Dams as Systems

Pat Regan

Federal Energy Regulatory Commission (FERC)
FERC

• >2,500 jurisdictional dams
  – 770 feet to 0.5 feet high

• Five Regions
  – Atlanta, Chicago, New York, Portland, San Francisco

• ~120 staff
A contemporary illustration of the broken South Fork Dam from Harper's Weekly.
Potential Energy

- A major dam like Grand Coulee or Oroville can store more than 100 times the energy released by the atomic bomb dropped on Hiroshima.
- The Sayano-Shushenskaya dam in Russia stores nearly 800 times the energy of the Hiroshima bomb.
WANTED

DAMN ENGINEER
DEAD OR ALIVE
Pre-Teton Dam (1976)

• Strictly standards based
• Three loading conditions
  – Static (normal)
  – Flood (unusual)
  – Seismic (extreme)
• Defined minimum factor of safety
  – Static (3.0*)
  – Flood (2.0*)
  – Seismic (1.3*)

* from FERC Engineering Guidelines, Chapter 3, 2002
Federal Guidelines for Dam Safety

• Three categories of dams
  – High Hazard Potential
    • Dams where failure or mis-operation will probably cause loss of human life. (one or more)
  – Significant Hazard Potential
    • Dams where failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns.
  – Low Hazard Potential
    • Dams where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses.
Post Teton

• Reclamation implemented a risk-based dam safety program
  – For the most part still only worried about the three loading conditions but included “piping”, the cause of the Teton failure
• Post Katrina, USACE is developing a risk-based program.
• Most states and the FERC are still in a deterministic world
  – FERC is in the process of developing a risk-informed approach
Taum Sauk
Failure without death
Taum Sauk Report

• It is our conclusion that the root cause of “the uncontrolled, rapid release of water from the Upper Reservoir” was the breach of the Rockfill Dike—a stability failure at the northwest corner of the Reservoir brought on by a rapid increase in the pore pressure at the Dike/foundation interface, stemming from the original design and construction which was flawed.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Location limited surface area of reservoir. Needed storage volume required 10’ high parapet wall with 8’ of water stored against wall</td>
<td>Assumed clean rockfill</td>
<td>Dirty Rockfill at best, rocky earthfill in some areas</td>
<td>Excessive settlement (~1’ in 4.5 years)</td>
<td>Continuous settlement, up to ~2’, results in cracking of concrete face slab and misalignment of parapet wall resulting in excessive seepage through dam</td>
<td>Geomembrane liner installed on upstream face to reduce seepage</td>
<td>Vibration from vortices loosens nuts on instrument support system</td>
</tr>
<tr>
<td></td>
<td>No spillway included</td>
<td></td>
<td></td>
<td></td>
<td>Penetration of liner not allowed. Instruments supported from top of dam to bottom by “suspension” system. Turnbuckle nuts not locked</td>
<td></td>
<td>PVC conduit bends due to vortices due to erroneous water levels</td>
</tr>
<tr>
<td></td>
<td>Emergency shut-off system includes high water alarm (alarm in PH) and high-high alarm (shuts off pumps at 1’ remaining freeboard)</td>
<td>Water level monitoring equipment placed near “morning glory” inlet-outlet works (shortest distance to PH)</td>
<td>Instrumentation firmly fastened to concrete upstream face</td>
<td>Water flow causes vortex development at inlet-outlet</td>
<td>Water flow causes vortex development at inlet-outlet</td>
<td>Emergency shut-off system installed at “design” elevations (ignoring the 2’ of settlement that had taken place)</td>
<td>On December 14, 2005, at about 0510 the dam overtopped during a pumping operation. The water level alarms did not sound because both alarms had to trigger to sound an alarm (after being rewired in parallel) and the high-high water alarm was about two feet higher than the lowest point on the wall (due to ignoring the settlement). Due to the lack of a spillway the parapet wall overtops. The water falls 10’ onto the earthen embankment rapidly eroding the material and undermining the parapet wall. The wall overtops unleashing a 10’ wall of water that rapidly erodes the remaining embankment. It took only about 12 minutes to drain the reservoir. Peak outflow was estimated at 289,000 cfs (more than the Mississippi River above its confluence with the Ohio River). Luckily a downstream park and campground was empty due the time of year and 5 people in a house survived even though the house was swept from its foundation.</td>
</tr>
<tr>
<td>Operation</td>
<td>1-2 pump cycles per week</td>
<td>Experienced local operating staff</td>
<td>Profit driven operation Remote operation</td>
<td>High water and high-high water level instruments re-wired in parallel to eliminate “false” readings</td>
<td>Operators reprogram computer to “account” for deflection of conduits</td>
<td>Overtopping events on Sept. 25 and 27, 2005</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One unit used to pump</td>
<td>Operations staff adjust water level controls to account for settlement</td>
<td>Pump-turbines replaced, 25% greater capacity (1999)</td>
<td>Operators reprogram computer to “account” for deflection of conduits</td>
<td>Operators reprogram computer to “account” for deflection of conduits</td>
<td>Overtopping events on Sept. 25 and 27, 2005</td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>No person designated to assure dam safety</td>
<td>Adjustment of water level controls not documents Arrogance - (letter to a FPC engineer) “I told him there would be no structural damage if the pumps failed to shut down”. (1968)</td>
<td>Retirement of experienced staff Loss of institutional knowledge No one considers impact of changed operation</td>
<td>Repair to water level conduits delayed until future planned outage to minimize impact on generation</td>
<td>Repair to water level conduits delayed until future planned outage to minimize impact on generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal Decisions</td>
<td>Rate of Return cost structure</td>
<td>Deregulation of electric industry (~1997). No guaranteed rate of return</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2 – Interaction Flow Chart – Taum Sauk Upper Dam Failure
The March to Failure

