.).

X2.2 Materials such as shells, crushed rock, slag, etc., should be identified as such. However, the processes used in this procedure for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this method may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol (see examples).

X2.4 Examples of how group names and symbols could be incorporated into a descriptive system for materials that are not naturally occurring soils follow.

Example 1: SHALE CHUNKS: Retrieved as 2- to 4-inch pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 hours, material identified as "SANDY LEAN CLAY (CL)" — About 60 percent fines with medium plasticity, high dry strength, no dilatancy, medium toughness; about 35 percent fine to medium sand; about 5 percent gravel-size pieces of shale.

Example 2: CRUSHED SANDSTONE: Product of commercial crushing operation; "POORLY GRADED SAND WITH SILT (SP-SM)" — About 90 percent fine to medium sand; about 10 percent nonplastic fines; maximum size, medium sand; dry, reddish-brown; strong reaction with HCl.

Example 3: BROKEN SHELLS: Natural deposit of shells; "POORLY GRADED GRAVEL WITH SAND (GP)" — About 60 percent gravel-size broken shells; about 35 percent sand and sand-size shell pieces; about 5 percent fines.

Example 4: CRUSHED ROCK: Processed from gravel and cobbles in Pit No. 7; "POORLY GRADED GRAVEL (GP)" — About 90 percent fine, hard, angular gravel-size particles; about 10 percent coarse, hard, angular sand-size particles; maximum size, 20 mm; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash (for example: SC/CL, CL/CH).

X3.1.1 A borderline symbol may be used when the percent fines is estimated to be between 45 and 55 percent. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil (for example: GM/ML, CL/SC).

X3.1.2 A borderline symbol may be used when the percent sand and the percent gravel is estimated to be about the same (for example: GP/SP, SC/GC, GM/SM). It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded (for example: GW/GP, SW/SP).

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay (for example: CL/ML, CH/MH, SC/SM).

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility (for example: CL/CH, MH/ML).

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils (for example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL).

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH - lean to fat clay
ML/CL - clayey silt
CL/ML - silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort should be made to place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENT OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method.*-The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method.*-Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material then can be estimated from the wash test (see subpar. X4.3).

X4.3 *Wash Test* (for relative percentages of sand and fines).-Select and moisten enough minus No. 4 sieve size material to form a 1-inch (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear, and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on mass, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

While washing, it may be necessary to break down lumps of fines with a finger to get the correct percentages.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5325-89

PROCEDURE FOR

PERFORMING GRADATION ANALYSIS OF GRAVEL SIZE FRACTION OF SOILS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5325. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for performing gradation analysis of the gravel size fraction of soils. The term "gravel" refers to particles of rock that will pass a 3-inch (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve. The sieve sizes included in this designation are noted.

U.S.A. Standard series sieve	
mm	in
75	3
37.5	1-1/2
19.0	3/4
9.5	3/8
4.75	(No. 4)

2. Auxiliary Tests

2.1 A sample must be obtained in accordance with USBR 5205 prior to performing this procedure. The moisture content of the soil must be determined in accordance with USBR 5300 as part of this procedure.

3. Applicable Documents

3.1 *USBR Procedures*:

USBR 1012 Calibrating Balances or Scales
USBR 1025 Checking Sieves
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR *4136 Sieve Analysis of Fine and Coarse Aggregates
USBR 5205 Preparing Soil Samples by Splitting or Quartering
USBR 5300 Determining Moisture Content of Soil and Rock by the Oven Method
USBR 5330 . Performing Gradation Analysis of Fines and Sand Size Fraction of Soils, Including Hydrometer Analysis
USBR 5335 Performing Gradation Analysis of Soils Without Hydrometer-Wet Sieve

3.2 *ASTM Standards*:

C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates
E 11 Specification for Wire-Cloth Sieves for Testing Purposes
E 323 Specification for Perforated-Plate Sieves for Testing Purposes

4. Summary of Method

4.1 Soil is separated in sizes by a series of sieves of progressively smaller openings. The mass retained on each sieve is determined and the percent of the total sample mass passing each sieve is calculated.

5. Significance and Use

5.1 The percentage and distribution of particle sizes influence the strength, permeability, and compressibility of a soil mass. The amount of fines, sand (USBR 5330), and gravel (USBR 5325) are used to obtain gradation curves. These curves are widely used for identification and classification of soils and in the assessment of in-place characteristics of a soil mass.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

6.1.1 *Gradation.*-The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges (ASTM definition).

6.1.2 *Gradation Analysis.*-The process of determining gradation (ASTM).

6.1.3 *Gravel.*-Particles of rock that will pass a 3-inch (75-mm) U.S.A. Standard sieve and be retained on a No. 4 (4.75-mm) sieve.

6.2 Terms not included in USBR 3900 specific to this designation are:

6.2.1 *Maximum Particle Size.*-The largest particle in a soil sample as related to sieve openings of 3-, 1-1/2-, 3/4-, 3/8-inch or the No. 4 sieve. A maximum particle size of 1-1/2-inch means the largest particle passes a 1-1/2-inch sieve, but is retained on a 3/4-inch sieve.

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* *Concrete Manual*, Bureau of Reclamation, part 2, in press.

6.2.2 *Pan.*- A pan used in a set (nest) of sieves placed beneath the smallest sieve size and used to collect the particles that pass the smallest sieve opening.

7. Apparatus

7.1 *Balance or Scale.*-A balance or scale of appropriate capacity for determining moisture content. The mass of the specimen can range from 200 g up to 35 kg or more depending on:

- Maximum particle size present
- Entire sample is tested
- Representative portion of sample tested

NOTE 1.-A typical set of balances or scales that would cover the requirements of this designation are:

Readable to	*Approximate capacity*
0.01 g	200 g*
0.1 g	1000 g*
1 g	20 kg
0.01 lbm	150 lbm

*Often same apparatus.

7.2 *Balance or Scale.*-A typical balance or scale used to measure the mass of soil particles retained on each sieve must be readable to 0.01 lbm (0.1 kg or 10 g) and have a capacity of about 150 lbm (80 kg).

7.3 *Sieves.*-U.S.A. Standard series 3-, 1-1/2-, 3/4-, 3/8-inch, and No. 4 (75-, 37.5-, 19.0-, 9.5-, 4.75-mm) sieves, conforming to the requirements of ASTM E 11 or ASTM E 323.

7.4 *Cans, Containers, or Bags.*-Suitable metal can, container, or bag for sample storage and containers for measurements of mass, as required.

7.5 *Sieving Device.*-A mechanical sieve shaker (fig. 1) that causes the particles to bounce and turn so that all particles have ample opportunities in various orientations to reach the sieve openings. The agitation of particles must be such that adequate sieving is reached within a reasonable time. Adequate sieving is reached when an additional 1 minute of sieving does not change the mass on any of the sieves by more than 1.0 percent.

The sieving device illustrated in USBR 5330 may be used except that it is generally impractical for maximum particle sizes of 1-1/2 inch and larger. Care must be taken not to overload the sieves (see subpar. 8.2.2).

7.6 *Separating Device* (Optional).-A device such as shown on figure 2 may be used for separating soils on the No. 4 sieve. This device should not be used to perform a gradation analysis.

8. Precautions

8.1 *Safety Precautions*:

8.1.1 Appropriate personal protective apparel are to be worn when handling the sample and during operation of the sieving device.

8.1.2 Ear protection should be worn during operation of the mechanical sieving device.

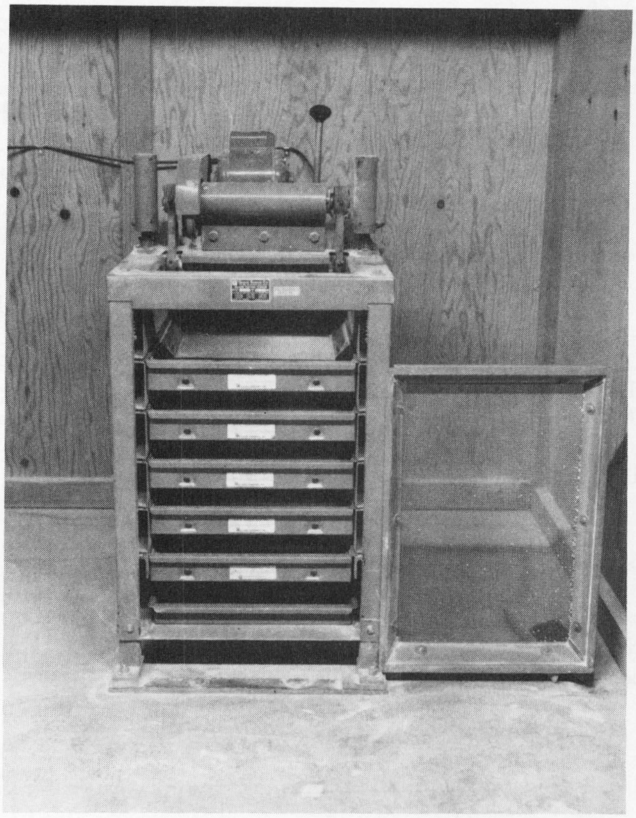


Figure 1. - Mechanical sieve shaker.

8.2 *Technical Precautions.*-

8.2.1 Due to the effects of sampling, handling, processing, and testing on some materials, results of this test may not reflect in-place conditions or the properties of the material caused by processing and placement during construction. Of particular concern are materials such as soft and/or friable decomposed granite, sandstone, shale, limestone, claystone, etc., or soils affected by air and/or oven drying. Such materials must be identified before processing and the person requesting the test should verify whether standard procedures are to be followed, whether modifications are appropriate, or whether the material should be processed and tested at all. Cautionary statements must be made on data forms and in reporting the test data.

8.2.2 Care must be taken to prevent overloading the sieves.

8.2.2.1 The total quantity of material to be sieved must be limited so that on a given sieve all the particles have an opportunity to reach sieve openings a number of times during the sieving operation. As a rule, if the material retained on a sieve at the completion of testing is spread out evenly over the area of the sieve, the layer of material should not be more than one particle thick.

8.2.2.2 For wire cloth sieves, the load on the cloth must never be so great that permanent deformation of the cloth occurs. This should be checked visually to avoid overloading the sieve.

