Learning from the Present & Past

An Industry Need and Supporting Resources

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Obtained from http://npdp.stanford.edu
Introduction

• Historical Background

• Today’s Dynamic Environment in Dam Safety Improving / Expanding Our View of Dams as Dynamic Systems

• Perspective on Dam Performance

• Development of New NPDP Online Resources

• Vision for Characterizing and Preserving (electronically) Information on Dam Performance

• Final Thoughts

Obtained from http://npdp.stanford.edu
Historical Background

• When dam engineers began collecting lists of dam failures and incidents, they were happy to just take names (so to speak) (1940s to the now).

• Identify the events, summarize the information with simple characterizations (one word (piping), a numeric code (3.1.2), or categories (Accident Type 2)).

• This was true when the National Performance of Dams Program (NPDP) started.

• However, dam safety and engineering is changing. Our needs to better understand how dam systems perform is evolving.
Today’s Dynamic Environment

- **PFMAs**
  - Ongoing & evolving (aka on the learning curve); new data & perspectives
- **Risk Analysis**
  - Evolving in a regulatory and business sense
- **Systems Engineering**
  - Evolving perspective; technical, management, operations, etc.
- **Field Experience**
  - Ongoing - real-life lessons on successes & failures
- **Deregulation**
  - Changes in the business climate and attitudes towards risk management
- **Business Side**
  - Asset Management & the inter-relationship with dam safety
- **Regulatory Change**
  - Stricter standards-based approaches; risk-informed approaches

Obtained from [http://npdp.stanford.edu](http://npdp.stanford.edu)
Where are the Needs?

- **Dam Safety**
  - The forgoing list of activities and factors effecting the hydro industry is changing/expanding our vision of how we look at dams and evaluate dam safety.
  - We are moving to a risk-informed, systems-based way of how we look at dams and how they will perform in the future.

- **Asset Management**
  - The notion of good stewardship of a critical (lifeline) infrastructure is changing.
  - Fiduciary responsibility
  - Community citizenship (supporting community resilience)
  - Reliability of services (water and power)

- **Good asset management (good business) is good dam safety**
Our Focus Today

• We want to take advantage of two key and inter-related pieces of information:
  – The results of PFMAs (in general, and specifically those conducted for hydropower projects regulated by the FERC),
  – National Performance of Dams Program (NPDP) datasets (U.S. only-so far), and
  – Work by ICOLD, USSCOLD (now USSD), Fell and others, etc. (international dam incidents)

• How can we leverage these resources to:
  – Support asset management,
  – Support dam safety evaluations,
  – Improve our efficiency, and
  – Support intelligent, risk-informed decision-making
Perspectives on Dam Performance

Obtained from http://npdp.stanford.edu
Dam Performance

• When we think of “Dam Incidents”, there has been in the past and generally there continues to be a focus on events involving unsatisfactory performance.

• Our perspective on this has been quite different. We view dam incidents in a much broader sense:
  
  – Dam incidents are events of engineering and safety interest that provide insight into the structural and functional integrity of dam systems and their operation.

• From this perspective, we are as (more) interested in success than we are failure or other levels of unsatisfactory performance.
Consider the Seismic Safety of Dams

- Following the 1971 San Fernando earthquake, there has been a tremendous focus on the evaluation and remediation of dams; particularly embankments.

- This is still true today. In about the last ten years alone in California, BC Hydro alone about $1.1 billion has been spent on seismic remediation of dams. Add Saluda and the number jumps to $1.3 billion.

- Historically, dams (thousands of them) have performed well during earthquakes!

- The obvious question is – are we spending our dam safety/infrastructure resources in the right places for the right reasons.
Leveraging Success

• Are we learning from and leveraging our successes?
  – It seems the answer is – not really.
  – The conventional notion of ‘dam incidents’ leads us to focus on negative performance – failure; uncontrolled release of the reservoir; unsatisfactory performance, etc.
  – Successes are almost taken for granted.

• How does success fit in?
  – Knowledge of and data on successes provides balance, perspective, and for the statistician in us – a means to understand the sample space and estimate rates/probabilities.

