Operational Failure Modes

Operational Failure Modes

- Can you get there?
- Will it Work?
- Stuff Happens – Just don't let it happen to you!

Noppikoski Dam

- Noppikoski Dam was a central core rockfill dam.
- The dam was remotely operated from a location 30 miles away.
- The spillway openings were controlled by steel stoplogs that were raised by using a hoist located on a moveable trolley.

Noppikoski Dam

- In September, 1985 a major storm occurred in central Sweden.
- During the initial phase of the flooding the stoplogs had been removed from the spillway bays. However, due to a lessening of the storm the left spillway stoplogs had been replaced and one stoplog was placed in the right bay and left hooked to the hoist.

Noppikoski Dam

- On September 6th, a Friday, the storm increased in intensity. An operator was dispatched to the site from his home.
- When the operator was about half way to the dam, he is informed that the road had been cutoff due to overflowing creeks.
- His remaining trip had just changed from 30 miles to 55 miles on lesser roads.

Noppikoski Dam

- When the operator arrived at the dam, it was raining very hard and, he could not raise the remaining stoplog in the right bay because it had become stuck. This effectively took the hoist out of service.
- A similar problem had occurred previously but was believed to have been fixed.
- A crane company was contacted in case the hoist was the problem.

Noppikoski Dam

- The crane company was delayed in dispatching the crane because the call came in late on a Friday evening and they had trouble finding an operator.
- Additional plant staff were dispatched to Noppikoski Dam to help raise the stoplogs.

Noppikoski Dam

- In case there weren't enough problems;
  - The telephone lines to the dam went down
  - An upstream dam was in danger of overtopping and the spill into Noppikoski was increased
  - The power station was in danger of being inundated and was shut down thereby losing the plant's discharge capacity
  - The mobile crane could not reach the dam, stopping a couple of hundred meters short due to the road being cutoff by a stream

Noppikoski Dam

- Operators tried to raise the embankment sections along the sides of the spillway with no success and the dam overtopped and failed.
- Luckily, the downstream residents had been warned and there were no fatalities.

Noppikoski Dam

Noppikoski Dam 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."