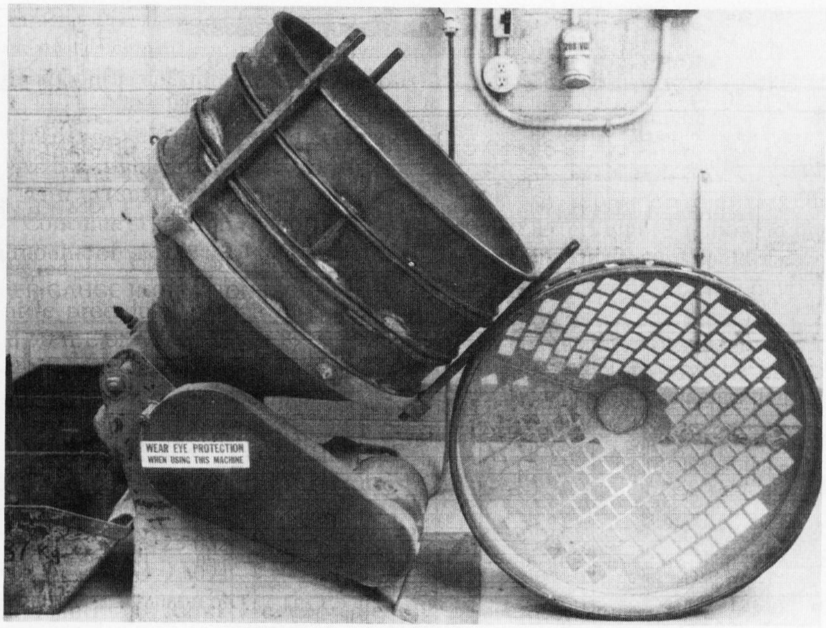


Figure 2. – Separating device.

9. Sampling, Test Specimens, and Test Units

9.1 *Sample Preparation*:

9.1.1 Prepare a test sample of minus 3-inch material in accordance with USBR 5205. The mass of the specimen to be tested depends on the maximum particle size present in the soil as follows:

Maximum particle size		*Minimum dry mass of test specimen*	
in	mm	lbm	kg
3/8	9.5	0.5*	0.25*
3/4	19.0	2.5*	1.1*
1-1/2	37.5	20	10
3	75	150	70

* For the equipment typically used in this procedure, a test specimen mass of at least 10 lbm (4.5 kg) is recommended (see subpar. 12.2.2).

These values are in terms of dry mass. Values for wet mass of the specimen will have to be adjusted based on an estimated moisture content.

10. Calibration and Standardization

10.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012 Calibrating Balances or Scales
USBR 1025 Checking Sieves

11. Conditioning

11.1 Before a soil can be separated by sieving, it must be at a moisture content such that soil lumps and/or individual soil particles will be free flowing and such that the soil can be separated by the sieving process.

11.1.1 Preparation of a sample in accordance with USBR 5205 will normally result in an appropriate moisture content for sieving.

11.1.2 If the entire amount of soil available is to be tested and is not reduced in size in accordance with USBR 5205, the soil must be conditioned to the appropriate moisture content in accordance with USBR 5205.

11.1.3 For soils to be tested at their natural moisture content, the test specimen should be separated on a No. 4 sieve with the minus No. 4 material not allowed to become drier than the natural moisture content. The plus No. 4 material can then be conditioned and tested in accordance with this designation. However, the dry mass of the minus No. 4 material must be determined and added to the dry mass of the total specimen as determined in this procedure.

12. Procedure

12.1 All data are to be recorded on a "Gradation Analysis" form as shown on figure 3 or 4.

12.2 For a specimen mass of 10 lbm (4.5 kg) or larger, all measurements of mass are to be determined and recorded to the nearest 0.01 lbm (0.01 kg).

12.2.1 A minimum specimen mass of 10 lbm (4.5 kg) is recommended when the mechanical sieving device, shown on figure 1, is used in combination with a balance or scale readable to 0.01 lbm (0.01 kg).

12.2.2 The required minimum specimen mass is 0.5 lbm for soil having a maximum particle size of 3/8-inch, and 2.5 lbm for a maximum particle size of 3/4 inch. If for some reason the specimen mass for these soils is less than 10 lbm, other combinations of sieving equipment (such as described in USBR 5330) and balances and scales

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS	Designation USBR 5325-89 Designation USBR 5330-__ Designation USBR 5335-__

SAMPLE NO. Example	PROJECT	FEATURE
AREA (individual)	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES

TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4 assumed 1.8	WET MASS OF TOTAL SPECIMEN 162.07
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4 12.3	TOTAL DRY MASS OF SPECIMEN 149.47

SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL			18.94	33.33	24.23	28.28	124.94
MASS OF CONTAINER			12.21	12.21	12.21	12.21	18.81
WET MASS RETAINED			6.73	21.12	12.02	16.07	106.13
DRY MASS RETAINED			6.61	20.75	11.81	15.79	94.51
DRY MASS PASSING		149.47	142.86	122.11	110.30	94.51	☒ lbm ☐ kg ☐ g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2	

GRADATION OF SAND SIZES

DRY MASS OF SPECIMEN g	$\text{FACTOR} = \frac{\%\ \text{TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$ = ____________ = ____________
DISH NO.	DRY MASS OF SPECIMEN (SIEVED)
SIEVING TIME	DATE

SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8					2.36 mm	
16					1.18 mm	
30					600 µm	
50					300 µm	
100					150 µm	
200					75 µm	
PAN						
TOTAL						

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE

HYDROMETER ANALYSIS

HYDROMETER NO.	DISPERSING AGENT	
STARTING TIME	DATE	AMOUNT mL

TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 µm	
4 min							19 µm	
19 min							9 µm	
60 min							5 µm	AUXILIARY TESTS: USBR 5205-89 USBR 5300-89
7 h 15 min*							2 µm	
25 h 45 min*							1 µm	

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE

*Not required for standard test.

GPO 852-184

Figure 3. - Gradation analysis (individual method) — example.

7-1451 (9-86) Bureau of Reclamation	**GRADATION ANALYSIS**	Designation USBR 5325-89 Designation USBR 5330-__ Designation USBR 5335-__
SAMPLE NO. Example	PROJECT	FEATURE
AREA (cumulative)	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES

TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4 assumed 1.8	WET MASS OF TOTAL SPECIMEN 162.07
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4 12.3	TOTAL DRY MASS OF SPECIMEN 149.47

SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL			18.94	40.06	52.08	68.15	124.94
MASS OF CONTAINER			12.21	12.21	12.21	12.21	18.81
WET MASS RETAINED			6.73	27.85	39.87	55.94	106.13
DRY MASS RETAINED			6.61	27.36	39.17	54.95	94.51
DRY MASS PASSING		149.47	142.86	122.11	110.30	94.52	☒ lbm ☐ kg ☐ g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2	

GRADATION OF SAND SIZES

DRY MASS OF SPECIMEN g	FACTOR = $\frac{\text{\% TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$ = ________ = ________
DISH NO.	DRY MASS OF SPECIMEN (SIEVED)
SIEVING TIME	DATE

SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING= % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8					2.36 mm	
16					1.18 mm	
30					600 µm	
50					300 µm	
100					150 µm	
200					75 µm	
PAN						
TOTAL		TESTED AND COMPUTED BY	DATE	CHECKED BY		DATE

HYDROMETER ANALYSIS

HYDROMETER NO.	DISPERSING AGENT	
STARTING TIME	DATE	AMOUNT mL

TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ= % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 µm	
4 min							19 µm	
19 min							9 µm	
60 min							5 µm	AUXILIARY TESTS: USBR 5205-89 USBR 5300-89
7 h 15 min*							2 µm	
25 h 45 min*							1 µm	

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE

*Not required for standard test.

GPO 852-184

Figure 4. - Gradation analysis (cumulative method) — example.

may be used. In this case, a balance or scale must be used such that the mass is determined and recorded to at least 0.1 percent of the total specimen mass.

12.3 Determine and record the *wet mass of total specimen* (or dry mass, if appropriate — see notes 2 and 3).

NOTE 2.–In this designation, "wet mass" refers to material that has not been ovendried and "dry mass" to material that has been ovendried or the dry mass calculated.

NOTE 3.–The gradation analysis may be performed on ovendried material. In this case, substitute "dry mass" for "wet mass" in this designation and disregard the steps pertaining to determining moisture content and calculating the dry mass. The data should be recorded in the spaces on the form for "dry mass."

12.4 Separation of specimen prior to sieving:

12.4.1 If the amount of material to be tested is greater than the capacity of the sieving equipment (do not overload the sieves), divide the specimen into appropriate portions for testing. For each portion, follow the steps in subparagraphs 12.5 through 12.11. Calculate the sum of the wet masses retained on each sieve and in the pan, and record as wet mass retained for each sieve size and in the pan and proceed with subparagraph 12.12.

12.4.2 Alternately, if the amount of material to be tested is greater than the capacity of the sieving equipment or to not overload the sieves, the specimen may be separated using a No. 4 sieve prior to testing. Separation on the No. 4 sieve also may be necessary for (1) testing the minus No. 4 portion of a soil before or during the testing of the plus No. 4, (2) convenience of test scheduling, or (3) when the plus No. 4 particles need to be soaked in water (see subpar. 12.7.1). The wet mass of the separated minus No. 4 material must be determined and then added to the wet mass of any minus No. 4 particles collected and measured during the sieving of the plus No. 4 material.

12.5 Assemble the set (nest) of sieves to be used in order of decreasing size of opening from top to bottom and place in the sieving device. The sieves may be the standard set as described in subparagraph 7.3, or others as required by the specifications covering the material to be tested. If desired, sieves coarser than the maximum particle size may be omitted from the set. However, a sieve at least one size larger than the anticipated maximum particle size should be included in the set. Additional sieve sizes may be added to restrict the amount of material on a particular sieve (see subpar. 12.4.1) or to protect individual sieves from excessive wear.

12.6 Place the soil specimen on the top sieve and turn on the sieving device. To avoid overloading the top sieve, it may be necessary to feed the soil onto the top sieve gradually. Sieve the material for about 15 minutes, or longer if necessary, to separate all the material. A satisfactory end-point is considered to have been reached when an additional one minute of sieving does not change the mass on any individual sieve by more than 1.0 percent.

12.6.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and accepted method of performing this procedure. Hand sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms.

12.7 Any significant amount of minus No. 4 particles adhering to the plus No. 4 particles must be brushed or wiped off and placed in the minus No. 4 fraction.

12.7.1 If the minus No. 4 material cannot be easily removed from the plus No. 4 particles, the plus No. 4 particles should be soaked and/or washed on a No. 4 sieve until all minus No. 4 material is removed. If tests are to be performed on the minus No. 4 material, the minus No. 4 particles must be collected and added to the minus No. 4 material and thoroughly mixed in. The plus No. 4 material must then be rescreened.

12.8 Determine and record the *mass of container(s)* to be used.

12.9 Starting with the coarsest sieve, remove all particles retained on each sieve and place in the container(s). Determine and record the *mass of container and retained material.* The mass may be determined and recorded as the mass for each individual sieve size (fig. 3) or as the mass on a cumulative basis (fig. 4). When removing the particles, take care to avoid permanent deformation of sieve openings or the sieve cloth.

