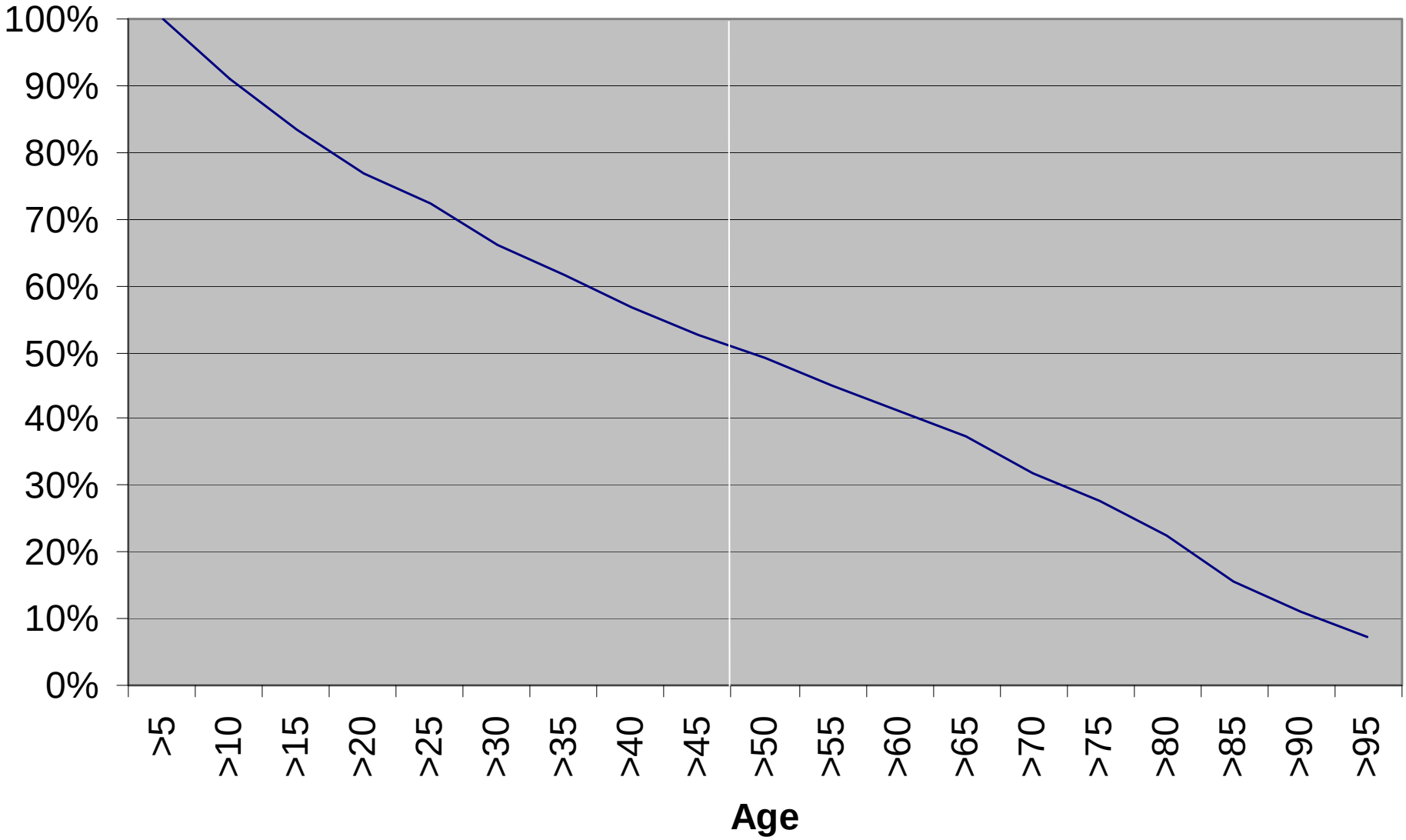
Operational Failure Modes

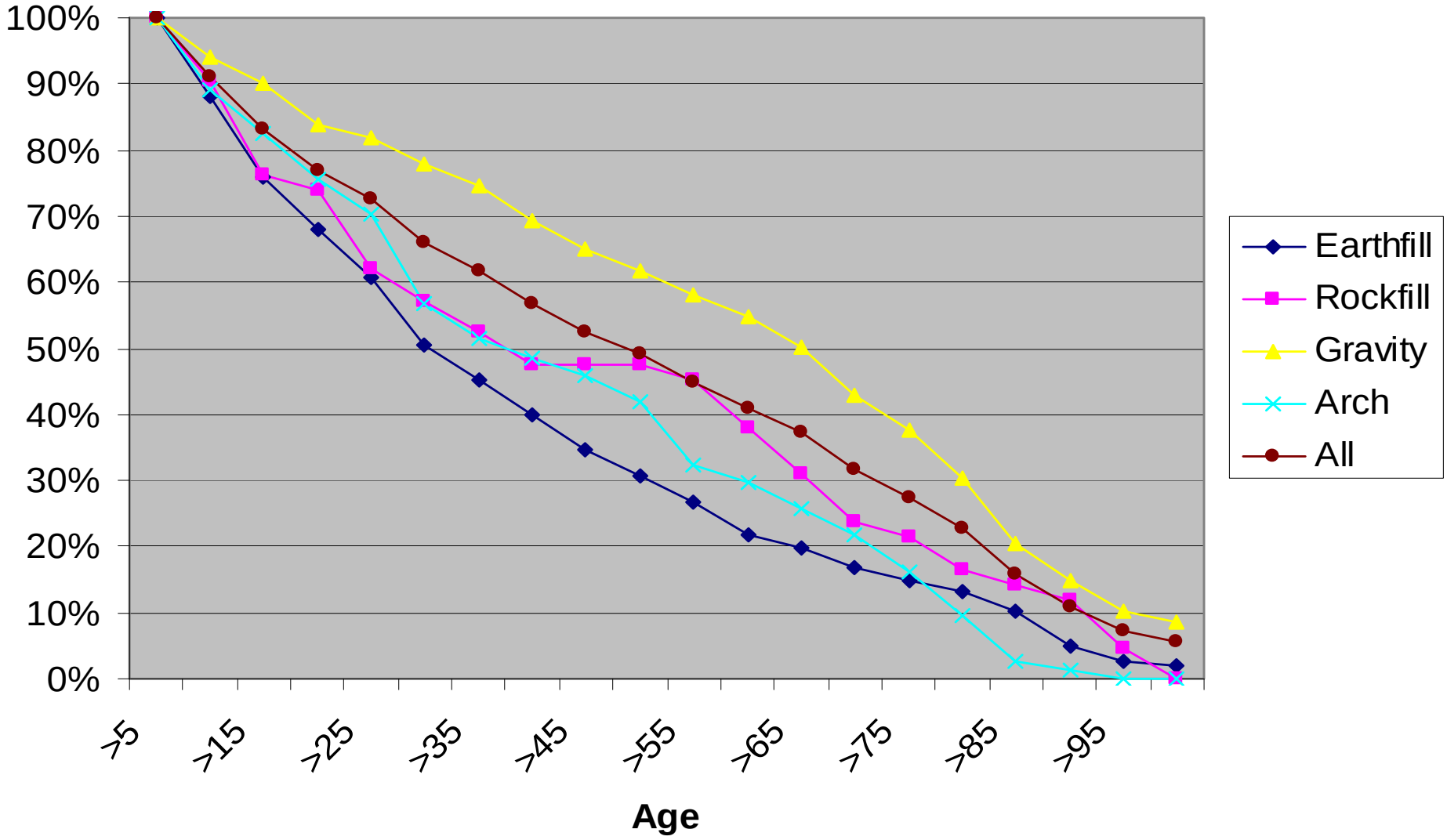
Key Concepts

- Operational failures can include:
  - Debris plugs spillway (perhaps with log boom failure), dam overtops
  - Gates fail to open (hoists, chains, binding, electrical, remote communications), dam overtops
  - Gates open inadvertently – life-threatening flows
  - Communication breakdown – no warning d/s
  - Loss of access to operate gates, dam overtops
  - Loss of release capacity (e.g. turbine), dam overtops
  - Overfilling off-stream reservoir, dam overtops
  - Reluctance to open gates and flood people out
  - Other external events