As Envisioned


- Design
- Construction
- Operating & Performance History
- Aging
- Remediation
- ODSP
- Focus on financial performance

OSHA safety at the expense of system safety
Fixing symptoms instead of fundamental problems
Complacency, Arrogance and Ignorance
Checking the regulatory box

TOTAL

Begin Design
The March to Failure

Begin Design

End Construction

Focus on financial performance
OSHA safety at the expense of system safety
Fixing symptoms instead of fundamental problems
Complacency, Arrogance and Ignorance
Checking the regulatory box
The March to Failure

- Design
- Construction
- Operating & Performance History
- Aging
- Remediation
- ODSP
- Focus on financial performance
- OSHA safety at the expense of system safety
- Fixing symptoms instead of fundamental problems
- Complacency, Arrogance and Ignorance
- Checking the regulatory box

TOTAL

Begin Design
End Construction
1968 Letter
The March to Failure

- Begin Design
- End Construction
- End Primary Settlement
- 1968 Letter

Focus on financial performance
OSHA safety at the expense of system safety
Fixing symptoms instead of fundamental problems
Complacency, Arrogance and Ignorance
Checking the regulatory box
As Envisioned


Design
Construction
Operating & Performance History
Aging
Remediation
ODSP
Focus on financial performance
OSHA safety at the expense of system safety
Fixing symptoms instead of fundamental problems
Complacency, Arrogance and Ignorance
Checking the regulatory box
TOTAL

The March to Failure

End Primary Settlement

Begin Design

End Construction

1968 Letter

Deregulation
The March to Failure

- Deregulation
- Design
- Construction
- Operating & Performance History
- Aging
- Remediation
- ODSP
- Focus on financial performance
- OSHA safety at the expense of system safety
- Fixing symptoms instead of fundamental problems
- Complacency, Arrogance and Ignorance
- Checking the regulatory box

End Primary Settlement
Begin Design
End Construction
Remediation
1968 Letter

TOTAL
House Foundation

Sediment Splay and Depositional Zone

Foundation of Park Superintendent’s Home

Car-Sized Boulder (Next Slide)

Downed Tree Orientation Shown in red – Current direction indicators

Scour And Deposition Zone

Highway N
My Interests

• How can we use systems engineering approaches to improve dam safety practices?
• How can we use systems engineering approaches to structure our approach to regulation?
My Interests

• Using Techniques and Practices built on STAMP to:
  – Guide Hazard Analysis
  – Guide Accident/Incident Causal Analysis and Understanding
  – Guide development of guidelines
  – Guide a study of the organizational structure of the FERC dam safety program