12.10 Remove all particles retained in the pan and place into a container. Determine and record the *mass of container and retained material.*

12.11 Calculate and record the *wet mass retained* on each sieve size (individual or cumulative) and in the pan by subtracting the *mass of container* from the *mass of container and retained material.*

NOTE 4.–As a check, the sum of the *wet mass retained* on each sieve (or cumulative on the No. 4 sieve) and the *wet mass retained* in the pan should be about equal to the *wet mass of total specimen.*

12.12 Determine and record to the nearest 0.1 percent the moisture content of the plus No. 4 material and the moisture content of the minus No. 4 material in accordance with USBR 5300.

12.12.1 A moisture content may be assumed for the plus No. 4 material if previous tests on similar material have been performed and the value is relatively constant. Note on the form that the value is *assumed.*

12.13 Using the moisture content of the plus No. 4 material and the wet mass retained, calculate and record the *dry mass retained* on each sieve (individual or cumulative).

12.14 Using the moisture content of the minus No. 4 material and the wet mass of soil retained in the pan (passing the No. 4 sieve), calculate and record the *dry mass retained* in the pan.

12.15 Calculate and record the *total dry mass of specimen* by one of the following methods:

12.15.1 Mass determined for each individual sieve (fig. 3).–Calculate the sum of the *dry mass retained* on each sieve and in the pan. Also, record this value as *dry mass passing* under the 3-inch sieve size column (or under the column for the next larger sieve size than the sieve size on which particles were retained).

12.15.2 Mass determined on cumulative basis (fig. 4).-Calculate the sum of the *dry mass retained* on the No. 4 sieve and the *dry mass retained* in the pan.

12.16 Calculate and record the *dry mass passing* each sieve by one of the following methods.

12.16.1 Mass determined for each individual sieve (fig. 3).-Starting with the coarsest sieve on which particles were retained, calculate the *dry mass passing* each sieve by subtracting the *dry mass retained* from the *dry mass passing* the next larger size sieve.

12.16.2 Mass determined on cumulative basis (fig. 4).-Calculate the *dry mass passing* each sieve by subtracting the *dry mass retained* from the *dry mass of total specimen*.

NOTE 5.-As a check, the *dry mass passing* the No. 4 sieve must equal (±0.01 lbm or kg)the *dry mass retained* in the pan.

12:17 Calculate and record to the nearest 0.1 percent the *percent of total passing* each sieve. Record 100.0 percent in the sieve size column that is one sieve size larger than the coarsest sieve size on which material was retained.

12.18 If required, plot the results as shown on figure 5. Typically, this procedure is performed in conjunction with USBR 5330 or 5335 to determine the gradation of the minus No. 4 material and the plot is prepared after the minus No. 4 gradation has been determined.

13. Calculations

13.1 Calculate the percent of total passing for each sieve using the following expression:

$$\text{Percent of total passing} = 100\left(\frac{\text{dry mass passing}}{\text{total dry mass of specimen}}\right)$$

14. Report

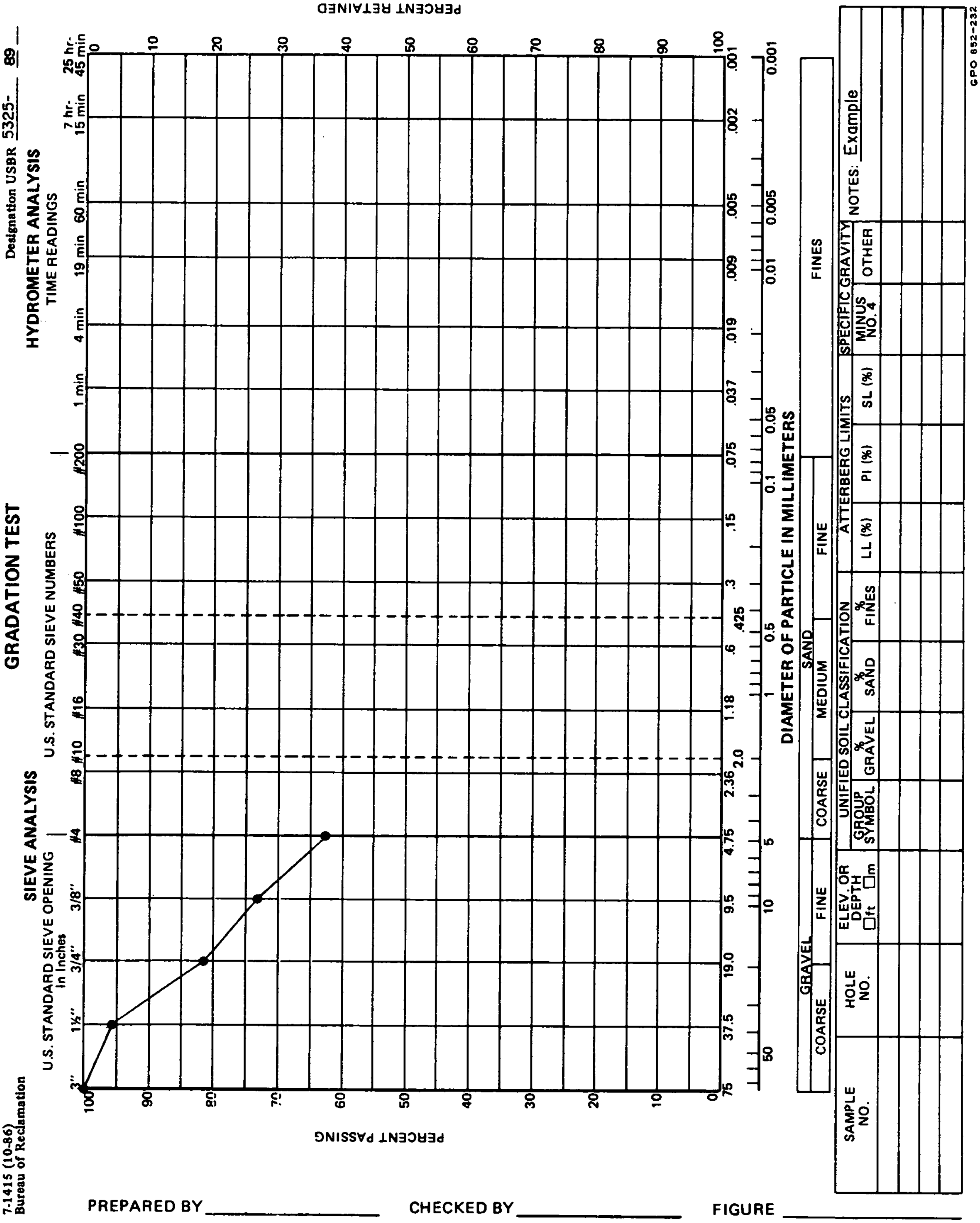
14.1 The report is to consist of a completed and checked "Gradation Analysis" form (fig. 3 or 4).

14.2 All calculations are to show a checkmark.

14.3 If required, the results are to be plotted as shown on the "Gradation Test" form (fig. 5).

14.4 For reports, summary tables, etc., the gradation percentages are generally reported to the nearest 1 percent. The percentages may be reported as either percent passing or percent retained.

14.5 In many cases, the gradation is reported in terms of percent gravel, percent sand, and percent fines. The percentages must add to 100 percent. Due to rounding, the total may be either 99 or 101 percent; 1 percent must be added to or subtracted from the component (gravel, sand, or fines) with the largest percentage so the total is 100 percent. If the percentages, when rounded to the nearest 1 percent are equal, make the adjustment to the coarser component.



Designation USBR 5325- 89

NOTES: Example

Figure 5. - Gradation test — example plot.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5330-89

PROCEDURE FOR

PERFORMING GRADATION ANALYSIS OF FINES AND SAND SIZE FRACTION OF SOILS, INCLUDING HYDROMETER ANALYSIS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, Code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5330. The number immediately following the designation indicates the year of acceptance or the year of last revision.

The method is similar to ASTM D 422-63, the principal difference being the sieve sizes used and the separation on the No. 4 instead of No. 10 sieve (4.75 and 2.00 mm) for the hydrometer test.

1. Scope

1.1 This designation outlines the procedure for performing gradation analysis of fines and sand size fraction of soils, including hydrometer analysis. It is used for the quantitative determination of distribution of particle sizes in soils.

1.2 The distribution of particle sizes larger than retained on the No. 200 sieve (75 µm) is determined by sieving, while the distribution of particle sizes smaller than No. 200 is determined by a sedimentation process, using a hydrometer to secure the necessary data.

1.3 If gravel size particles were present in the original soil sample, this test is usually performed in conjunction with USBR 5325.

1.4 If the particle size distribution of the minus No. 200 (75 µm) sieve size soil is not required, USBR 5335 may be used in place of this designation.

1.5 Two methods of dispersing the soil are provided (1) a mechanical stirring device, and (2) an air dispersion tube. The air dispersion method must be specially requested or specified and its use noted on the test form (see subpar. 5.3).

2. Auxiliary Tests

2.1 A soil sample must be prepared in accordance with USBR 5205 prior to performing this procedure.

3. Applicable Documents

3.1 *USBR Procedures*:

USBR 1012 Calibrating Balances or Scales
USBR 1020 Calibrating Ovens
USBR 1025 Checking Sieves
USBR 1405 Calibrating Hydrometers
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR *4136 Sieve Analysis of Fine and Coarse Aggregates
USBR 5205 Preparing Soil Samples by Splitting or Quartering
USBR 5325 Performing Gradation Analysis of Gravel Size Fraction of Soils
USBR 5335 Performing Gradation Analysis of Soils Without Hydrometer-Wet Sieve

3.2 *ASTM Standards*:

C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates
E 1 ASTM Thermometers
E 11 Specification for Wire-Cloth Sieves for Testing Purposes
E 100 Specification for ASTM Hydrometers
D 422 Standard Method for Particle-Size Analysis of Soils

4. Summary of Method

4.1 A sample of minus No. 4 (4.75-mm) material is prepared and placed in a dispersing agent (usually sodium hexametaphosphate) for a period of at least 16 hours. Then it is mixed thoroughly and placed in a 1000-mL hydrometer cylinder and filled with distilled water. Hydrometer readings are taken at time intervals of 1, 4, 19, and 60 minutes after the beginning of sedimentation.

For soils with a high percentage of very small particles, readings are also taken at time intervals of 7 hours 15 minutes, and 25 hours 45 minutes after the beginning of sedimentation.

4.2 After completion of the hydrometer analysis, the material is washed on a 200-mesh sieve. The fraction retained on the No. 200 sieve is ovendried and separated on the following sieves. (The sieving is done using a powered sieve shaker.)