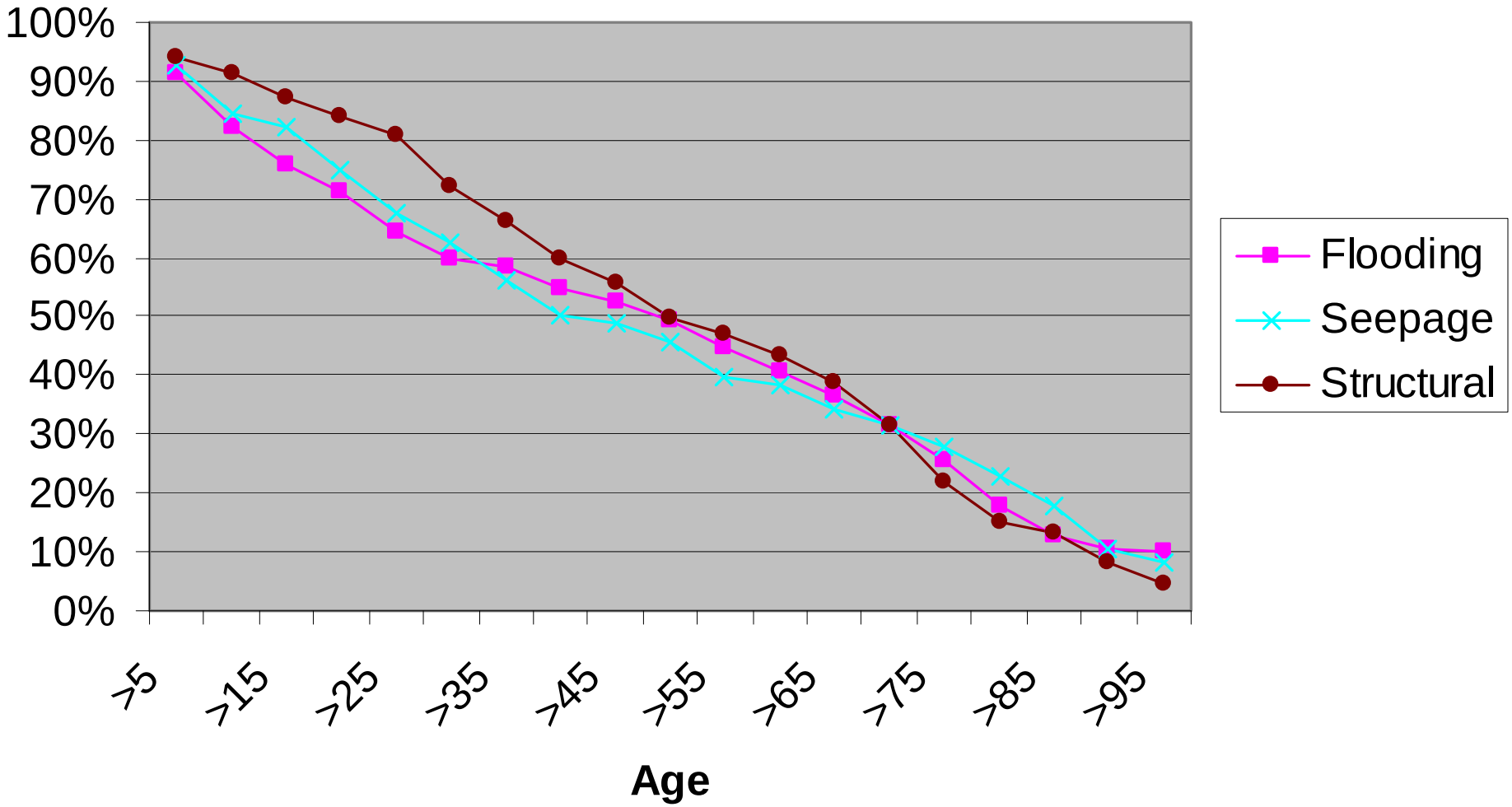
% of Incidents that Occur at an Age Greater Than All Dams that Survive their 1st Five Years



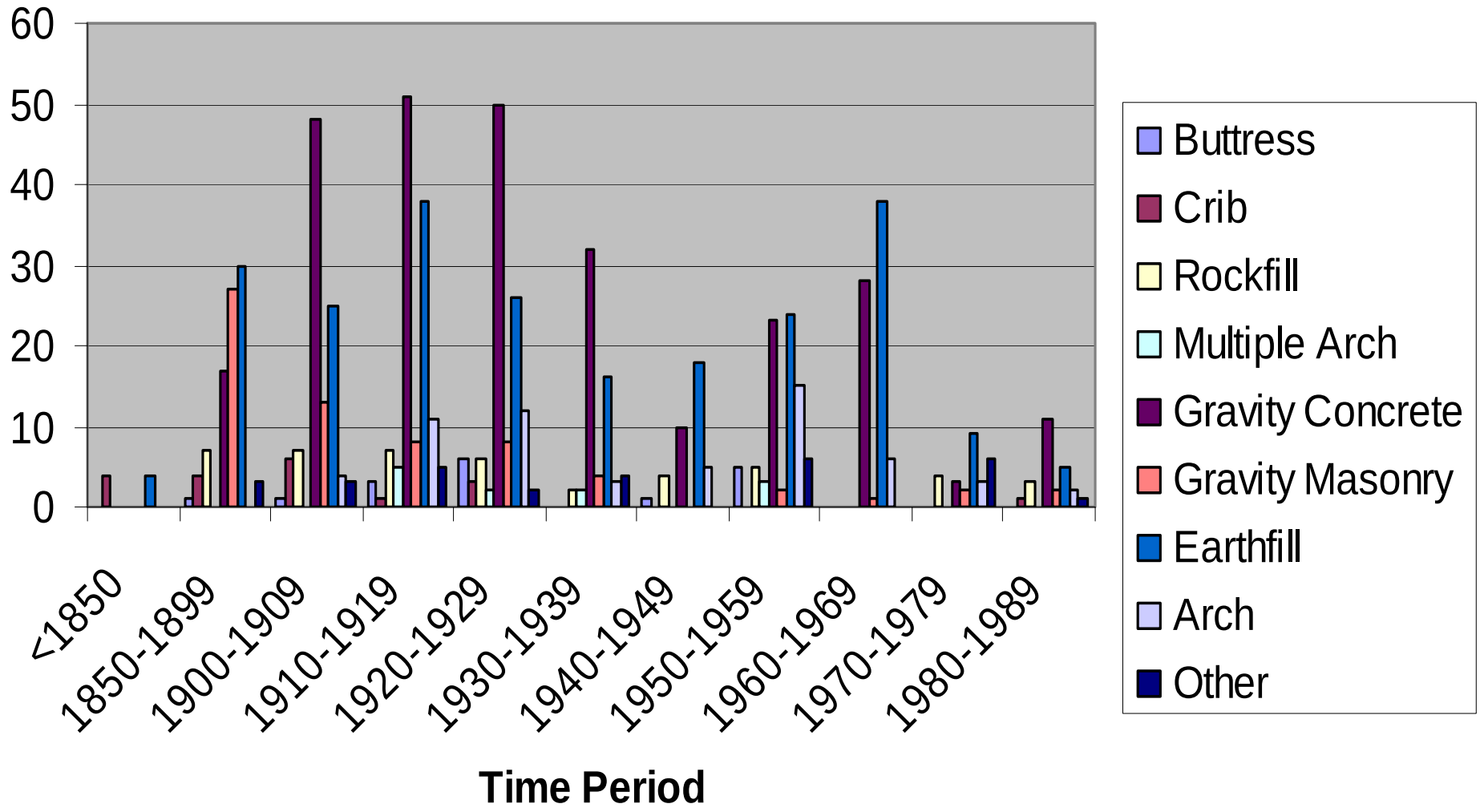
% of Incidents That Occur At An Age Greater Than By Type of Dam



