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New Recommendations for ASR Mitigation in Reclamation Concrete Construction

Technical Services Center, Denver Colorado

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Civil Engineering Services Division
Materials Engineering and Research Laboratory Group
Denver, Colorado

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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.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Materials Engineering and Research Laboratory Group, 86-68180

MERL Laboratory Report 09-23

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Executive Summary

Cement industry experts indicate the probability of producing new concrete susceptible to alkali-silica reaction is increasing due to the lack of availability of low-alkali cements. The quality of concrete aggregate is quickly declining as the best sources are depleted. Environmental air quality standards are forcing the cement manufacturing industry to increase the amount of alkalis in the cement and assess the effectiveness of supplementary cementitious materials. Specification of low-alkali cement for mitigating ASR in concrete structures is no longer considered effective. Testing aggregates using new standard tests is now a reliable approach to mitigating ASR in concrete. Recommended specifications have been developed for inclusion in Reclamation contracts.

Introduction

A FY04 program resulted in a technical memorandum 8340-2005-26 titled "Guidance for Testing Concrete Aggregates to Prevent ASR" by the author, September 2005. The report suggested employing new methods for evaluating reactive aggregates. We learned of a risk evaluation approach, adopted by the Canadian Standards Association (Thomas, et. al., 1997), to systematically make decisions about the use of reactive aggregates in concrete with respect to the type of concrete structure. Subsequently, we have visited the Federal Highways Administration (FHA) Laboratory in Lakewood Colorado and discovered the Alkali-Silica Benchmarking Workshop Final Report, (Cooley, 2006) which provides the insight of concrete industry experts.

Cement industry experts indicate the probability of producing new concrete susceptible to alkali-silica reaction is increasing due to the lack of availability of low-alkali cements which was discussed in the September 2005 report. The quality of concrete aggregate is quickly declining as the best sources are depleted. In addition, environmental air quality standards are forcing the cement manufacturing industry to increase the amount of alkalis in the cement and the effectiveness of some pozzolans to fully mitigate ASR is no longer certain. These combined issues have increased the likelihood of concrete deterioration due to alkali-silica reaction in future concrete construction of hydraulic structures.

The current Reclamation specifications needs to be updated to address the lack of availability of low-alkali-cement, increased usage of poor quality aggregates, increased alkali content of concrete, and reduction of availability of suitable class F fly ash. This paper will discuss available mitigation techniques. Background material will be presented to explain essential components of alkali-silica reaction (ASR) attack and historical specifications measures that have been used by Reclamation and the concrete industry to mitigate alkali-reactivity. Case histories will be studied to indicate what works. Newer specification used by other agencies will be examined for possible incorporation into future Reclamation specifications. Specific recommendations will be made regarding mitigation of potential ASR in Reclamation structures. Newer, more reliable tests have been developed which allow for testing of aggregate to determine its reactivity potential and of a pozzolan to determine its effectiveness.

Conclusions

1. Specification of low-alkali cement as a stand alone requirement for mitigating ASR in concrete structures is no longer considered effective. Studies have shown that internal sources of alkalis, i.e. aggregates, pozzolans, chemical admixtures, and external sources i.e. using deicing salts to on hardened concrete surfaces can elevate the alkali content of the paste to harmful levels even if low-alkali cement has been used.

2. Test methodologies such as ASTM C 227 (Mortar Bar Method) and ASTM C 289 (Chemical Method) that were once considered reliable indicators of aggregate reactivity do not correlate to field performance.

3. Conventional petrographic methods of analysis, i.e. ASTM C 295, ASTM C 856, have proven to be effective in identifying many, but not all, reactive minerals in aggregates or reaction products in concrete, however, they are dependent upon the skills of the individual petrographer. Petrographic examination of aggregates should be used in concert with other tests and field performance data to assess aggregate reactivity potential but not as a stand alone measure.

3. Newer, more reliable tests have been developed which allow for testing of aggregate to determine its reactivity potential, i.e. ASTM C 1260, ASTM C 1293. These tests are designed to be performed in conjunction with petrographic analysis.

4. Newer, more reliable tests, i.e., ASTM 1567, have also been developed to assess the effectiveness of supplementary cementitious materials including fly

ash, ground granulated blast furnace slag, and silica fume in mitigating ASR expansion.

5. Some industry and government agencies have incorporated newer tests and analysis techniques into their specifications as a means of preventing ASR in concrete.

6. Reclamation must also incorporate newer tests and analysis methodologies into its standard specifications to provide state-of-the-art ASR mitigation measures.