Operations Potential Failure Modes

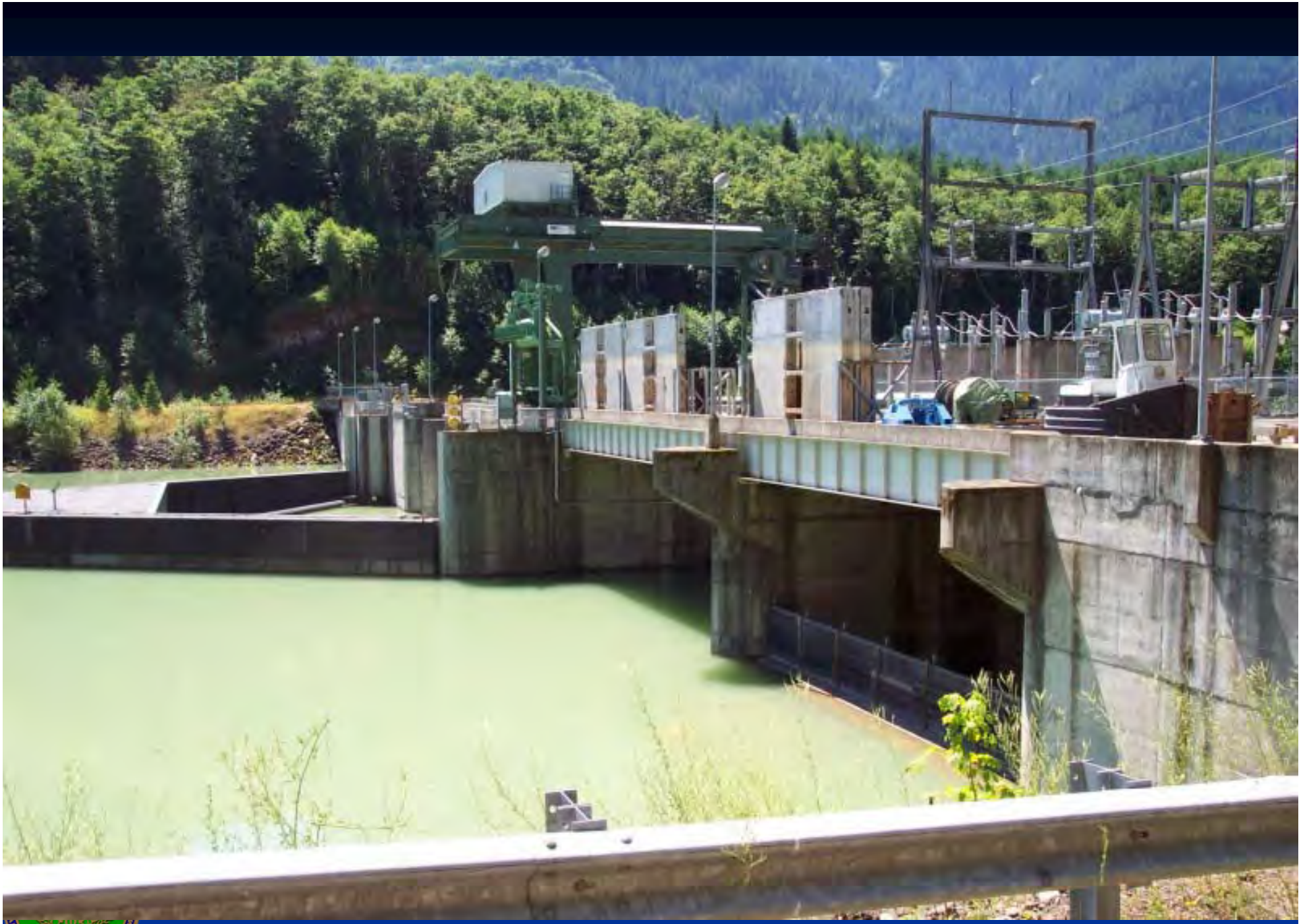
- Limited amount of overtopping flow (no structural concern) may result in effects which reduce discharge capacity and result in major overtopping and potential failure
  - knock out transformers to plant
  - take out power supply to gates
  - prevent access to gates

Operations Potential Failure Modes

- Flow through powerhouse is necessary to pass PMF
- Powerhouse has a design feature whereby the turbines are "blocked" to prevent rotation while flow passes through the units.
- Field assumed headquarters would make call to block turbines. Headquarters assumed field knew when to do it.
- SOP developed so all know who makes call and when.

Operations Potential Failure Modes

- Dam is designed with spillway flows passing over low level outlets
- SCADA system is designed to NOT allow spill when low level outlets are open due to excessive vibration of open gates
- SCADA system fault allowed gate operation. Also bypassed a limit switch intended as "fail safe" backup
- Excessive vibration damaged gate to extent it would not close resulting in draining reservoir



Operations Potential Failure Modes

- During gate operations, a failed position sensor allowed the gate to raise more than intended.
- Vibrations during prior gate operations apparently caused the connection to fail.