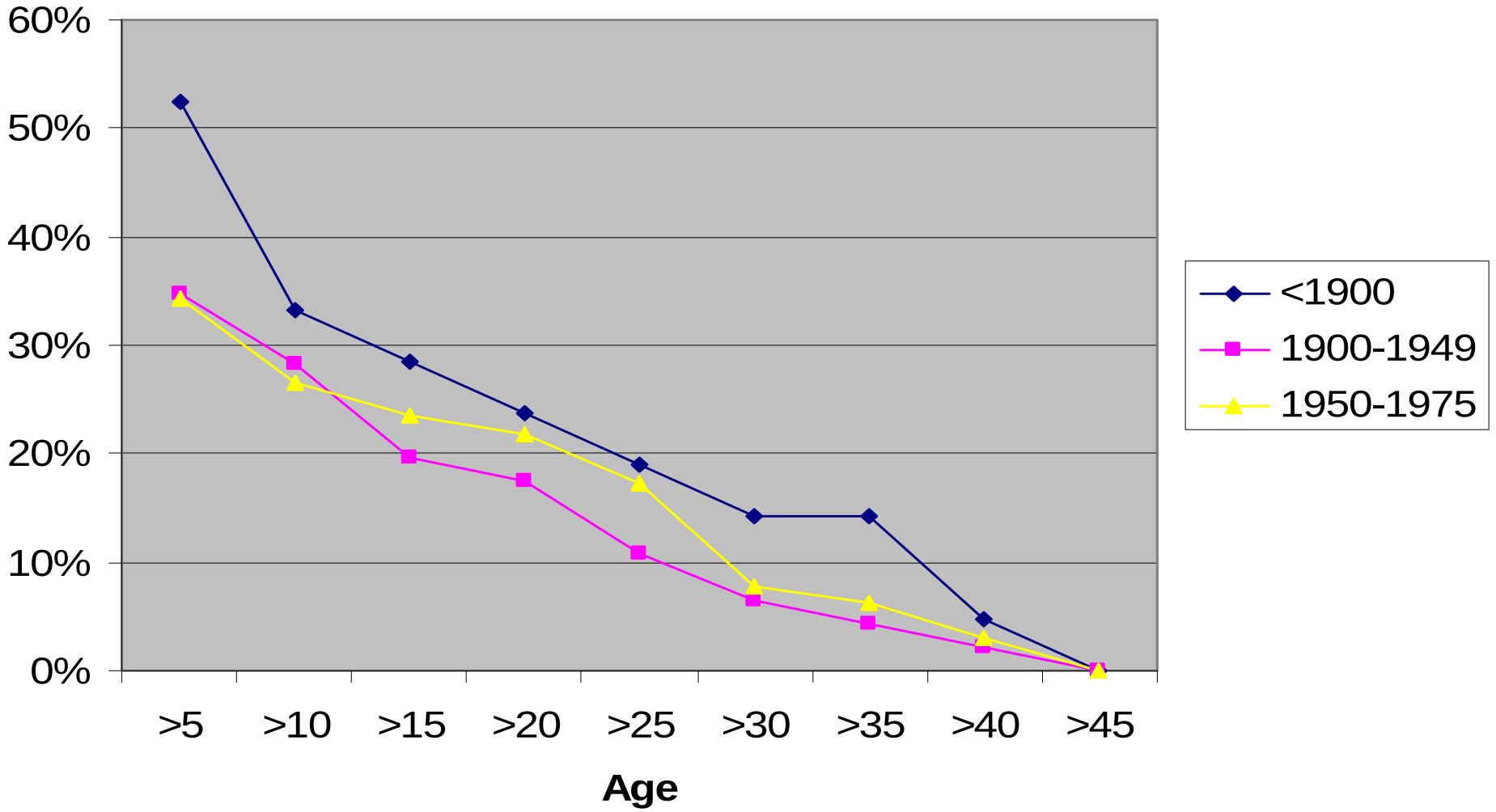
% of Incidents that Occur at an Age Greater Than by Failure Mode After 1st 5 Years of Operation