Recommendations for a New Specification

Recommended specifications have been developed for inclusion in Reclamation contracts whenever concrete structures are built. They have been included in Appendix A. Since the expertise for ASR analysis and testing lies within the Material Engineering and Research Laboratory Group (MERL) Concrete Laboratory of the Technical Services Center (TSC), the specifications have been designed to utilize this expertise. The protocol for testing including submission of materials, sample sizes, and timeframes for testing has been included in Appendix B. The MERL Manager should be contracted for scheduling and pricing. Discussions with the TSC's Estimating, Specifications, and Construction Management Group regarding a new specification are in progress.

Essentials Components of ASR Attack

The susceptibility of concrete to alkali-silica reaction depends on the presence of potentially alkali-reactive aggregates, high humidity, and high alkali concentration in the pore solutions of hardened concrete. The high concentration of anions (negative charges) from the dissolution of the calcium hydroxide ion (portlandite, ($Ca(OH)_2$) in hardened concrete pore solutions is proportional to the high concentration of alkali cations (positive charges) of the hydrated cement and the requirement of electrical neutrality of the pore solution. That is, the alkali content of the cement directly affects the alkalinity and pH of the concrete pore solutions. The highly alkaline and high pH solutions destabilizes and attacks susceptible siliceous aggregates and alkali-silica gel forms in the aggregates, at the paste-aggregate contact, or in the concrete paste. The gel is susceptible to free water absorption and expansion. Expansion of the gel with exposure to available free moisture results in increased internal pressures and distorted and cracked concrete structures. In extreme case, the expansion of the concrete can cause problems with the operation of gates and power generating facilities. Typically, concrete deterioration due to ASR affects the durability and longevity of the concrete.

Mitigating ASR in a hydraulic concrete structure requires the mixture to be proportioned with consideration to the available materials. The alkalis in the cement can be lowered by placing a limit on the alkali content of the job cement and/or using a suitable pozzolan to lower the alkali content of the mixture. One can use only innocuous aggregates or avoid the use of potentially alkali-reactive aggregates. The mixture can be designed to make the concrete dense and water-tight in wet conditions by keeping the water cement ratio low. Mortar bar and chemical reactivity testing can identify unsuitable cement aggregate combinations in some cases, but slowly reacting aggregates can confound the results. Experience has shown that Reclamation's ASR mitigation techniques are not always satisfactory.

Conventional Techniques for Mitigation of ASR

Stanton was a California Division of Highways engineer who discovered high alkali contents in cement caused concrete deterioration when certain siliceous aggregates were used. He used mortar bar tests to establish the 0.6 percent alkali as equivalent sodium oxide limit on cements used with reactive aggregates in concrete. Reclamation placed a 0.6 percent alkali as equivalent sodium oxide limit on cement used in 1941 (Hobbs, 1988, and Stark, 1992 and 1995) after the cracking of two dams due to ASR and drying shrinkage cracking of laboratory concrete specimens using high alkali cement (Burrows, 1999).

Reclamation used the 0.6 percent alkali as equivalent sodium oxide limit in specifications and the Concrete Manual. The revised 8th edition of Reclamation's Concrete Manual, 1981, recommends that "aggregates petrographically similar to known reactive types, or which on the basis of service history or laboratory experiment are suspected of reactive tendencies, should be used only with cement that is low in alkalis." Cement low in alkalis was specified as 0.5 to 0.6 percent of the cement and recommended the use of an effective pozzolan. The alkali content of cement was defined as Na_2O plus 0.658 K_2O.

Events of the recent past in Reclamation history and elsewhere have indicated that the limit of 0.6 percent alkalis does not prevent ASR damage to concrete in every case. The 0.6 percent limit was developed using reactive aggregates that show relatively rapid reaction times. Certain slowly reactive aggregates, such as quartzite, may slowly react to lower alkali cements under moist environmental conditions. Concrete damage due to ASR may not be evident until decades have passed since construction, e.g. Seminoe Dam.

In 1995, Stark indicated that there is no safe level of cement alkalis, especially in the western United States where structures have developed ASR problems with cements with very low-alkali contents. He suggested that specifications with the 0.6 percent alkali as equivalent sodium oxide limit may not prevent concrete damage in all cases. Also, alkalis from other sources in the concrete mixture may elevate the alkali content to significant levels even if low-alkali cement is used.

These observations prompted academia, industry, and government agencies to seek better ways to mitigate the effects of ASR.

Case Histories

Ririe Dam Bridge

Ririe Dam was built by the USACE from 1970 to 1977 and currently is operated by Reclamation. Ririe Dam is located 6 miles southeast of Ririe, Idaho, in the Willow Creek Drainage on the western flank of the Caribou Range.