U.S.A. Standard series sieves	
No. 8	2.36 mm
No. 16	1.18 mm
No. 30	600 µm
No. 50	300 µm
No. 100	150 µm
No. 200	75 µm

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* *Concrete Manual*, Bureau of Reclamation, part 2, in press.

4.3 After sedimentation and sieving, the percentage of particles passing specified sizes are calculated, recorded, and plotted.

5. Significance and Use

5.1 Gradation is a descriptive term which refers to the proportions by dry mass of a soil or fragmented rock distributed in specified particle-size ranges.

5.2 The gradation of a soil gives an indication of the engineering properties of the soil. Permeability, compressibility, and shear strength are all influenced by the gradation characteristics of a soil mass. Therefore, reliable determination of the amount of fines, sand, and gravel in a representative soil sample is of extreme importance for design considerations.

5.3 Normally, the mechanical stirring device is used to disperse the soil specimen. Its use may cause degradation of some soil particles. Performing the gradation analysis on a mechanically dispersed specimen and on an air-dispersed specimen may be useful in evaluating the durability and hardness of sand size particles.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

6.1.1 *Dispersing Agent.*-An agent used to assist in separating individual fine soil particles and to prevent them from flocculating when in suspension.

6.1.2 *Fines.*-Portion of soil finer than a No. 200 (75 µm) U.S.A. Standard sieve (ASTM definition).

6.1.3 *Gradation.*-The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges (ASTM).

6.1.4 *Gradation Analysis.*-The process of determining gradation (ASTM).

7. Apparatus

7.1 *Balance or Scale.*-A typical balance or scale used for this designation must be readable to 0.1 g and have a capacity of about 500 g.

7.2 *Soil Hydrometer.*-A soil hydrometer, graduated to read in grams per liter of suspension and conforming to the requirements for hydrometer 152H in ASTM E 100.

7.3 *Hydrometer Cylinder.*-A glass cylinder essentially 18 inches in height and 2-1/2 inches (457- by 64-mm) in diameter, and marked for a volume of 1000 mL. The inside diameter is to be such that the 1000-mL mark is 14±1 inch (355±25 mm) from the bottom of the inside.

7.4 *Stirring Apparatus* (malt mixer).-A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 revolutions per minute without load. The shaft should be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber. The shaft is to be of such a length that the stirring paddle will operate not less than 1-1/2 inches (38 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown on figure 1 should be used.

7.5 *Water Bath* (optional).-A water bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory constant temperature bath is an insulated tank with automatic temperature control that maintains the soil suspension at a convenient constant temperature at or near 68 °F (20 °C). Such a device is shown on figure 2. If a constant temperature water bath is not used, a water-filled container (such as an additional hydrometer cylinder) must be used to store the hydrometer between readings. The water in this storage cylinder must be at the same temperature as the solution in the test hydrometer cylinder.

7.6 *Thermometer.*-0 to 50 °C range, 0.5° divisions, conforming to the requirements of ASTM E 1.

7.7 *Rubber Stopper.*-An appropriate size rubber stopper to adequately seal the hydrometer cylinder.

7.8 *Sodium Hexametaphosphate.*-A chemical agent in powder, crystal, or granular form, used as a dispersing agent, of technical grade or better.

7.9 *Evaporating Dish.*-A porcelain evaporating dish, 300-mL capacity, approximately 4-1/2 inches in diameter by 2 inches (115 by 50 mm) deep.

7.10 *Tubing.*-Flexible tubing of sufficient length and diameter to direct the flow of water for washing the soil specimen through a No. 200 (75-µm) sieve.

7.11 *Timing Device.*-A clock or stopwatch with a second hand.

7.12 *Sieve Set.*-A set of sieves, of square-mesh, woven-wire cloth, conforming to the requirements of ASTM E 11. A full set of sieves includes the following:

A lid	
No. 8	2.36 mm
No. 16	1.18 mm
No. 30	600 µm
No. 50	300 µm
No. 100	150 µm
No. 200	75 µm
A pan	

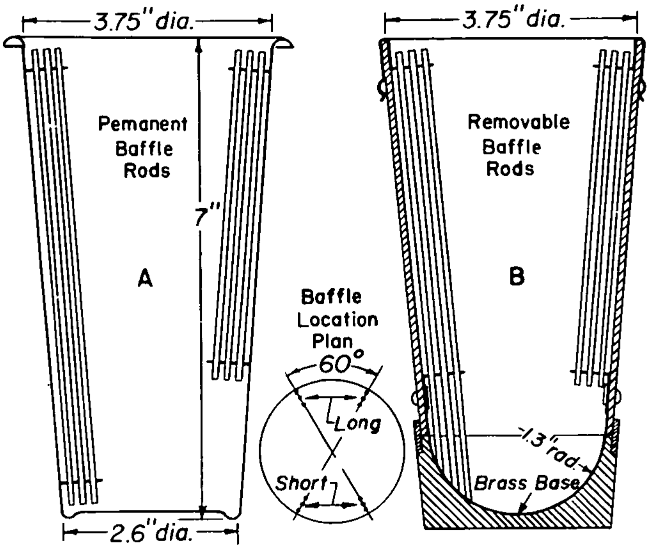
7.13 *Washing Sieve.*-No. 200 washing sieve may be fabricated, or 8-inch (203-mm) brass No. 200 sieve may be used.

7.14 *Sieve Shaker.*-A motor-driven electric sieve shaker, equipped with timer as shown on figure 3, should be used.

7.15 *Brush.*-A fine brass wire brush used for removing soil from the sieves and pan.

7.16 *Drying Oven.*-An oven, thermostatically controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 230±9 °F (110±5 °C) throughout the drying chamber.

7.17 *Air Dispersion Tube and Air Supply.*-An air dispersion tube conforming to the requirements of figure 4. The air supply must be capable of producing 2 cubic feet per minute for each dispersion tube. A water trap on the air line may be useful to remove water that condenses



Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

Figure 1. - Dispersion cup designs [ASTM D 422].

in the air line when not in use. Otherwise, the water must be blown out of the air line before using for dispersion purposes.

7.18 *Graduated Cylinder.*–250 mL capacity, graduated in 2 mL divisions or other suitable container or method to measure 125 mL of the dispersing agent solution.

8. Reagents and Materials

8.1 Distilled water is to be used whenever water is called for in this procedure except for water in the water bath or when washing the specimen on a No. 200 sieve. Tapwater that is free of acids, alkalies, or oils and suitable for drinking may be used to fill the tank, provided the water is changed regularly (about once per week).

8.2 A 4-percent sodium hexametaphosphate solution is used to disperse the representative soil sample.

8.3 To prepare a 4-percent sodium hexametaphosphate solution, the following procedure is to be followed:

8.3.1 Fill a 1000-mL hydrometer cylinder with distilled water to approximately 750 mL.

8.3.2 Obtain 40 grams of sodium hexametaphosphate and place into the dispersion cup. Add approximately 100 mL of distilled water to the sodium hexametaphosphate. Mix the sodium hexametaphosphate and water for 5 minutes using the malt mixer or until the sodium hexametaphosphate is completely dissolved.

8.3.3 Add the solution from the dispersion cup to the hydrometer cylinder. Fill the hydrometer cylinder to the 1000-mL line with distilled water. Insert the rubber stopper and securely place it on top of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the bottom, shake the hydrometer cylinder to thoroughly mix the solution.

8.4 In some instances, an 8- or 12-percent solution may be required as a dispersing agent. The following amounts of sodium hexametaphosphate are used for the required percent solution of sodium hexametaphosphate.

Solution required, percent	*Sodium hexametaphosphate required, grams*
4	40
8	80
12	120

8.5 If an 8- or 12-percent solution is required, the procedure outlined in subparagraph 8.3 is to be used along with the appropriate amount of sodium hexametaphosphate as given in subparagraph 8.4.

8.6 A prepared sodium hexametaphosphate solution may be stored for no more than 21 days if the storage temperature remains near room temperature of 73 °F (23 °C), and for no more than 7 days if the temperature of the storage area consistently exceeds 73 °F.

8.7 All containers of the dispersing solution must have the date of preparation and percent solution marked on them.

9. Precautions

9.1 *Technical Precautions*:

9.1.1 Ensure that the hydrometer is clean, especially the reading portion of the stem, by washing the hydrometer with soapy water, then rinsing it with alcohol and again in clean water.

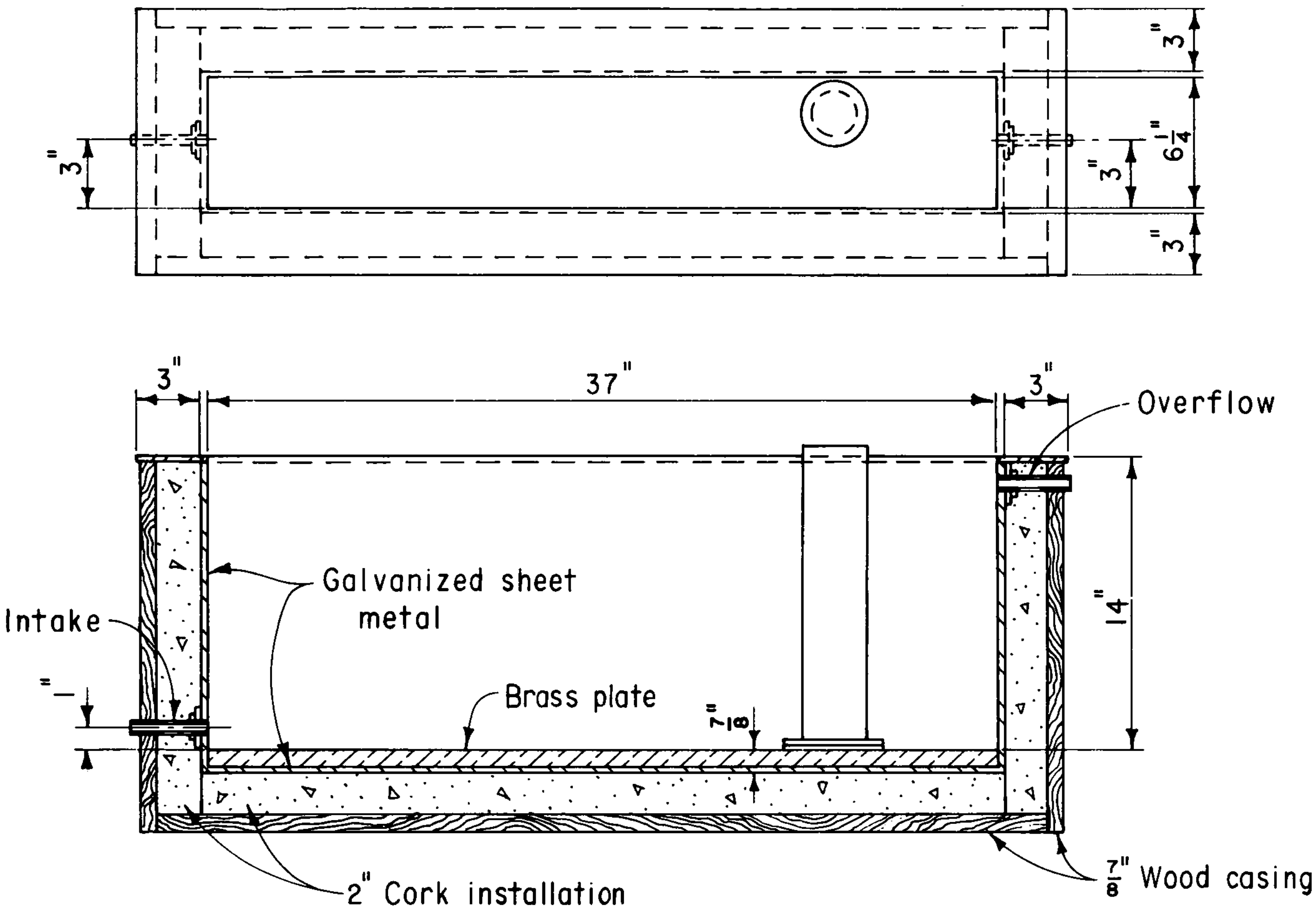
9.1.2 Because sodium hexametaphosphate in powder, granular, or crystalline form absorbs moisture, the material must be stored in airtight containers.