of Incidents by Type of Dam vs. Decade Built
Dams that Survived 1st 5 Years of Operation

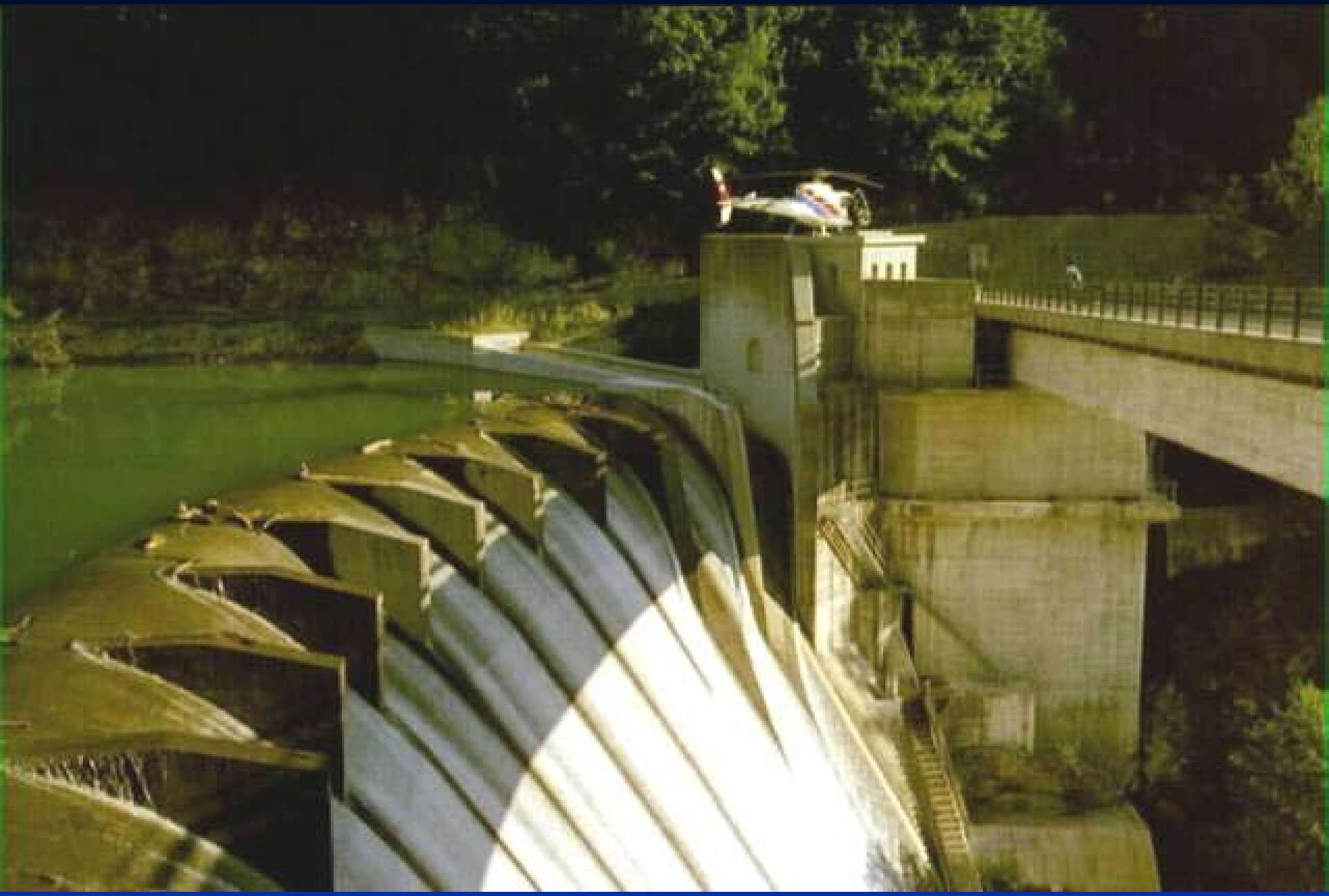


Earth Dam Seepage Incidents % of Incidents Beyond a Given Year by Era of Construction (Data Beyond 45 Years of Age Removed)