The Ririe Dam Design Memorandum dated February 1978 was briefly reviewed during a damsite inspection. The Concrete Operations and Test portion indicated type II and III low-alkali cement, no pozzolan, and a design water cement ratio of 0.47 was used. The USACE Petrographic Report by Higgs dated December 1966, evaluated the aggregate source from Ready-to-Pour aggregate in Idaho Falls. The examined coarse aggregate was composed of 78% siliceous quartzite, 8% quartzose sandstone, 6% dolomitic limestone, 4% granite, 1% acid volcanics, 2% vesicular basalt, and 1% chert. The fine aggregate was composed of 39% obsidian (some highly porous rhyolite), 44% quartzite, 2% sandstone, 15% other and granite with minor acid volcanics.

ASTM C 227 mortar bar expansion tests were performed in January 1968. The results indicated expansion of 0.092 percent at 6 and 12 months with high-alkali cement and expansions of only 0.023 and 0.027 percent at 6 and 12 months, respectively, with low-alkali cement. The mortar bar tests results suggested no potential for deleterious expansion. However, the petrographic report recommended the possible use of a pozzolan due to the amount of potentially alkali-reactive aggregate particles observed. A pozzolan was not specified. Shortly after construction early cracking of bridge parapet walls was observed. A bridge inspection in October 2004 indicated extensive cracking of the bridge abutments and the pier concrete as well as expansion and dislocation of the bridge parapet walls and a concrete testing program was initiated and completed.

Petrographic reports (Hurcomb, 2005 and 2006) observed that the rhyolite particles in the sand were associated with alkali-silica gel filled fractures in the bridge abutment and pier concrete. Deterioration due to alkali-silica reaction is evidenced by alkali-silica gel soaking paste, lining coarse aggregate sockets, filling cracks penetrating aggregates, filling cracks at the paste-aggregate contact, and lining voids. The reaction appears to be progressing from the top of the structure down to lower depths. Petrographic examination indicates weakening of the paste-aggregate bond due to the effects of ASR on the smooth to slightly rough, rounded coarse aggregate particles. No evidence of deterioration other than ASR was observed during Petrographic examination.

It appears that the 0.6 percent alkali as equivalent sodium oxide limit of the cement and satisfactory ASTM C 227 mortar bar test results did not prevent alkali-aggregate reaction from affecting the concrete at 30 year old Ririe Dam. The obsidian and quartzite are likely slowly reactive and any porous acid volcanic materials, like rhyolite, react rapidly with the low-alkali cement. The Ririe Dam Bridge concrete is a good example of where a suitable pozzolan should have been used. This is also a good example of the unreliability of the ASTM C 227 mortar bar test.

Friant Dam

Friant Dam is a good example of a structure in which the 0.6 percent limit in combination with a good pozzolan worked to prevent expansion.

Friant Dam was built from 1939-1942 and is currently operated by Reclamation. Friant is a concrete gravity dam located about 20 miles northeast of Fresno, California on the San Joaquin River forming Millerton Lake.

According to the petrographic report (Hartwell, 1990) "the concrete was fabricated with aggregates containing deleteriously alkali-reactive cherty and glassy volcanic particles and both high- and low-alkali cements, with and without pumicite pozzolan as a cement replacement." The present condition of the concrete is variable. Compressive strength and elasticity test results indicate concrete made with high alkali-cements deteriorated due to alkali-aggregate reaction. High- and low-alkali blended cement concrete with pumicite pozzolan did not deteriorate to any appreciable extent. Stark and DePuy, 1987, indicated the extent and severity of the alkali-silica reactivity varied with location and sufficient moisture available to permit further expansion of the concrete.

Apparently the use of high- or low-alkali cement concrete with pumicite mitigated the alkali-silica reaction where used; only very small amounts of gels were observed and any voids were unfilled. Silica gel was extremely rare in concrete produced with low-alkali cement and pozzolan and only very fine cracks were observed (Hartwell, 1990). It appears that the combination of low-alkali-cement and pozzolan prevented significant alkali-aggregate reaction. Friant Dam concrete is a good example how the use of a suitable pozzolan mitigated alkali-silica reaction in a dam.

El Vado and Palisades Dam Spillway Concrete

Recent petrographic examinations of deteriorated concrete at El Vado Dam, located on the Rio Chama about 160 miles north of Albuquerque, New Mexico and Palisades Dam located on the Snake River about 55 miles southeast of Idaho Falls, Idaho indicate minor alkali-silica reaction. The concrete required low alkali cement and state-of-the-art concrete. The spillway structures were built or modified in the 1950's or later, and low alkali-cement was prescribed to prevent deterioration due to ASR.