9.1.3 Due to the effects of sampling, handling, processing, and testing on some materials, results of this test may not reflect in-place conditions or the properties of the material caused by processing and placement during construction. Of particular concern are materials such as soft and/or friable decomposed granite, sandstone, shale, limestone, claystone, etc., or soils affected by air and/or ovendrying. Such materials must be identified before processing and the person requesting the test should verify whether standard procedures are to be followed, whether modifications are appropriate, or whether the material should be processed and tested at all. Cautionary statements must be made on test data forms and in reporting the test data.

9.1.4 A temperature differential may create convection currents in the solution—in the hydrometer cylinder—that would affect the hydrometer reading. When the hydrometer is read during the test, it is important that the equipment and the fluids are all at the same temperature. The test should be performed away from sources of heat or cold such as direct sunlight or heating/air conditioning vents.

10. Sampling, Test Specimens, and Test Units

10.1 Prepare a test sample of approximately 500 grams of minus No. 4 (4.75-mm) material in accordance with



Metric Equivalents

in.	7/8	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

Figure 2. - Constant temperature bath [ASTM D 422].

USBR 5205. If 500 grams of soil is not available, obtain at least enough soil to have an ovendried test specimen that meets the requirements of subparagraph 10.3.

10.2 Place the test sample into a suitable container and ovendry the sample for a minimum of 16 hours.

10.3 Thoroughly mix the soil and obtain a specimen of approximately 100 grams for sandy soils and about 50 grams for silty or clayey soils by splitting in accordance with USBR 5205. Determine the mass of the specimen to the nearest 0.1 g and record on the "Gradation Analysis" form as shown on figure 5.

10.4 The test specimen must be dispersed in accordance with either subparagraph 10.5 or 10.6 (see subpar. 5.3). If the air dispersion method is used, it must be noted on the test form.

10.5 *Dispersion of Soil Specimen* (mechanical stirring):

10.5.1 Place the soil specimen in an evaporating dish.

10.5.2 Add 125 mL of 4-percent sodium hexametaphosphate solution and enough distilled water to cover the soil.

10.5.3 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours.

10.5.4 Wash the specimen into a dispersion cup with distilled water.

10.5.5 Continue adding distilled water until the dispersion cup is within 2 inches (50 mm) of being filled.

10.5.6 Mix the contents of the dispersion cup using the malt mixer for 1 minute.

10.6 *Dispersion of Soil Specimen* (air dispersion):

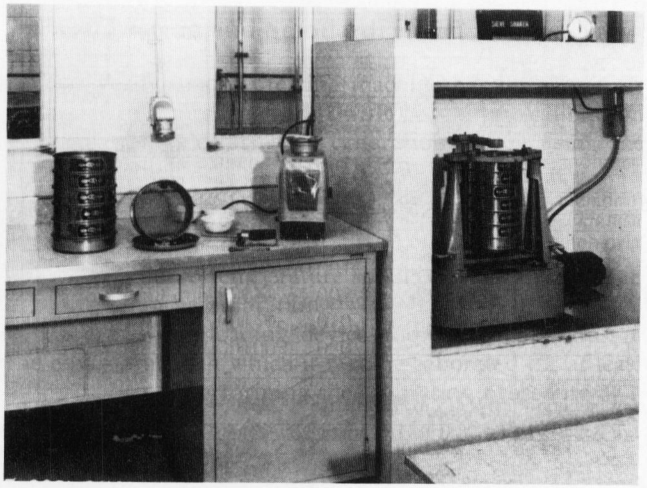


Figure 3. – Sieve analysis equipment.

10.6.1 Place the soil specimen into a hydrometer cylinder.

10.6.2 Add 125 mL of 4-percent sodium hexametaphosphate solution to the hydrometer cylinder.

10.6.3 Add enough distilled water to the hydrometer cylinder to bring the volume to about 250 mL and stir.

10.6.4 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours.

10.6.5 Turn on the air supply to the air dispersion tube so there is a small air pressure (about 1 to 2 lbf/in^2) and insert the tube into the hydrometer cylinder.

10.6.6 Increase the air pressure to about 15 lbf/in^2 and let the mixture disperse for 10 minutes. Occasionally rinse the sides of the cylinder with distilled water. For some soils containing coarse sand particles, it may be necessary to increase the air pressure to adequately agitate and disperse the particles.

10.6.7 Decrease the air pressure to a very low pressure and slowly withdraw the air dispersion tube. Rinse the tube with distilled water as it is being withdrawn and rinse the sides of the hydrometer cylinder.

11. Calibration and Standardization

11.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012	Calibrating Balance or Scales
USBR 1020	Calibrating Ovens
USBR 1025	Checking Sieves
USBR 1405	Calibrating Hydrometers

12. Conditioning

12.1 A water bath is recommended for maintaining the soil suspension at a constant temperature during the hydrometer analysis.

12.2 The temperature of the soil suspension and water bath should be checked to ensure that they remain within the range of temperatures bracketed during calibration of the hydrometer (USBR 1405).

13. Procedure

13.1 All data are to be recorded on the "Gradation Analysis" form as shown on figure 5.

13.2 Record the hydrometer number.

13.3 Place the dispersed soil specimen that was prepared according to subparagraph 10.5 into a hydrometer cylinder or take the hydrometer cylinder containing the specimen as prepared in subparagraph 10.6 and fill the cylinder to a level approximately 2 inches (50 mm) below the 1000-mL mark with distilled water. The hydrometer cylinder and its contents, the constant temperature water bath (or extra hydrometer cylinder filled with water), and the hydrometer must all be at the same temperature before starting the test.

13.4 Place a rubber stopper over the mouth of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the hydrometer cylinder bottom, thoroughly mix the contents by turning the cylinder end over end for 1 minute.

13.5 Place the hydrometer cylinder into the constant temperature water bath (if available) and start the timing device.

13.6 Remove the stopper and quickly and carefully wash into the cylinder—with distilled water—any soil that may be present on the stopper or along the top of hydrometer cylinder. The water level should be approximately at the 1000-mL mark.

13.7 Carefully place the hydrometer into the hydrometer cylinder. Record hydrometer readings after elapsed times of 1, 4, 19, and 60 minutes. The hydrometer is read to the nearest 0.5 gram per liter at the top of the menicus formed by the suspension around its stem.

NOTE 1.–When the hydrometer is initially placed in the dispersed soil specimen, foam may appear round the hydrometer stem making it difficult to read. A few drops of alcohol can be added to remove the foam and aid in making an accurate reading of the hydrometer.

13.8 Record the temperature of the liquid in the hydrometer cylinder to the nearest 0.5 °C at each hydrometer reading interval. Over the period of 60 minutes the temperature of the solution in the hydrometer cylinder must not vary by more than ±2 °C. If it does, the test must be abandoned and started over.

13.9 After the 4-minute reading, remove the hydrometer from the hydrometer cylinder after each reading and wash off the hydrometer in the constant temperature water bath. Place the hydrometer in the constant temperature water bath until it is needed for the next reading.

NOTE 2.–If a constant temperature water bath is not available, the hydrometer is to be stored between readings in a water-filled hydrometer cylinder. The water is to be of the quality described in subparagraph 8.1. The water must be at the same temperature as the solution in the test hydrometer cylinder.

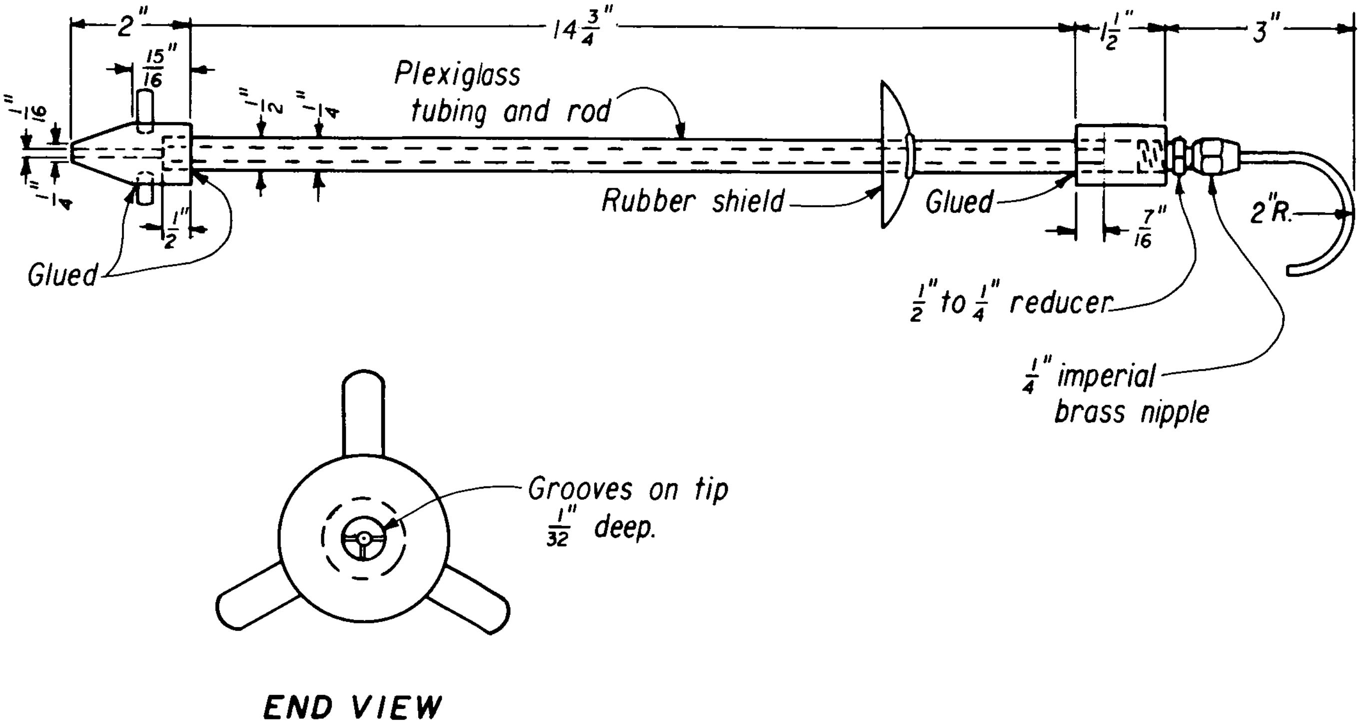


Figure 4. – Air dispersion tube. 101-D-523

13.10 Place the hydrometer in the hydrometer cylinder approximately 30 seconds before subsequent readings are to be taken.