Lower Elevation
Looking Southeast

Overtopping of Palagnedra arch dam during 1976 flood in Switzerland (Courtesy T. Martinoli)



Background Information

- Spillway has two bays
- Each bay is closed by a set of four steel stoplogs
- The stoplogs are raised by a hoist mounted on a trolley. One hoist services both bays.
- Dam is operated from a central control room located 50 km from the site.
- The dam is visited a few times a week.
- Radio and telephone service is available at the site

Antecedent Conditions

- In central Sweden the summer of 1985 was exceedingly wet. July saw 175% of average precipitation, August 137%, and September 244%, most of which fell in the beginning of the month
- Rainfall was estimated to be a 1:2000+ event
- As the rainfall was diminishing on the on September 5, 1985, the stoplogs, which had been removed earlier, were replaced in the left spillway bay and a single log was placed in the right bay. This stoplog was hooked to the hoist.

Failure Mode

- Rainfall is increasing in intensity
- An operator is dispatched to the site from the central station
- The main access road is blocked by flooding. The secondary route to the dam is 90 km (rather than 50 km) on secondary roads.
- The operator attempts to remove the stoplog
- The stoplog gets stuck in the spillway bay

Failure Mode

- The design of the hoist system precludes unhooking the stuck stop log from the hoist thereby preventing removal of left bay stoplogs.
- A crane is requested to assist in removing the left bay stoplogs.
- It's late Friday night and the crane company has trouble locating an operator.
- A larger upstream dam is in danger of overtopping and releases from that dam are increased

Failure Mode

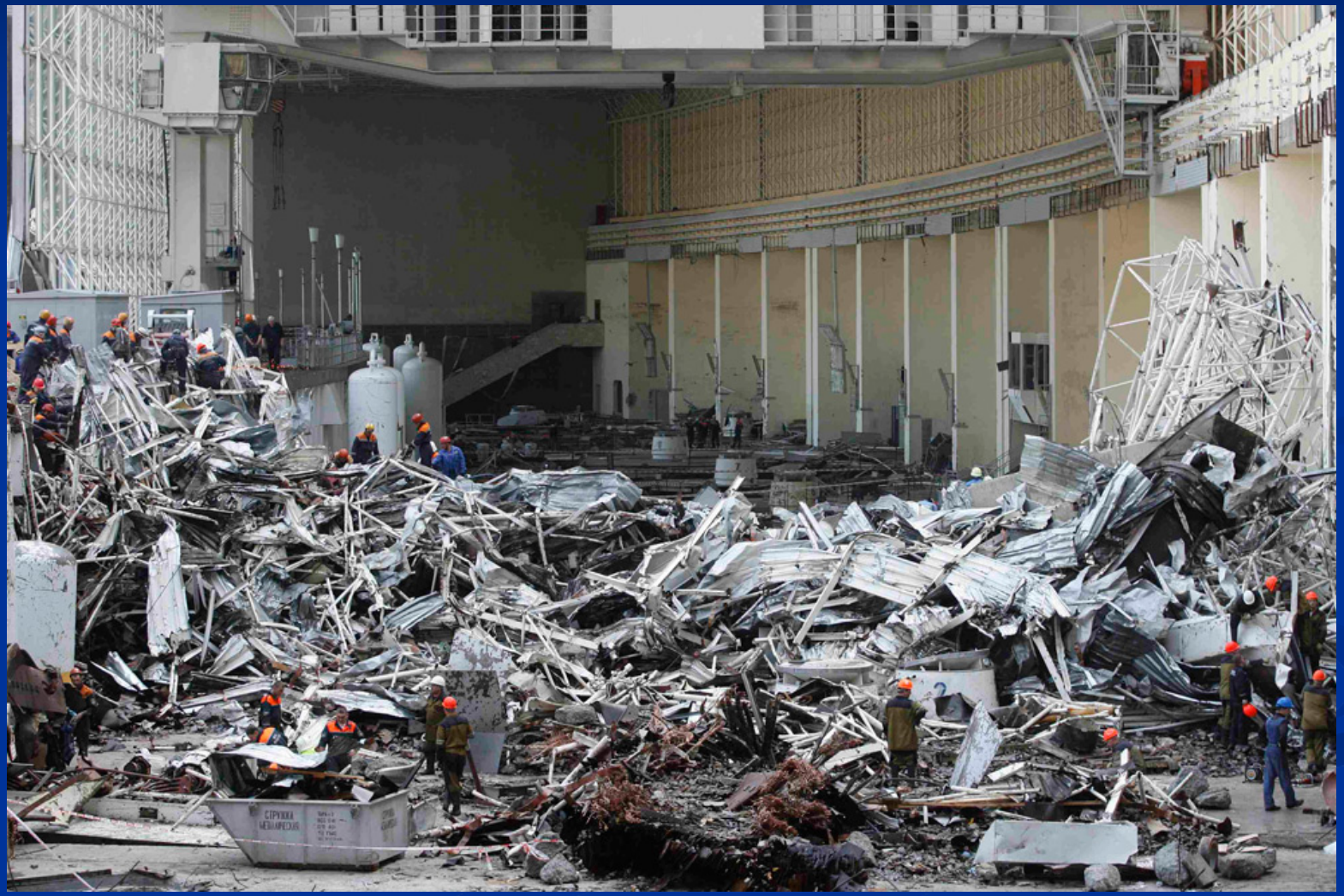
- Operation of the powerhouse at Noppikoski is curtailed to minimize damage from the rising tailwater.
- The crane gets within a few hundred meters of Noppikoski Dam, and is halted by flooding across the road.
- The dam overtops
- The overtopping downcuts through the dam to bedrock.