Colorado Springs and Denver International Airport

The runway concrete of two airports illustrates how external factors can influence concrete.

Runway concrete at the two Colorado airports is relatively new and experiencing ASR or a combination of ASR and drying shrinkage cracking. The airport runways in Colorado Springs and Denver were originally placed in the 1970's and 1990's, respectively. The damage is due to the use of modern deicing fluids containing alkalies which react with alkali-reactive aggregates used in the concrete. Very expensive concrete slabs and whole runways are currently being replaced at both airports. The use of modern deicing fluids was not taken into consideration in the specifications for cement and aggregates used to make the concrete. The result is a massive and costly concrete replacement program which is being paid for by the taxpayer due to the FAA's safety concerns about foreign object damage (FOD) to jet engines.

Experience has shown that in certain cases the 0.6 percent alkali as equivalent sodium oxide limit does not work when slowly-reacting rock types such as certain dense volcanic glasses, phyllites, rocks containing strained quartz, and quartzites are used as concrete aggregates. Also, alkali sources other than cement can raise the alkali content of the concrete mixture making the hardened concrete more susceptible to ASR.

Approaches to ASR Mitigation by Other Agencies

CSA Risk Evaluation Approach

Canadian researchers have developed a risk based approach to prevention of ASR which was adopted by the Canadian Standards Association (CSA) (Fournier, Berube, and Rogers, 2000). The alkali-reactivity of aggregates, cements, and supplementary cementing materials are evaluated before use in concrete structures to reduce risk of ASR and the loss of service. Field performance of the aggregate is considered and if long-term performance data is lacking laboratory tests are recommended including Petrographic Examination and the Canadian version of the ASTM C 1260 mortar bar method, CSA A23.2-25A, and the longer term ASTM C 1293 concrete prism test, CSA A23.2-14A.

The Canadian risk evaluation approach for avoiding ASR problems involves determining the degree of potential reactivity of aggregates, the size of the structure and environmental conditions at the site, and the design service life of the concrete structure. The alkali content of the cement is limited by using low-alkali cement, supplementary cementing materials (SMC), or a combination of both.

Field performance is evaluated by field information and petrographic examination of hardened concrete, when needed, to assure the proposed aggregates are identical to those used in service. The field investigation evaluates the cement used and alkali level, concrete age, exposure conditions, and records indicating any supplementary cementitous materials and water-cement ratio (w/c). If field performance of the concrete does not meet the CSA criteria then a laboratory investigation is initiated including petrographic examination of the aggregates, the mortar bar test method, and the concrete prism test.

The flow chart in figure 1 is used for the process of evaluation of potential alkali-reactivity of the concrete aggregates under consideration. The flow chart requires the results of the mortar bar method and concrete prism test as well as selection of various levels of risk and prevention measures. The expansion values from the mortar bar method and concrete prism test provide information on the potential alkali-reactivity using the proposed aggregate. The size of the structure and environmental conditions are considered and determine the need for preventive measures including rejecting the aggregate, limiting the alkali content of the cement, and allowing the use of supplementary cementing material or other special admixtures in appropriate amounts to minimize deleterious reaction. The risk evaluation approach also helps determine the risk of poor performance of concrete considering the size of the concrete element, the humidity of the environment, and the degree of reactivity of the aggregates.

Mitigation of Reactive Aggregates with a Specifications Approach

The Federal Highway Administration held a ASR Benchmarking Workshop in 2006 to develop a program to address the alkali-silica reactivity problem and how to mitigate ASR in new and existing concrete. Four topics were discussed and the first two topics are relevant to the discussion of testing of materials for mitigation of ASR. Participants from academia, industry and government discussed ASR Test Methods and Identification Techniques including:

- ASTM C 289, Test Method for Potential Alkali – Silica Reactivity of Aggregates (Chemical Method)
- ASTM C 295, Guide for Petrographic Examination of Aggregates for Concrete
- ASTM C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- ASTM C 1260, Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
- ASTM C 1293, Test Method for Determination of Length of Change of Concrete Due to Alkali-Silica Reactivity (Concrete Prism Test)
- ASTM C 1567, Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitous Materials and Aggregates (Accelerated Mortar-Bar Method)

Major comments were:

- These are inference tests and they do not evaluate the actual mix design selected
- The tests usually only evaluate aggregates and not actual concrete mixtures
- The tests do not simulate field exposure conditions
- The test duration is not similar to field conditions and are therefore not reliable
- The tests do not accommodate material changes during construction
- Most practitioners do not understand the test methods
- Petrographer's generally do not have enough experience identifying ASR

There was general agreement on the use of ASTM C 1260, ASTM C 1567, and ASTM C 1293 to test the effectiveness of supplementary cementitous materials in concrete mixtures. Methods of controlling ASR include limiting alkali-reactive aggregates, limiting alkalis in the mixture, and specifying the amount and characteristics of any supplementary cementitous materials.