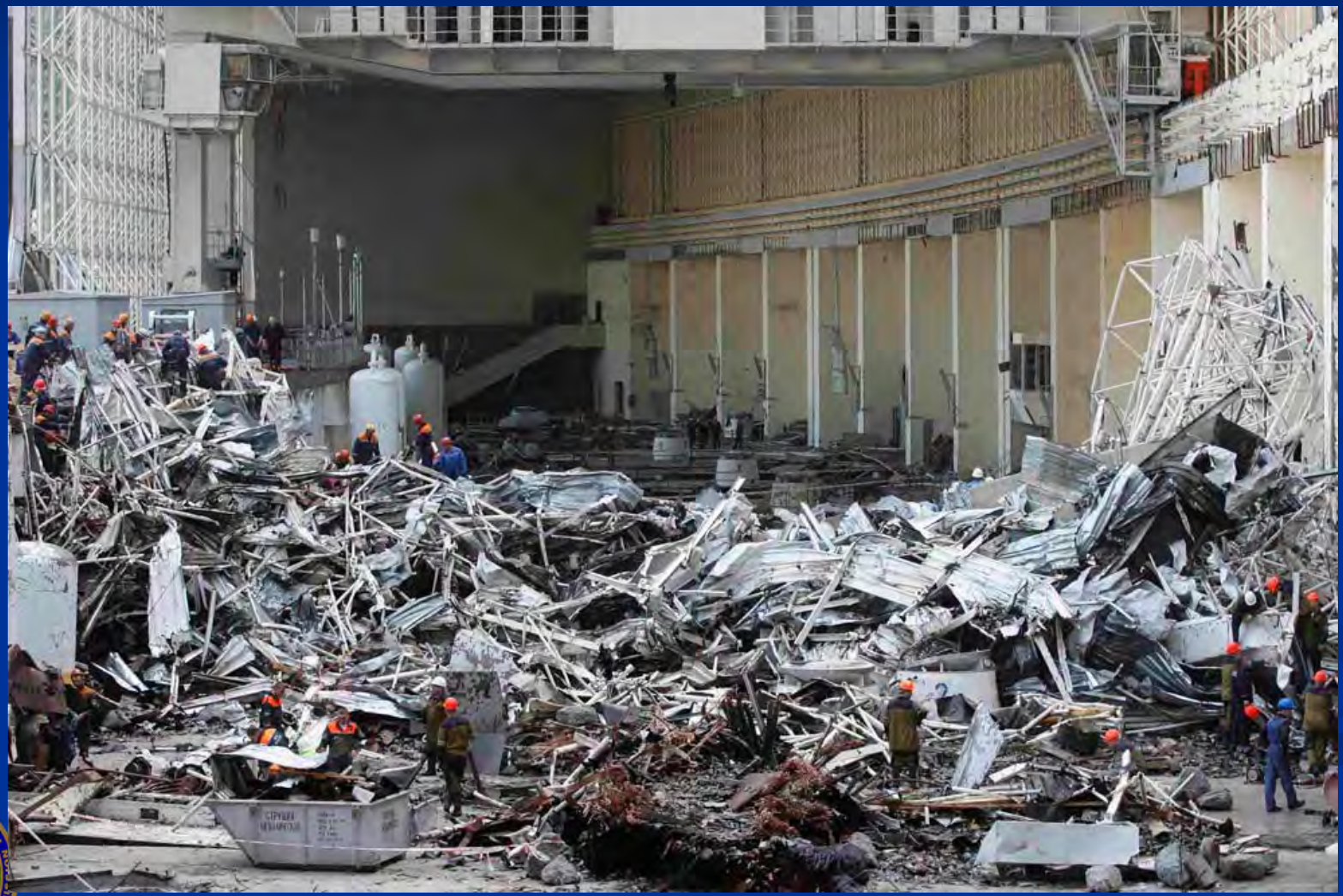
Operations Potential Failure Modes

- Change in gate operations from a few times a year to daily (for fish passage)
- Lubrication schedule remained the same.
- Gearbox stripped, gate dropped on one side

Operations Failure Mode

- Over-pumping of the upper reservoir of a pumped storage project to overtop and fail.
- Many contributing factors
  - Settlement of parapet wall
  - Failure of anchoring system for water level sensors
  - Rewiring of high water alarms effectively cutout alarms