13.11 If the 60-minute reading indicates that 40 percent or more of the specimen is smaller than the 0.005-mm size, continue the test by taking temperature and hydrometer readings at 7-hour 15-minute and 25-hour and 45-minute time intervals. If the 60-minute reading indicates that less than 40 percent of the specimen is smaller than the 0.005-mm size, the test is complete. (See subpars. 14.3 and 14.4 for the necessary calculations.) If the temperature is more than ±2 °C from the last temperature reading, keep taking temperature readings over the next 30 minutes to ascertain whether the system was at equilibrium when the hydrometer reading was made. If more than ±2 °C temperature change occurred in the 30-minute period, do not use the reading.

13.12 After the hydrometer readings have been completed, carefully wash the soil specimen on a No. 200 sieve until all fines are removed.

13.13 Pour the remaining soil into an evaporating dish and decant excess water.

13.14 Place the evaporating dish into an oven at 230±9 °F (110±5 °C) and dry for 16 hours.

13.15 Remove the specimen from the oven after 16 hours and obtain the dry mass of the specimen.

13.16 Place the specimen into the top sieve of a sieve set and place the lid on the top sieve. Place the sieve set into a sieve shaker. The sieve set should consist of the six sizes noted in subparagraph 7.12.

13.16.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and accepted method of performing this procedure. Hand sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms.

13.17 Sieve the soil specimen for approximately 15 minutes using the powered sieve shaker and record the mass of the soil retained on each sieve to the nearest 0.1 gram as shown on figure 5.

13.18 Calculate and record to 0.1 percent the percent of total soil mass passing each size for both the hydrometer and sieve analysis.

13.19 Plot the percent of total mass passing versus the particle diameter as shown on figure 6.

14. Calculations

14.1 Computations required on the "Gradation Analysis" form are divided into three parts:

- Gradation of gravel sizes
- Gradation of sand sizes
- Hydrometer analysis

14.2 *Gradation of Gravel Sizes.*–The method and calculations required to determine the percentages and distribution of particles larger than the No. 4 sieve size are outlined in USBR 5325.

14.3 *Gradation of Sand Sizes:*

14.3.1 Calculate the factor used to compute the percentage of the total sample mass passing a given sieve or the percentage of the total sample mass smaller than a given particle size as follows:

$$F = \frac{W,\%}{W} \tag{1}$$

where:

F = percent factor, %/g (record to 0.001)
$W,\%$ = percent of total sample mass passing the No. 4 (4.75-mm) sieve
W = total dry mass of minus No. 4 sample, g

14.3.2 Calculate the mass of soil passing each sieve using the following expression:

$$\text{Dry mass passing, g} = \text{dry mass of sample, g} - \text{dry mass retained, g} \tag{2}$$

14.3.3 Calculate the "*% of total passing*" each sieve by multiplying the mass passing each sieve, "*mass passing*," on the form by the factor F calculated in accordance with subparagraph 14.3.1.

14.4 *Hydrometer Analysis*:

14.4.1 The hydrometer reading obtained is corrected using the following expression:

$$(1) = (2) - (3) \tag{3}$$

where:

(1) = corrected hydrometer reading
(2) = hydrometer reading obtained from test
(3) = hydrometer correction obtained from USBR 1405

NOTE 3.-The hydrometer correction value can be either positive or negative. Care should be taken when applying this correction to ensure that the proper mathematical sign is used.

14.4.2 Calculate the percentage of the total sample mass smaller than a given particle size.

$$(4) = F(1) \tag{4}$$

where:

(4) = percent of total mass passing, %
F = factor calculated in accordance with subparagraph 14.3.1
(1) = corrected hydrometer reading

NOTE 4.-The results of several hundred tests on widely different soil types indicated that the maximum size particles in suspension for any given time of sedimentation varied over a comparatively narrow range, and was sufficiently independent of temperature, hydrometer reading, and soil type that the determination of the maximum particle size in suspension—based on hydrometer reading times—is sufficiently accurate for analyzing soils for construction purposes. If a more accurate particle size determination is desired, the method given in ASTM D 422 may be used.

15. Report

15.1 The report is to consist of the completed and checked:

"Gradation Analysis" form (fig. 5).
"Gradation Test" plot (fig. 6).

15.2 All calculations are to show a checkmark and all plotting must be checked.

15.3 For reports, summary tables, etc., the gradation percentages are generally reported to the nearest 1 percent. The percentages may be reported as either percent passing or percent retained.

15.4 In many cases, the gradation is reported in terms of percent gravel, percent sand, and percent fines. The percentages must add to 100 percent. Due to rounding, the total may be either 99 or 101 percent; 1 percent must be added to or subtracted from the component (gravel, sand, or fines) with the largest percentage so the total is 100 percent. If the percentages, when rounded to the nearest 1 percent are equal, make the adjustment to the coarser component.

APPENDIX

X1. COMMENTS ON CERTAIN ASPECTS OF THE HYDROMETER TEST

X1.1 A review of procedures and standards published by various sources revealed a variety of recommended reading times for the hydrometer test. The times traditionally used by the Bureau of Reclamation (and continued with this procedure) were selected based on the following rationale.

X1.2 It has been found to be convenient to assume a value of specific gravity for the hydrometer test. The value assumed is 2.65. This is a reasonable assumption, and moderate variations from this value have only a small effect on test results. By assuming a value of specific gravity, it was possible to print gradation forms with both particle diameter and time of reading values on the abscissa. This eliminates the need to calculate Stoke's Law (or use a nomograph) for each reading, thus reducing the chance for error. The particular times selected — at which readings are to be taken — were based on both convenience in performing the test, and in obtaining data points which have approximately equal spacing when plotted on the form. The three longer time readings (60 min, 7 h 15 min, and 25 h 45 min) correspond to particular particle sizes of interest (0.005, 0.002, and 0.001 mm, respectively).

X1.3 There are various recommendations concerning storage of the hydrometer between readings. These recommendations range from placing in clean water to distilled or demineralized water. While distilled water is required for preparing the soil suspension, the hydrometer may be stored between readings in either distilled water or tapwater that is free of acids, alkalies, or oils and is suitable for drinking. The tapwater will not cause a flocculating reaction with the soil, and allows laboratories that use water baths for controlling hydrometer test temperatures to store the hydrometer in the water bath between readings. Test results are not affected as long as the hydrometer bath water is changed regularly (about once per week).

7-1451 (9-86) Bureau of Reclamation	**GRADATION ANALYSIS**	Designation USBR 5325-__ Designation USBR 5330-89 Designation USBR 5335-__

SAMPLE NO.	PROJECT	FEATURE
AREA	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES

TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4	WET MASS OF TOTAL SPECIMEN
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4	TOTAL DRY MASS OF SPECIMEN

SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL							
MASS OF CONTAINER							
WET MASS RETAINED							
DRY MASS RETAINED							
DRY MASS PASSING		(example from U.S.B.R. 5325)					☐ lbm ☐ kg ☐ g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2	

GRADATION OF SAND SIZES

DRY MASS OF SPECIMEN 59.1 g	FACTOR = $\frac{\text{\% TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}} = \frac{63.2}{59.1} = 1.069$
DISH NO. 17	DRY MASS OF SPECIMEN (SIEVED) 39.2
SIEVING TIME 15 min.	DATE

SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING= % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8	3.4	55.7		59.5	2.36 mm	
16	8.3	50.8		54.3	1.18 mm	
30	14.2	44.9		48.0	600 µm	
50	22.1	37.0		39.6	300 µm	
100	30.8	28.3		30.3	150 µm	
200	39.0	20.1		21.5	75 µm	
PAN	0.1	TESTED AND COMPUTED BY	DATE	CHECKED BY		DATE
TOTAL	39.1					

HYDROMETER ANALYSIS

HYDROMETER NO. 189	DISPERSING AGENT Sodium Hexametaphosphate 4%
STARTING TIME 10:15	DATE
	AMOUNT 125 mL

TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ= % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min	27.0	16.5	3.5	13.0		13.9	37 µm	
4 min	27.0	11.0	3.5	7.5		8.0	19 µm	
19 min	27.0	8.0	3.5	4.5		4.8	9 µm	
60 min	27.0	6.5	3.5	3.0		3.2	5 µm	AUXILIARY TESTS: USBR 5205-89 USBR 5300-__
7 h 15 min*							2 µm	
25 h 45 min*							1 µm	

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE

*Not required for standard test.