The ASR Benchmarking Workshop participants seemed to agree that outdated tests such as ASTM C 289 and ASTM C 227 (USBR 4227-92), both developed and previously used by Reclamation in major construction test programs, should be discontinued because of inherent unreliability. The mortar bar test (USBR 4227-92) is recommended in the revised eighth edition of the Concrete Manual.

Federal Highway Administration Specification

The Federal Highway Administration's (FHWA) aggregate specification is a good example of the use of specifications to mitigate ASR. The FHWA uses the following standards: ASTM C 295, ASTM C 1260, ASTM C 1293, and ASTM C 1567 to test for the reactivity of aggregates in concrete (Michael Peabody, personal communication).

If both the coarse and the fine aggregates tested separately by ASTM C 1260 exhibit expansion of less than 0.10 percent at 16 days than the aggregates are considered innocuous. The aggregates are approved for use in the proposed concrete.

If the aggregates tested by ASTM C 1260 exhibit expansion between 0.10 and 0.20 percent at 16 days, the aggregates are acceptable if supplemental information confirms the expansion is not due to ASR. If the petrographic examination indicates that the aggregate is not potentially deleteriously reactive, the aggregate is acceptable for use in the proposed concrete. The aggregate is not acceptable if the petrographic examination indicates the presence of potentially deleteriously reactive aggregates, which would lead to the use of ASTM C 1567 to find a combination of cement, aggregate, and supplemental cementitious materials to effectively mitigate any expansions greater than 0.10 percent at 16 days

If the aggregates tested by ASTM C 1260 exhibit expansions greater than 0.20 percent at 16 days, the cement and aggregates combination is subject to additional testing using ASTM C 1567. ASTM C 1567 is used to find a combination of cement, aggregate, and supplemental cementitious materials to effectively mitigate any expansions greater than 0.10 percent at 16 days. The FHWA does not allow the the use of lithium compounds during testing to mitigate ASR. If suitable combinations of materials are non-expansive, the aggregate is acceptable for use in the proposed concrete mixture.

Substitution of ASTM C 1293 for ASTM C 1260 is acceptable but the average concrete prism expansion must be less than 0.04 percent at one year.

Highlights of New Test Methodologies

ASTM C 295, Guide for Petrographic Examination of Aggregates for Concrete

The petrographic examination of aggregate samples provides a quick and reliable way to identify potentially reactive aggregate types. Petrographic examinations are typically performed to initially screen samples prior to a laboratory test program as well as examine samples previously used in concrete constructions. Petrographic examination identifies potentially alkali-reactive particles in a sample but cannot determine if potentially reactive particles are deleteriously reactive when combined with cementitious material to make concrete. Research and experience has indicated that petrographic analysis can fail to identify slowly reactive aggregates.

ASTM C 1260, Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

ASTM C 1260 takes 16 days to perform and measures aggregate reactivity potential. The test method identifies slowly reactive rock types that are hard to detect by other tests. It is a quick and reliable but harsh test that can characterize the potential reactivity of slowly as well as rapidly reactive rock types.

ASTM C 1293, Test Method for Determination of Length of Change of Concrete Due to Alkali-Silica Reactivity (Concrete Prism Test)

The concrete prism test takes a year to perform and is similar to the accelerated mortar bar test except that it uses concrete prisms instead of mortar bars. The test evaluates aggregates in concrete instead of in mortar. The test is used to assess both fine and coarse aggregate in concrete.

This year-long test would benefit Reclamation when exploring new aggregate sources for modification of existing concrete structures, replacement concrete structures, new construction, and significant repairs of older structures.

ASTM C 1567, Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregates (Accelerated Mortar-Bar Method)

ASTM C 1567 takes 16 days to perform and is used as a means of measuring effectiveness of supplementary cementitious materials (SCM) to control ASR expansion. The test evaluates cement, pozzolans, ground granulated blast furnace slag, and aggregate combinations to limit expansion. It cannot be used to measure effectiveness of low-alkali-cement or lithium admixtures.