Sayano-Shushenskaya



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

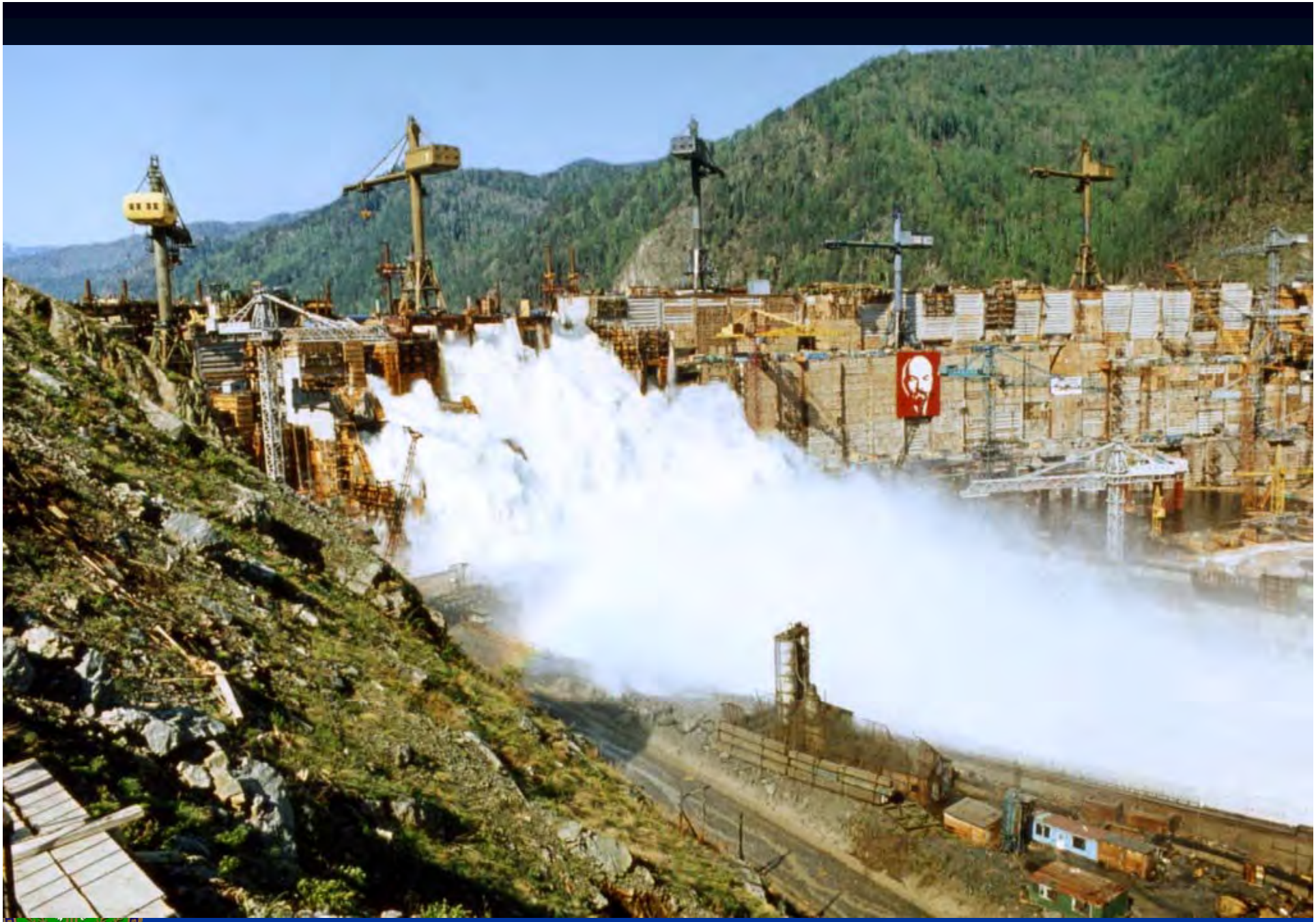
Sayano-Shushenskaya

- 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

Can a Problem in a PH Cause a Dam Failure?

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

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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 may lead to large runoff in 2010

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.