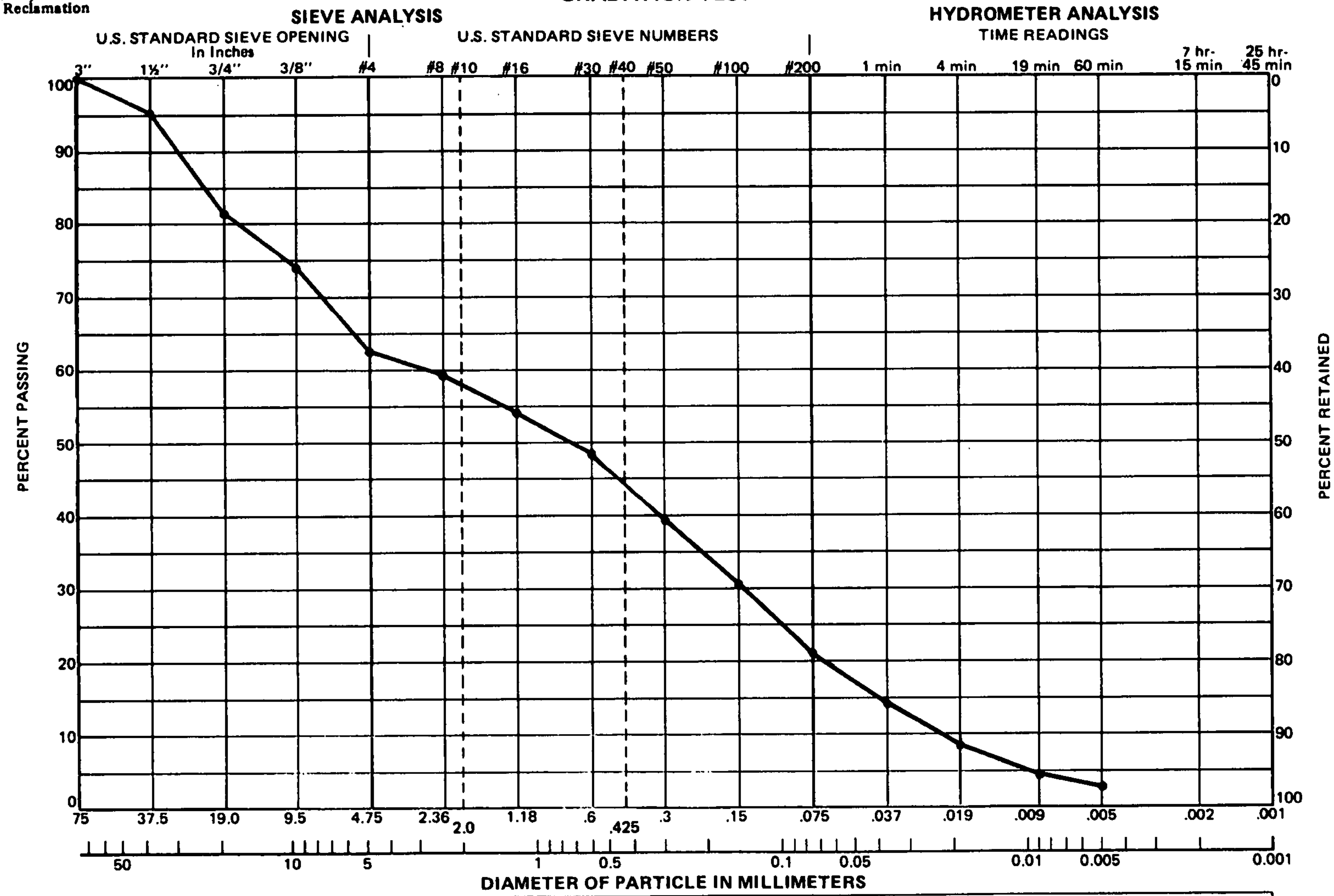
GPO 853 - 659

Figure 5. - Gradation analysis — example.

7-1415 (10-86)
Bureau of Reclamation

GRADATION TEST

Designation USBR 5330 - 89



GRAVEL		SAND			FINES
COARSE	FINE	COARSE	MEDIUM	FINE	

SAMPLE NO.	HOLE NO.	ELEV. OR DEPTH ☐ft ☐m	UNIFIED SOIL CLASSIFICATION				ATTERBERG LIMITS			SPECIFIC GRAVITY		NOTES: Example
			GROUP SYMBOL	% GRAVEL	% SAND	% FINES	LL (%)	PI (%)	SL (%)	MINUS NO. 4	OTHER	

GPO 852-232

PREPARED BY ______________ CHECKED BY ______________ FIGURE ______________

Figure 6. – Gradation test — gradation analysis data plot — example.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5450-89

PROCEDURE FOR

DETERMINING WATER SOLUBLE SOLIDS IN SOILS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760 and the Applied Sciences Branch, code D-3740, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under fixed designation USBR 5450. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines a procedure for determining the amount of water soluble solids in soil.

2. Auxiliary Tests

2.1 A soil sample must be prepared in accordance with USBR 5205 prior to performing this procedure.

3. Applicable Documents

3.1 *USBR Procedures*:
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5205 Preparing Soil Samples by Splitting or Quartering
3.2 *ASTM Standards*:
D 1125 Standard Test Methods for Electrical Conductivity and Resistivity of Water
E 1 Specification for ASTM Thermometers

4. Summary of Method

4.1 Distilled water is mixed with soil and agitated frequently over a period of 4 days to extract water soluble solids from soil. The solution containing the dissolved solids is separated from the soil-water mixture by filtration and a portion is evaporated to obtain a dry residue. The percent water soluble solids in soil is determined from the mass of the dry residue.

5. Significance and Use

5.1 Water soluble soil minerals, referred to as "water soluble solids," may be dissolved and transported by flowing water from exposed soil. The resulting reduction in soil volume may allow compression of the soil and subsidence of the ground surface. Additionally, where removal of soil material occurs by solutioning of solids by water, soil pore spaces are increased which may allow more water to flow through the soil.

5.2 The method presented does not predict actual field soil performance due to leaching by water. However, the percent of water soluble solids in soils under test conditions may indicate potential for compression, leaching, and subsidence of soils in contact with water.

5.3 Chemical components of soils (such as trace metals, sulfates, and chlorides which dissolve in water) may be determined from solutions prepared by this method.

6. Terminology

6.1 Definitions are in accordance with USBR 3900.

6.2 Terms not included in USBR 3900 specific to this designation are:

6.2.1 *Conductance*.–A measure of the ability to conduct an electrical current in siemans, S. For this designation, conductance is measured in microsiemans, μS.

6.2.2 *Conductivity*.–Specific conductance, which is a measure of the ability of an aqueous solution to carry an electrical current between two conductors of a given surface area and distance apart, at a specified temperature, expressed in microsiemans per centimeter, μS/cm.

7. Apparatus

7.1 *Sample Preparation Apparatus*.–Sample splitter.

7.2 *Extraction Apparatus*:

7.2.1 *Pan Balance*.–A balance that is readable to 0.1 g and has a capacity of about 1200 g.

7.2.2 *Graduate*.–500-mL capacity, readable to 5 mL.

7.2.3 *Flask*.–500-mL Erlenmeyer flask with rubber stopper.

7.2.4 *Flask*.–500-mL capacity vacuum filtration flask.

7.2.5 *Paper*.–Filter paper, 20 to 25 μm particle retention; 7-, 9-, or 11-cm diameter, having high wet strength for vacuum filtration.

7.2.6 *Funnel*.–Buchner type porcelain filtering funnel with flask adapter; 83-, 100-, or 126-mm diameter (to fit filter size selected).

7.2.7 *Vacuum*.–Vacuum source or water aspirator device.

7.2.8 *Bottle*.–1000-mL capacity, glass-stoppered glass bottle.

7.3 *Apparatus for Drying the Extract Solution*:

7.3.1 Porcelain evaporating dish, 75-mL capacity.

7.3.2 An analytical balance readable to 0.0001 g having a capacity of about 200 g.

7.3.3 Steam-heated or low-temperature electric hot plate.

7.3.4 Desiccator (containing anhydrous calcium sulfate).

7.3.5 Convection oven set at 105±5 °C.

7.4 *Apparatus for Measuring Conductance*:

7.4.1 Wheatstone bridge conductivity meter, ±3.0 percent accuracy, meeting requirements of ASTM D 1125.

7.4.2 Pipet or dip-type conductivity cell (cell constant = 1 cm^{-1}) meeting requirements of ASTM D 1125.

7.4.3 Thermometer, 0 to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

7.4.4 1000-mL volumetric flask.

8. Reagents and Materials

8.1 Distilled water is to be used any time water is called for in this test method.

8.2 Potassium chloride (KCl), reagent grade quality as designated by the American Chemical Society, dried at 105 °C for 2 hours.

9. Precautions

9.1 *Safety Precautions*.-This procedure may involve hazardous materials, operations, and equipment. Heating equipment and hot containers can cause serious burns if handled improperly. Use a container holder whenever handling hot containers.

9.2 *Technical Precautions*:

9.2.1 Saturation of the extract mixture must be checked by determining the conductivity of the extract mixture. Soil samples that contain large amounts of soluble solids may exceed solution capacity of the extract mixture. If all soluble solids are not in solution, water soluble solids determination will not reflect the true percentage of soluble solids in the sample.

9.2.2 Electrical conductivity increases with temperature at a rate of 1.9 percent per degree Celsius. Procedures (used in this method) correct for measurements—not at 25 °C—by applying the response of a conductivity cell to a potassium chloride (KCl) reference solution at the same temperature as the extract mixture.

10. Calibration and Standardization

10.1 Verify that equipment is currently calibrated in accordance with applicable calibration procedure. If the calibration is not current, calibrate conductivity equipment in accordance with ASTM D 1125.

11. Preparation of Potassium Chloride Reference Solution

11.1 The reference solution is prepared to determine the response of the conductivity cell at the temperature of the extract mixture prepared in paragraph 13.

11.1.1 Dissolve 744.0 mg of potassium chloride (KCl) in water and dilute to 1000 mL at 20±2 °C in a volumetric flask. This is the standard reference solution (0.01 N) which has a conductivity of 1408 μS/cm at 25 °C. Store solution in a glass-stoppered glass bottle.

12. Sampling, Test Specimens, and Test Units

12.1 Prepare a sample of about 500 g of U.S.A. Standard series minus No. 4 (4.75 mm) sieve size material in accordance with USBR 5205.

12.2 Mix the 500-g sample thoroughly and reduce to a test sample of about 60±10 g using a sample splitter in accordance with splitting procedure and equipment described in USBR 5205. Save remainder of sample—in a properly labled container—for possible future use.

13. Preparation of Extract Mixture

13.1 All data are to be recorded on "Water Soluble Solids Determination" form as shown on figure 1.

13.2 Record the sample number and any other required identification data.

13.3 Mix the 60-g test sample thoroughly and measure out a test specimen of 40±0.5 g. Determine and record the mass of test specimen to the nearest 0.1 g.

13.4 Place test specimen in a clean 500-ml Erlenmeyer flask.

13.5 Measure 400±5 mL of distilled water into a graduated cylinder. Determine and record volume of water to nearest 5 ml.

13.6 Add water to flask containing the test specimen. Stopper flask tightly.

13.7 Calculate and record the extraction ratio to nearest 0.1 mL/g.

13.8 Agitate mixture of soil and water in flask by swirling flask. Agitate mixture at least four times daily for 4 days.

NOTE 1.-A standard agitation time of 4 days has been adopted for this procedure. The agitation time may be modified (either shortened or lengthened) depending on the solubility of the solids in the soil being tested. The standard agitation time may be modified if testing is performed to determine the relationship between extract mixture conductivity (an indication of solubility) and agitation time. If conductivity becomes constant with increasing agitation time, the shortest agitation time which results in constant conductivity may be used for routine testing of the soil. If no trend develops in the data or if extremely long agitation times are required to reach constant conductivity use of the 4-day standard time is recommended.