Recommendations for Mitigation of ASR

The recently developed ASTM standard tests, ASTM C 1260, -1293, and 1567 should be used in Relamation's specifications to provide a reliable approach to mitigating alkali-aggregate reactivity, rather than rely on the use of low-alkali cement.

Consider following the newer guidelines of the Standard Specification for Concrete Aggregates, ASTM C 33-03, particularly appendix items X1.1, X.1.2, and X1.3. Other good practices include:

- Obtain field service records of existing concrete using the same aggregates in similar structures under similar conditions.
- Require petrographic examination, following ASTM C 295, where service records of the proposed concrete aggregates do not exist or ASTM C 1260 has not been performed.
- Use supplementary cementitious materials, i. e., suitable pozzolan or blast-furnace slag, which lower the alkali content of the cement and improve the durability and water-tightness of the concrete.
- Require the mortar bar method, ASTM C 1260 (16 days result). The concrete prism test, ASTM C 1293-05 (1 year for results) using the job cement, aggregates, and supplementary cementitious materials used in the concrete should be optional.
- Use the accelerated mortar bar method, ASTM C 1567, to evaluate combinations of the cement, supplementary cementitious materials, and aggregate combinations to limit expansion.
- Field service condition information of existing concrete using the aggregates in similar structures predicts the effect of environment.
- Perform a field performance survey of concretes using the same aggregates and cement under the same or more severe conditions.
- Perform laboratory studies of cement, supplementary cementitious materials, and aggregate combinations.
- Use ASTM C 295 (petrographic examination) to identify potentially reactive rock types.
- Investigate any supplementary cementing materials (SCM) including fly ash, ground granulated blast furnace slag (GGBFS), silica fume, and

natural pozzolans to control expansions when used with the intended concrete aggregates.

- Limit the alkali level of Portland cement where practical but also consider combinations of higher alkali cements with supplementary cementitious materials to prevent excessive expansions due to ASR.
- Avoid reactive aggregates where practical but also consider combinations of high or low-alkali cement with supplementary cementitious materials to control the alkali content.
- Limit exposure to moisture or design crack resistant, watertight concrete to limit moisture ingress to the structure.
- Use ASTM C 1260 to detect expansion in mortar bars.
- Use ASTM C 1567 to evaluate the ability of the pozzolans and ground granulated blast furnace slag to control expansions when used with the intended concrete aggregate and cement.
- Use ASTM C 1293 to detect expansion in concrete prisms of mixes designed with the aid of ASTM C 1260 and 1567.
- Use chemical additives, i. e., lithium-based compounds and liquids where practical to mitigate ASR.
- Design mixes with the appropriate water cement ratio for performance, water-tightness, and durability.

References:

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- ASTM C 289, Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates
- ASTM C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- ASTM C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- ASTM C 1260, The Standard Test Method for Potential Alkali Reactivity of Aggregates
- ASTM C 1293, Standard Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction
- ASTM C 1567. Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combination of Cementitious Materials and Aggregates

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CSA A23.2-27A Standard Practice to Identify Degree of Alkali-Reactivity of Aggregates and to Identify Measures to Avoid Deleterious Expansion in Concrete

PCA/acpa IS 415.06T Guide Specifications for Concrete Subject to Alkali-Silica Reactions (includes flow chart showing steps to control ASR)

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USBR Concrete Manual, 8th edition, 1981

Appendix A

Suggestion for New Cast-In-Place Concrete Aggregate Specification

86-68180
RES-3.40

MEMORANDUM

To: Manager, Estimating, Specifications, & Construction Management

From: Doug Hurcomb, Geologist, Materials Engineering and Research Laboratory Group

Subject: Suggestion for New Cast-In-Place Concrete Aggregate Specification

Materials Engineering and Laboratory Report No. MERL -09-18

INTRODUCTION

Cement industry experts indicate the probability of producing new concrete susceptible to alkali-silica reaction (ASR) is increasing due to the lack of availability of low-alkali cements. Specification of low-alkali cement as a stand alone requirement for mitigating ASR in concrete structures is no longer considered effective. Conventional petrographic methods of analysis have proven to be effective in identifying many, but not all, reactive minerals in aggregates or reaction products in concrete. Newer, more reliable tests have been developed which allow for testing of aggregate to determine its reactivity potential and tests are available to assess the effectiveness of supplementary cementitious materials in mitigating ASR expansion.

We have recently examined air-entrained concrete from Reclamation projects, produced using low-alkali cement, which is experiencing deterioration due to ASR and apparent subsequent freezing and thawing deterioration.