• Success comes in many different forms:
  – *PURE* success, and
  – Success buried in the midst of events
Looking at Success

• Events that occur at a dam typically of combination of factors that:
  – Are *causally related* (one thing occurs and it leads to something else happening as a result), and/or
  – Occur *coincidently* (proverbial bad luck - the earthquake occurred when the reservoir was at its highest level)
  – This is true for failures and successes

• A PURE success might be an event such as – The PMF occurred and everything worked as designed, no damage at the project.

• Buried Success(es) – An event is a combination of ‘successes’ and failures (unsatisfactory performance); aka - event tree sequence.
Success Story Example

- 1971 – Performance and Survival of the Lower San Fernando Dam
  - This event had a multitude of events/elements that contributed to the outcome that was realized.

Obtained from http://npdp.stanford.edu
FIG. 2.—Cross Section of Lower San Fernando Dam (Los Angeles Department of Water and Power)

Crest elevation 1144.6 ft

Spillway elevation 1134.65 ft

Reservoir Level on Feb. 9, 1971 1109.40 ft

"Normal" free board ~ 10 ft

Free board on Feb. 9, 1971 ~ 35 ft

(Idriss and Gutierrez, 2009)

Obtained from http://npdp.stanford.edu
Success Story Example

• Consider these events/factors:
  – A downstream berm is added to the embankment (reasons unknown), and
  – DSOD restricts the reservoir level due to seismic safety concerns, and
  – The restrictions are lifted, and
  – The winter is dry so the reservoir level remains low, and
  – It is winter and the water is locked as snow in the mountains, and
  – Earthquake occurs, and
  – Significant embankment slide/failure due to liquefaction, and
  – An intake fails, and
  – The other intake survives, and
  – Seepage/piping does not occur, and
  – Aftershocks do not lead to subsequent damage and breaching, and
  – The reservoir is lowered in a timely manner and uncontrolled release is averted.

 Obtained from http://npdp.stanford.edu
Lessons from Success

• Where and how can success experiences be documented and the lessons taken advantage of?

• There are a number of examples where performance experience (successes and unsatisfactory performance) information can be gathered to support quantitative estimates of reliability, fragility, etc.
Development of New NPDP Online Resources

Obtained from http://npdp.stanford.edu
Data Resources

• We looking at ways to:
  – Leverage our evaluation and field experiences
  – Support engineering and dam safety evaluations

• Utilize world-wide experience

• There are a number of data resources we can utilize.
  – FERC licensee mandated PFMs for hydropower projects
  – NPDP dam incident database
  – International dam incident database (ICOLD, etc.)
FERC Potential Failure Mode Data

- Data has been culled from the PFMAs submitted to FERC

- Information that has been extracted includes:
  - Initiating Event
  - Failure Mode
  - Failure mode description
  - Structure/component type

- We are in the early stages of culling, reviewing, etc. this data.

- No project identifiable information is in the database.

Obtained from http://npdp.stanford.edu
• There are 7,535 PFM that have been extracted

• At this point they have not been fully reviewed, filtered, etc.
  – There are replicates
  – Some are not well defined

• Expected that future Part 12 evaluations will improve the consistency and quality of this dataset.
FERC Potential Failure Mode Data (cont.)

![FERC Potential Failure Modes Database](http://npdp.stanford.edu)
There are a number of resources we are utilizing:
- ICOLD, USSD (USCOLD) reports, etc.
- NPDP database

Between us, we have collected:
- List of dam incidents; U.S. and international.
- Documents (engineering reports, newspaper articles, photographs, 35mm slides, etc.
- Also, personal library of an engineer who spent a large part of his life in the dams and hydro business.
- USCOLD (USSD) contributions

We are in the process of bringing this information together online.
Dam Performance Data (cont.)

- Resources that we are bringing together:
  - 4,285 U.S. & international dam incidents
  - Approximately 4,500 U.S. incidents (beyond those in the above list).

- USCOLD (USSD) paper files gathered during the compilation of their 1975 book on dam incidents.

- Photographs – estimated to be over 8,000

- Initially starting with the list of international dam incidents (4,285 events)
Dam Performance Data (cont.)