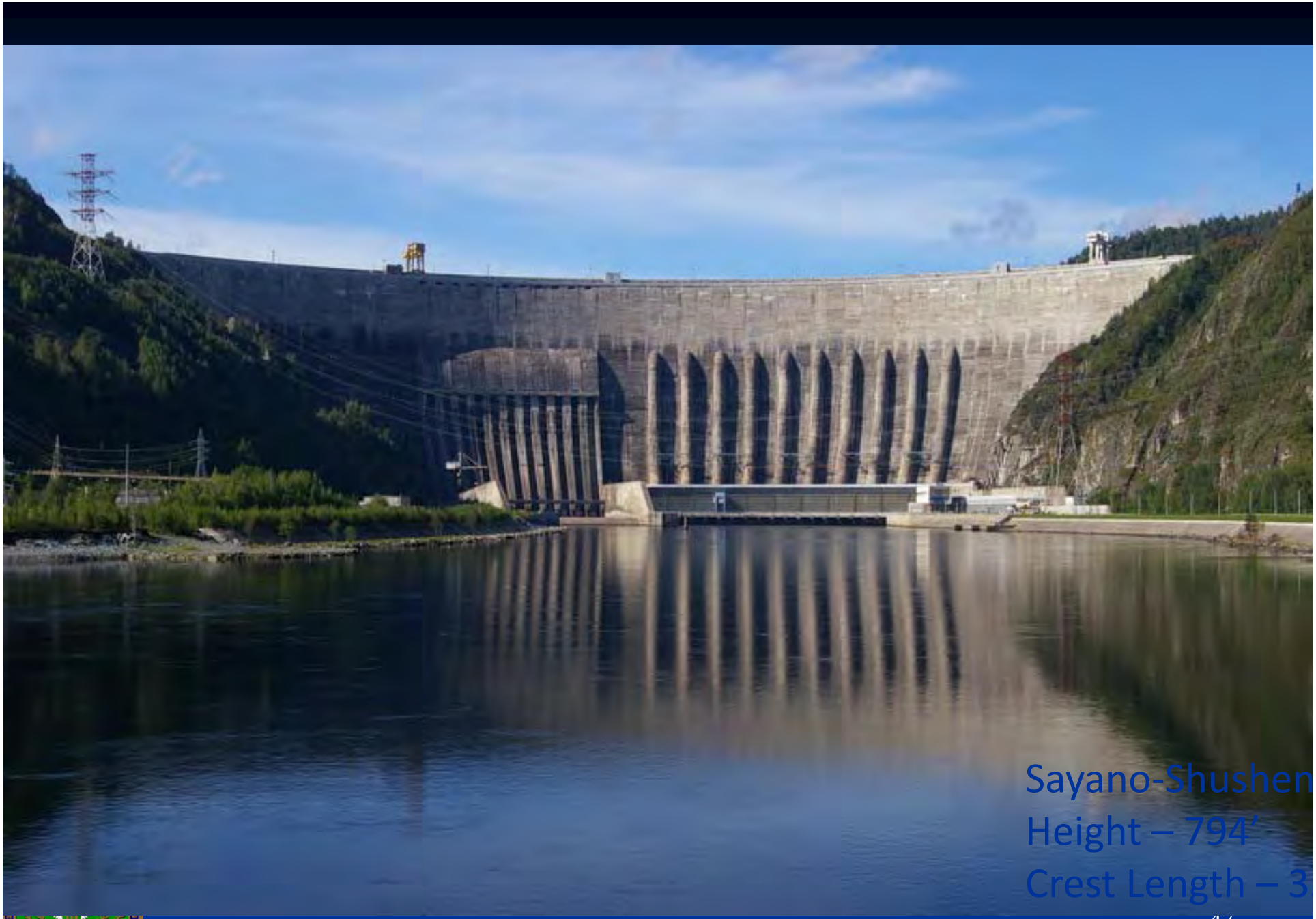
Potential Failure Mode Continued

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 is a reality
- Over one million people live downstream of the dam
- There is an embankment dam 12 miles downstream that would fail if overtopped