I believe that the current Reclamation specifications needs to be updated to address the lack of availability of low-alkali-cement, poor quality aggregates, and increased alkali content of concrete. I am working on a paper which will discuss new mitigation techniques and standard methods. Included in the paper are specific recommendations regarding mitigation of potential ASR in Reclamation structures.

Some industry and Government agencies have incorporated newer tests and analysis techniques into their specifications as a means of preventing ASR in concrete. Reclamation must also incorporate newer tests and analysis methodologies into its standard specifications to provide state of the art ASR mitigation measures.

I would like to propose a new cast-in-place concrete aggregate specification. I have borrowed heavily from the approach used and practiced by the Federal Highway Administration, Central Federal Lands Highway Division, and described to me by Michael Peabody. J.C. Roumain, Holcim, Inc., presented similar concepts to the Rocky Mountain Chapter – ACI last fall. The Alkali-Silica Benchmarking Workshop Final Report, (Cooley, 2006) provided me with the insight of other concrete industry experts.

OLD SPECIFICATION FOR CAST-IN-PLACE CONCRETE FOR COMPARISON

Reclamation Specification for Cast-In-Place-Concrete 03300, Part 2, Products, 2.01 Cementitious Materials, E., Low-Alkali Limitations:

> "Low-alkali limitation for Portland cement and mortar expansion limit for pozzolan and blended hydraulic cement may be waived by Government when concrete aggregate source has previously been tested by Bureau of Reclamation and aggregate source does not contain potentially deleterious amounts of particles which may react with alkalis in cementitious materials as evidenced by petrographic examination or mortar bar tests, or both"

PROPOSED SPECIFICATION FOR CAST-IN-PLACE-CONCRETE

The low-alkali limitation for Portland cement and mortar bar expansion limit for supplementary cementitious materials and blended hydraulic cement may be waived by Government when concrete aggregate source has previously been tested or used in concrete by Bureau of Reclamation and aggregate source does not contain potentially deleterious amounts of particles as determined by the use of the test methods listed below.

- ASTM C 295 "Standard Guide for Petrographic Examination of Aggregates for Concrete"
- ASTM C 1260 "Standard Test Method for Potential Alkali Reactivity of Aggregates"
- ASTM C1293 "Standard Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction"
- ASTM C 1567 "Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combination of Cementitious Materials and Aggregates"

The 1260, 1293, and 1567 methods test the reactivity of aggregates in mortar or concrete batches prior to their use in constructions. These standards will be used to evaluate aggregates and cementitious materials, or combinations of both.

General guidelines and interpretation of results:

ASTM C 295 provides screening of potentially deleteriously alkali-reactive and poor physical quality particles and should be used at the discretion of the materials engineer evaluating any aggregate source.

If the aggregates tested by ASTM C 1260 exhibit expansion of less than 0.10 percent at 16 days then the aggregates are considered innocuous. The aggregates are suitable for use in the proposed concrete.

If the aggregates tested by ASTM C 1260 exhibit expansion between 0.10 and 0.20 percent at 16 days, the aggregates are acceptable if supplemental information confirms the expansion is not due to ASR. If the petrographic examination indicates that the aggregate is not potentially deleteriously reactive, the aggregate is acceptable for use in the proposed concrete. The acceptable limit for the 1260 test is less than 0.10 percent expansion at 16 days.

If the aggregates tested by ASTM C 1260 exhibit expansions greater than 0.20 percent at 16 days, the cement and aggregates combination is subject to additional testing using ASTM C 1567.

ASTM C 1567 is used to find a combination of cement, aggregate, and pozzolans to effectively mitigate any expansions greater than 0.10 percent at 16 days without the use of lithium compounds. If suitable combinations of materials are non-expansive, the aggregate is acceptable for use in the proposed concrete mixture. The acceptable limit for the 1567 test is less than 0.10 percent expansions at 16 days.

Substitution of ASTM C 1293 for ASTM C 1260 is acceptable and the limit for the 1293 test is less than 0.04 percent expansion at one year.

Discussion

The paper "Guidance for Testing Concrete Aggregates to Prevent ASR", September 2005, http://intra.usbr.gov/~tsc/techdocs/others.html, addresses ASTM C 1260 and ASTM C 1293 and how and when to use the standards. Typically only the 1260 mortar bar test and petrographic examination would be performed unless the test results indicate excessive expansions.