Afterthoughts

After the failure the operator presented a paper describing the factors that contributed to the failure. In conclusion he stated:

"In my opinion, the important question of how to adapt the plants – with the exception of augmented discharge functions – to practical operation, in view of the complications of the kind previously listed, has not been considered or documented to the same extent."

Sayano-Shushenskaya



Can a Problem in a PH Cause a Dam Failure?

Sayano-Shushenskaya

- Dam Type: Gravity Arch
- Dam Height 242 meters / 794 ft
- Reservoir Capacity: 31.3 km^3 / 25.4M ac-ft
- Spillway Capacity: 12,800 m^3/s / 455K cfs
- Powerhouse Capacity: 3,500 m^3/s / 124K cfs
- Flood of Record: 24,300 m^3/s

Sayano-Shushenskaya

- No low-level outlet – maximum draft 45 m
- Est. storage volume in top 45 m – 18.1 cu km
- No TSV on the penstocks
- Reservoir filled as dam was raised
- Upstream monoliths raised first

Sayano-Shushenskaya

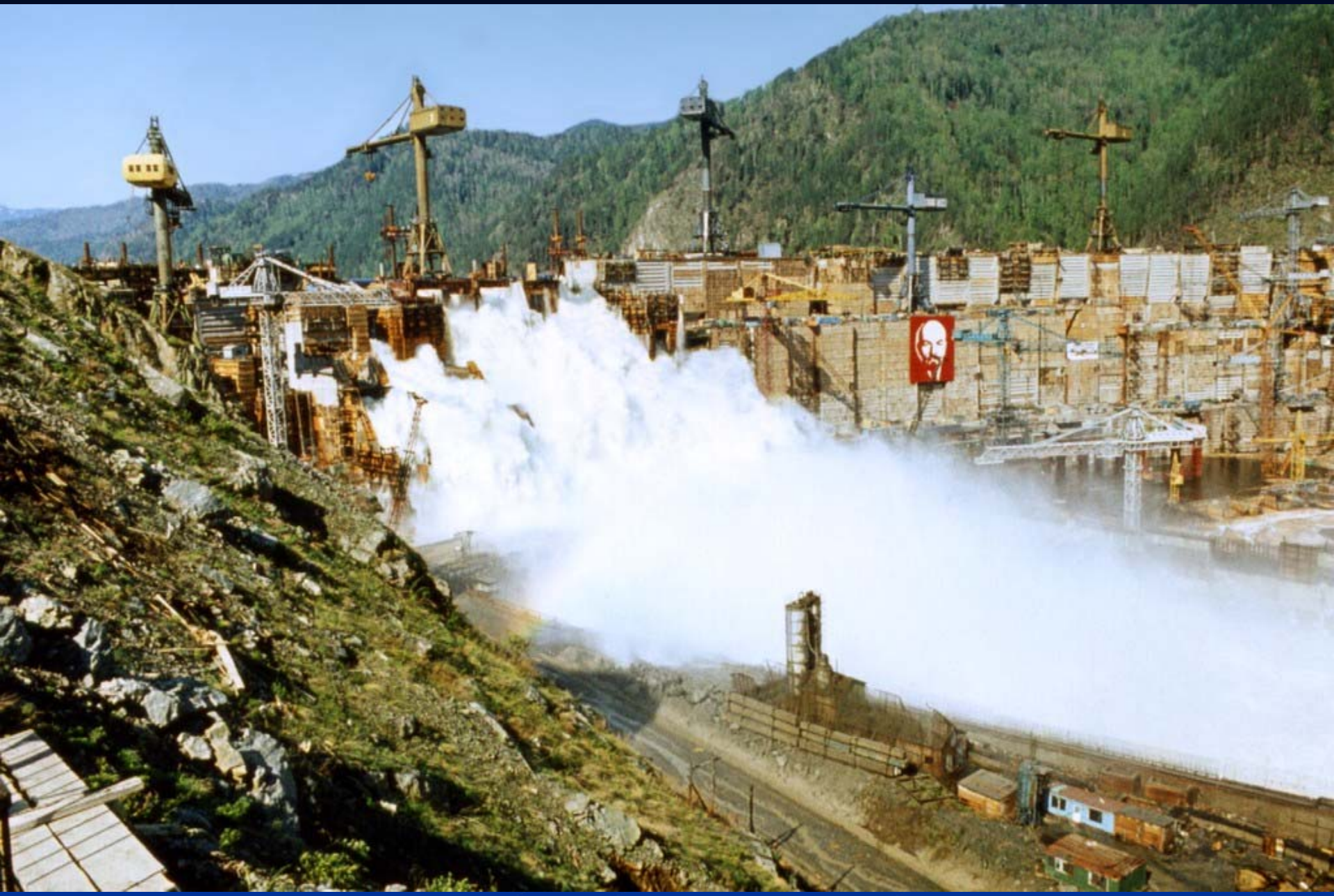
- Certification for Operation in 2000 noted need for additional spillway capacity
- Construction of additional spillway capacity delayed due to lack of funding
- Spillway currently being constructed on expedited schedule. 2,000 m^3/s of additional capacity will be available in June 2010