Hoover Dam
Height – 726.4’
Crest Length – 12


Sayano-Shushen
Height – 794'
Crest Length – 3

How Big is Big

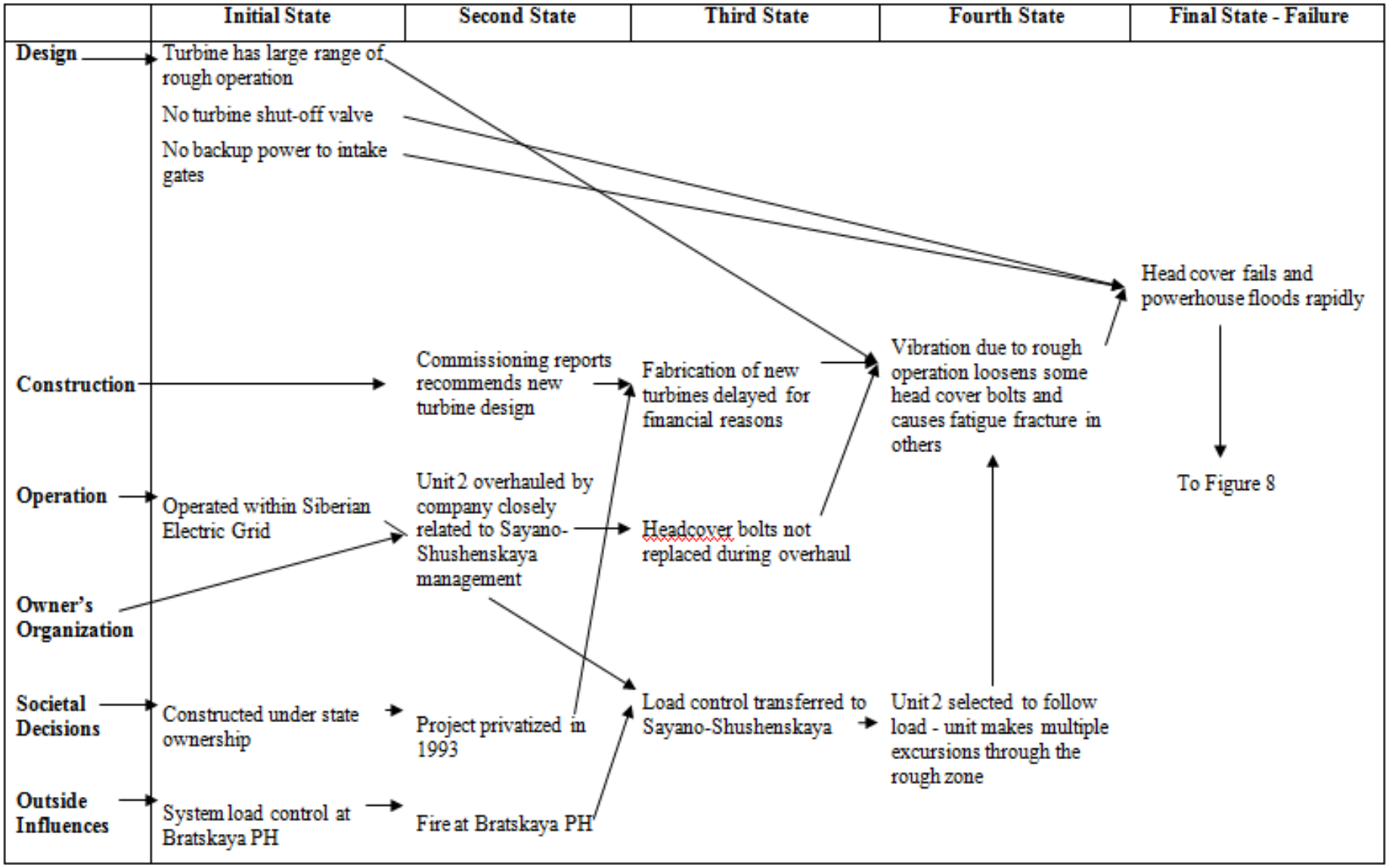


Figure 5 – Interaction Flow Chart – Failure of Sayano-Shushenskaya Powerhouse Turbine Headcover