A new mortar bar test, ASTM C 1567, introduced in 2004, is similar to the 1260 test. The 1567 test is performed on combinations of cement, pozzolans, and aggregates to find an acceptable non-expansive mixture. If a combination of materials cannot be found to prevent expansion of the mortar bars greater than 0.10 percent, the aggregate cement combination is unacceptable for use in concrete and a new source of cement or aggregate should be evaluated.

The ASTM C 1293 concrete prism test evaluates concrete instead of mortar and takes one year to complete. The 1293 test would benefit Reclamation when exploring new aggregate sources for modification of existing concrete structures, replacement concrete structures, new construction, and significant repairs of older structures.

cc: 86-68180 Hurcomb, Kepler

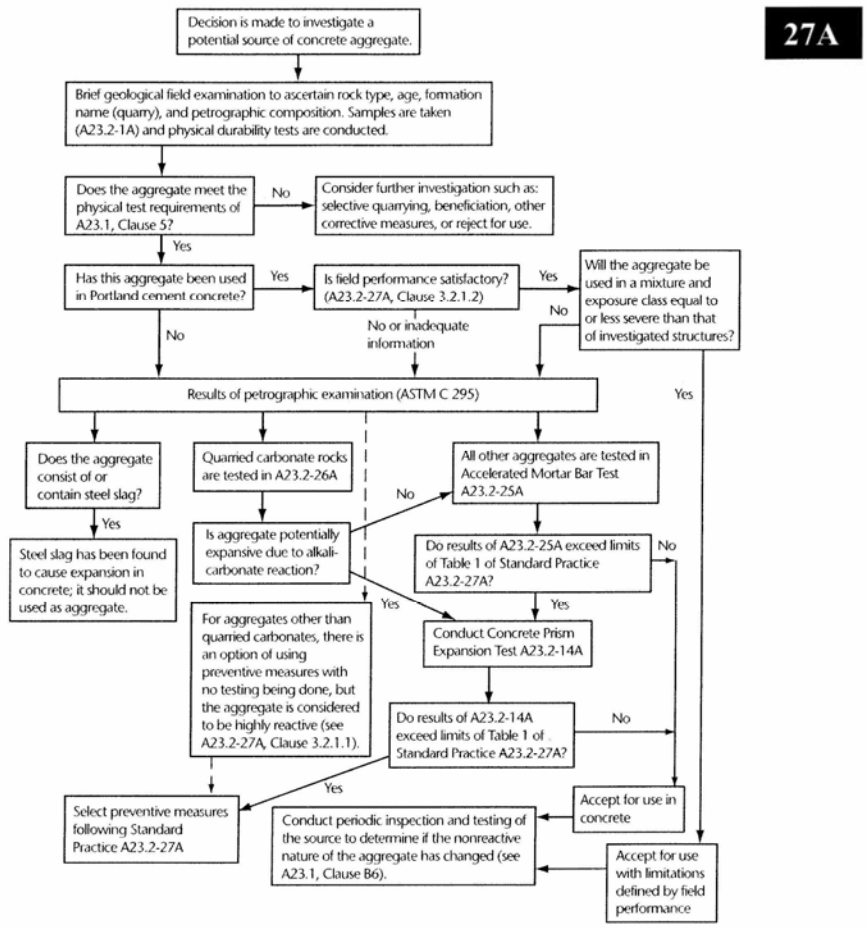

Figure 1
Process for Determining the Potential Alkali-Aggregate Reactivity of Concrete Aggregate
Table 1

September 2000

Figure 1 - Process for Determining the Potential Alkali-Aggregate Reactivity of Concrete Aggregate, from A23.2-27A, Standard Practice to Identify Degree of Alkali-Reactivity of Aggregates and to Identify Measures to Avoid Deleterious Expansion in Concrete, CSA International – September 2000.

Appendix B

Protocol for Testing

Contact the Materials Engineering and Research Laboratory Group manager, Bill Kepler, at 303 445-2386 or wkepler@usbr.gov for scheduling and pricing. He can direct you to the Concrete Technology or Concrete Repair Team member most qualified to assist you.

- Concrete Technology team—evaluates and tests concrete and concrete making materials, prepares and reviews specifications, and provides concrete mixture proportions for unusual design or construction requirements. It also provides concrete technology training, supplies inspection and calibration services, and assists with procurement of unique testing equipment.

- Concrete Repair team—provides guidance and technical advice in failure analysis, condition assessment, maintenance, repair, rehabilitation, and preservation of concrete infrastructure.

Bill Kepler or a team member will discuss submission of materials, sample sizes and timeframes for testing, as well as how to work with the Technical Services Center. The website http://www.usbr.gov/pmts/tech_services/about/business.html provides assistance with TSC business operations.