13.9 After final agitation, allow soil particles to settle—typically overnight. The extract mixture is the clear liquid remaining over the settled soil particles.

14. Conductivity Determination

14.1 Measure temperature of extract mixture. Measure temperature of KCl reference solution prepared in paragraph 11. If temperatures are not within ±2 °C of each other, store the liquids in the same area until temperatures are within ±2 °C of each other.

14.2 Determine response of the conductivity cell to the KCl reference solution as follows:

14.2.1 Rinse the conductivity cell with distilled water.

14.2.2 Rinse conductivity cell three times with the KCl reference solution.

14.2.3 Fill conductivity cell with enough KCl reference solution to cover electrodes; be careful to avoid entrapment of air bubbles in the cell.

14.2.4 Determine and record conductance, K_1, of the KCl reference solution, to nearest 10 μS, using conductivity meter following instructions provided by manufacturer of instrument.

14.3 Determine and record conductance, K_x, of the extract mixture according to subparagraphs 14.2.1 through 14.2.4 using the extract mixture in place of the KCl reference solution.

NOTE 2.-This procedure also can be performed using the extract solution prepared in subparagraph 15.2.

14.4 Calculate and record cell response, J, to nearest 0.01 cm^{-1}.

14.5 Calculate and record conductivity, K, of extract mixture to nearest 10 μS/cm.

14.5.1 If conductivity is larger than 2200 μS/cm, extract mixture may be saturated and cannot be used. Discard the entire soil and water mixture and prepare another extract mixture in accordance with paragraph 13 except use less soil (higher extraction ratio). The conductivity of the new extract mixture is checked to determine that saturation of the extract mixture has not been exceeded.

15. Procedure

15.1 All data are to be recorded on "Water Soluble Solids Determination" form (fig. 1).

15.2 Take the extract mixture (prepared in par. 13) and filter 70±10 mL of the clear liquid by pouring through a paper filter using the vacuum apparatus. The filtered fluid is the extract solution. If the extract solution is cloudy, refilter using a finer filter paper.

15.3 Dry an evaporating dish in a convection oven for 1 hour at 105±5 °C and cool in a desiccator. Determine and record mass of evaporating dish to nearest 0.0001 g.

15.4 Obtain 50±10 mL volume of extract solution.

15.5 Pour the 50±5-mL volume of extract solution into evaporating dish.

15.6 Determine and record the mass of dish and extract solution to nearest 0.0001 g.

15.7 Place dish and solution on a steam-heated or electric hot plate set at 98 °C and evaporate liquid.

15.8 Place dish and residue in to a convection oven at 105±5 °C and dry 1 hour.

15.9 Place dish and dried residue into a desiccator to cool.

15.10 Determine and record the mass of dish and residue to nearest 0.0001 g.

15.11 Calculate and record mass of residue to nearest 0.0001 g.

15.11.1 If mass of residue is less than 0.01 g or more than 0.25 g, results cannot be used. Repeat subparagraphs 15.2 through 15.11 using more or less extract solution as appropriate.

15.12 Calculate to the nearest 0.1 percent and record the water soluble solids content determined by evaporation.

16. Calculations

16.1 *Specimen Preparation*:

16.1.1 Calculate extraction ratio.

$$R = \frac{V}{m_s} \tag{1}$$

where:

R = extraction ratio, mL/g
V = water volume, mL
m_s = specimen mass, g

16.1.2 Calculate cell response.

$$J = \frac{1408}{K_1} \tag{2}$$

where:

J = cell response to KCl reference solution at measurement temperature, cm^{-1}
K_1 = measured conductance of KCl reference solution at temperature of extract mixture, μS
1408 = conductivity of the KCl reference solution at 25 °C, μS/cm

16.1.3 Calculate conductivity of extract mixture.

$$K = J K_x \tag{3}$$

where:

K = conductivity of extract mixture, μS/cm
J = cell response to KCl reference solution at measurement temperature, cm^{-1}
K_x = measured conductance of extract mixture, μS

16.1.4 Calculate mass of residue.

$$m_r = m - m_d \tag{4}$$

where:

m_r = mass of residue, g
m = mass of dish and residue, g
m_d = mass of dish, g

16.1.5 Calculate water soluble solids content.

$$W_{ss} = 100 \left(\frac{m_r R}{m_x - m_d}\right) \tag{5}$$

where:

W_{ss} = water soluble solids content, %
R = extraction ratio, mL/g
m_r = mass of residue, g

m_d = mass of dish, g
m_x = mass of dish and extract solution tested, g
100 = convert from decimal to percent

17. Report

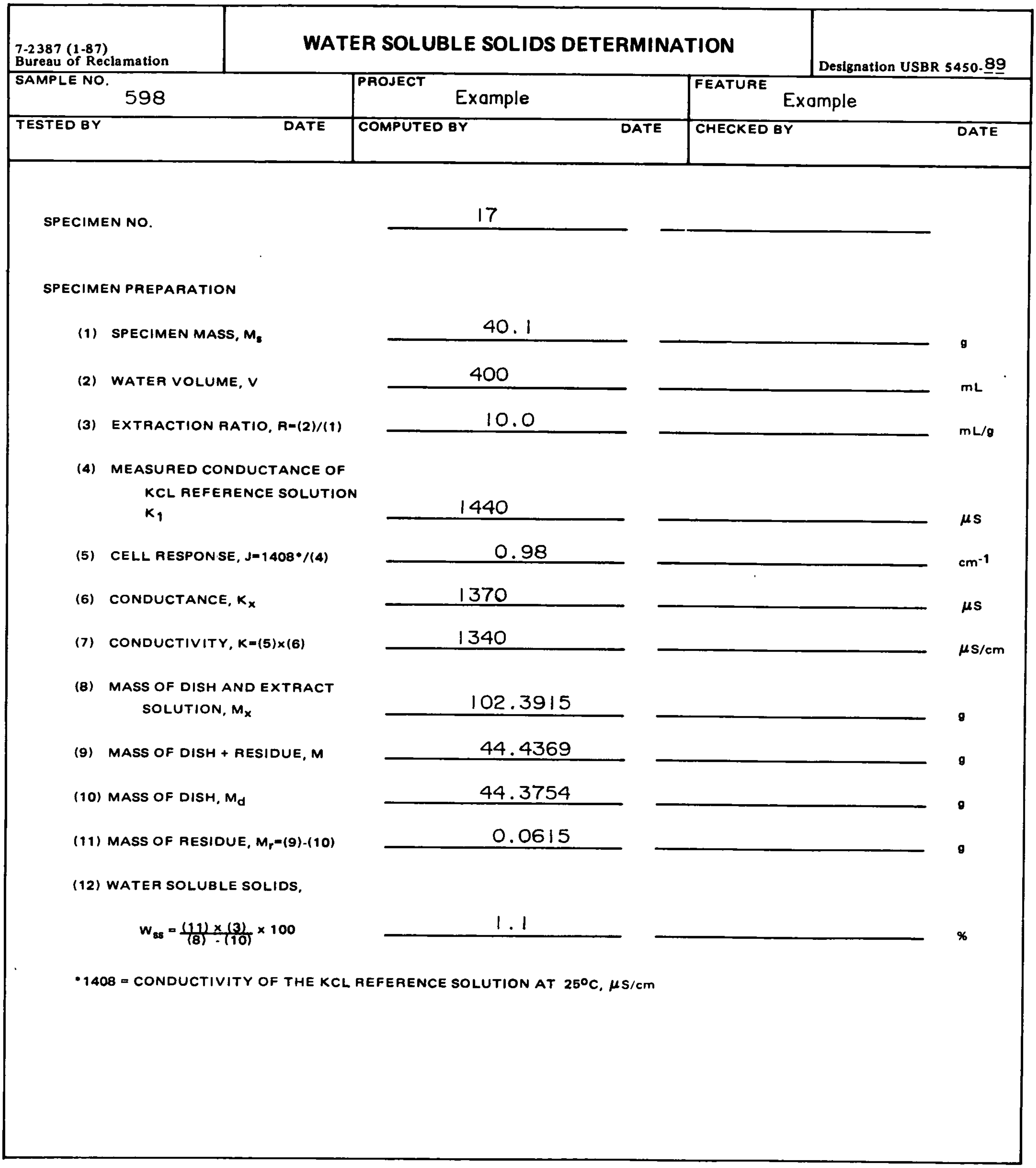
17.1 The report is to consist of a completed and checked "Water Soluble Solids Determination" form (fig. 1).

17.2 All calculations are to show a checkmark.

18. Background References

Method of Test for Determining the Quantity of Soluble Sulfate in Solid (Soil or Rock) and Water Samples, Bureau of Reclamation, Division of Research and Laboratory Services, 2 p., May 1973.

Agricultural Handbook No. 60, 1954, "Diagnosis and Improvement of Saline and Alkali Soils," United States Department of Agriculture.



7-2387 (1-87) Bureau of Reclamation	**WATER SOLUBLE SOLIDS DETERMINATION**	Designation USBR 5450-89
SAMPLE NO. 598	PROJECT Example	FEATURE Example
TESTED BY DATE	COMPUTED BY DATE	CHECKED BY DATE

SPECIMEN NO.	17		
SPECIMEN PREPARATION			
(1) SPECIMEN MASS, M_s	40.1		g
(2) WATER VOLUME, V	400		mL
(3) EXTRACTION RATIO, R=(2)/(1)	10.0		mL/g
(4) MEASURED CONDUCTANCE OF KCL REFERENCE SOLUTION K_1	1440		μS
(5) CELL RESPONSE, J=1408*/(4)	0.98		cm^{-1}
(6) CONDUCTANCE, K_x	1370		μS
(7) CONDUCTIVITY, K=(5)x(6)	1340		μS/cm
(8) MASS OF DISH AND EXTRACT SOLUTION, M_x	102.3915		g
(9) MASS OF DISH + RESIDUE, M	44.4369		g
(10) MASS OF DISH, M_d	44.3754		g
(11) MASS OF RESIDUE, M_r=(9)-(10)	0.0615		g
(12) WATER SOLUBLE SOLIDS, $W_{ss} = \frac{(11) \times (3)}{(8) - (10)} \times 100$	1.1		%

*1408 = CONDUCTIVITY OF THE KCL REFERENCE SOLUTION AT 25°C, μS/cm

Figure 1. - Water soluble solids determination — example.