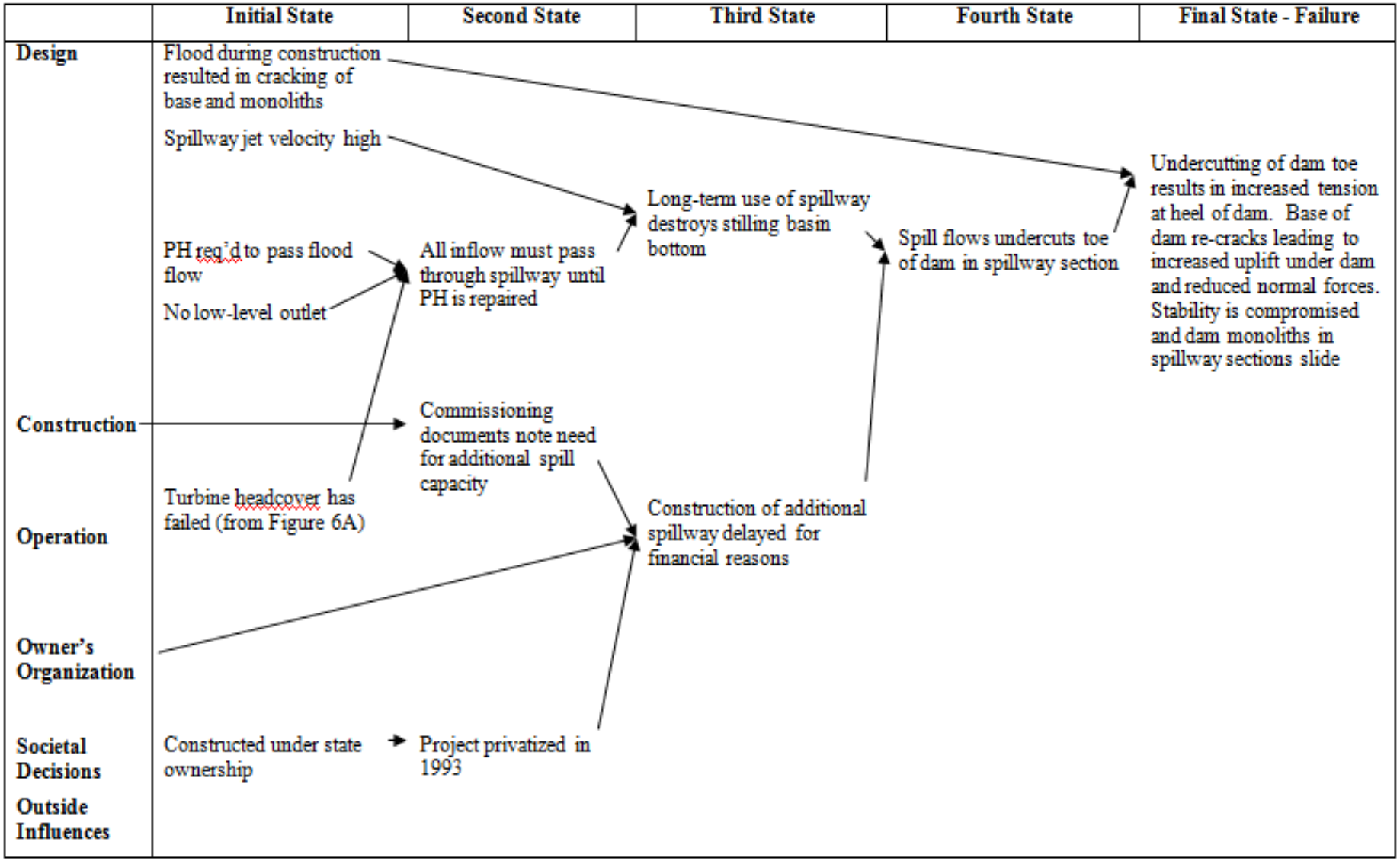


Figure 8 – Interaction Flow Chart – Potential Failure Mode Sayano-Shushenskaya Dam