Sayano-Shushenskaya

- Turbine has large area of rough operation
  - Need for new design recognized in 2000
  - Plant control system does not take into account area of rough operation
- Operates in Unified Electric System – Siberia
- Constructed under Russian state ownership
- Privatized in 1993

A Little Background

- During construction the spillway was used to pass water
- During construction a flood resulted in 4500 m^3/s being discharged through the spillway
- The spillway stilling basin was severely damaged while passing 4500 m^3/s - 7m of the foundation was eroded
- The flood also overtopped the partially constructed dam cracking the dam-foundation interface and some concrete monoliths
- The damage to the spillway was repaired




17.07.86

A Little Background

- The foundation and monoliths were grouted (under 200 meters of head)
- In 1988 a flood of 4400 m^3/s damaged the stilling basin again
- Again, the stilling basin was repaired
- A new tunnel spillway is being constructed

Potential Failure Mode

1) Under Normal Operation
2) A fire at a remote power plant causes the system dispatcher to transfer load-following responsibility to SSH hydro plant
3) SSH staff start Unit 2 and place in load following mode
4) Operation of Unit 2 over the course of 30 years causesd partial to complete fatigue failure of the bolts holding down the turbine head cover

Potential Failure Mode

5) In load following mode Unit 2 transitions through the rough operating region on several occasions
6) The fatigue failure of the head cover bolts reaches a critical state
7) The turbine head cover tears loose ejecting the turbine through the generator

Potential Failure Mode

8) The open head cover allows water to flood into the powerhouse
9) The flooding water knocks out station power cutting power to the penstock intake gates
10) Water flows for half an hour until the gates can be closed using manual operators
11) The flooding damages the powerhouse to the extent that all 10 units are forced off line and only two units will be available to help pass flow in the coming runoff season

Potential Failure Mode

12. Damage to the powerhouse results in the majority of inflow passing through the spillway for an extended period
13. Operation through the winter results in icing over the spillway and collapse of a crane used to access the stilling basing for repair
14. Higher than normal snowfall in the watershed leads to large runoff (near the flood of record)

Potential Failure Mode Continued

15) The high runoff requires the spillway to run full
16) The excess inflow rapidly fills the reservoir
    - 17 days if one tunnel spillway is operable
    - 15 days if the tunnel spillway is unavailable
    - 8 days if the service spillway becomes inoperable
17) The excess inflow overtops the dam reinitiating the crack at the dam foundation interface
18) High spillway flows destroys the stilling basin bottom and begins to undercut the dam toe
19) Undercutting continues as the spillway passes flow.

Potential Failure Mode Continued

20) Cracking of the dam-foundation interface leads to increased uplift under the dam
21) The combination of continued toe undercutting and increasing uplift under the dam leads to a sliding failure of the dam

How Big a Problem is This?

- Everything except the last 2 slides was a reality
- Over one million people live downstream of the dam
- There is an embankment dam 12 miles downstream that would fail if overtopped

Tirlyan Dam

- 10 m high
- 7,000 ac-ft

Tirlyan Dam Failure.wmv