Cumulative Number of Dam Incidents

Year

Cumulative Number

Obtained from http://npdp.stanford.edu
Dam Performance Data (cont.)

Cumulative Number of Fatalities

Year

Cumulative Number

0 50,000 100,000 150,000 200,000 250,000 300,000


Obtained from http://npdp.stanford.edu
Dam Performance Data (cont.)

Cumulative Number of Fatalities
w/o 1975 Banqiao Dam Failure

Year
Cumulative Number
0 5,000 10,000 15,000 20,000 25,000

Obtained from http://npdp.stanford.edu
Vision for Online Data Accessibility

- Our vision for online accessibility of dam evaluation (PFMs) and performance (incident) information is multi-fold.

- Provide online accessibility to these resources; a digital library (data, documents, photographs, etc.)

- Inter-relate some of these resources to support dam safety evaluations.

- Expand the database schema and tools for characterizing events at dams that better supports current needs in dam safety.

Obtained from http://npdp.stanford.edu
First Steps

• Database on PFM
  – The result of a prospective assessment of dams
  – Support an initial understand of the potential vulnerabilities of dams

• Dam performance
  – Give a retrospective view of events that have occurred.
  – Realization of how the ‘whole’ dam system performed under certain circumstances

• Our initial database developments efforts:
  – Getting the PFM online,
  – Getting the international incidents online, and
  – Relating the two of these; the prospective to the ‘real’
Vision for Online Access

Potential Failure Modes

Dam Performance Events (aka Incidents)

References

Photos

Obtained from http://npdp.stanford.edu
A Short Tour

Obtained from http://npdp.stanford.edu
International Incidents and Failure Mode Data Access

Search the Failure Mode Database:

Search by Structure/Component Type
Search by Dam Sub-System Type
Search by Keyword

Search the International Dam Incident Database

Search All Incidents
Search Success Stories
Search Incident Reference Documents
View a Map of all Dam Incidents by Country

Obtained from http://npdp.stanford.edu
Results for Search by Structure/Component Type

Found 1383 record(s)

<table>
<thead>
<tr>
<th>Initiating Event Type</th>
<th>High Level Failure Mode</th>
<th>Failure Mode Description</th>
<th>More...</th>
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<tbody>
<tr>
<td>all</td>
<td>Internal Erosion</td>
<td>piping through foundation of concrete spillway</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Internal Erosion</td>
<td>piping through foundation of concrete spillway</td>
<td></td>
</tr>
<tr>
<td>all</td>
<td>Internal Erosion</td>
<td>piping or internal erosion fails embankment leading to the potential uncontrolled release of the reservoir.</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Internal Erosion</td>
<td>Piping Failure through main embankment - Normal Pond up to PMF</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Internal Erosion</td>
<td>The PFM sequence involves a failure of the left pier of the sector gate due to piping of the underlying alluvial material resulting in a breach and uncontrolled release of the reservoir.</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Internal Erosion</td>
<td>Failure of Right Abutment due to Piping</td>
<td></td>
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<tr>
<td>all</td>
<td>Internal Erosion</td>
<td>spillway failure due to piping of foundation or crib resulting in an uncontrolled release of the reservoir.</td>
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<tr>
<td>all</td>
<td>Internal Erosion</td>
<td>piping of spillway foundation fails the spillway, leading to the potential uncontrolled release of the reservoir.</td>
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<tr>
<td>Any</td>
<td>Internal Erosion</td>
<td>Failure of the Main and Wing Dikes due to piping from seepage flow under normal pond or flood conditions</td>
<td></td>
</tr>
<tr>
<td>Any</td>
<td>Internal Erosion</td>
<td>Failure of the Main Dam, Canal Dike and Middle Dike due to piping from seepage flow under normal pond or flood conditions</td>
<td></td>
</tr>
</tbody>
</table>

Obtained from http://npdp.stanford.edu
SEARCH THE INCIDENT DATABASE

COUNTRY
- ANY -

SYSTEM PERFORMANCE

DAM TYPE

STRUCTURE/COMPONENT

TYPE

DAM HEIGHT (ft.)

RESERVOIR STORAGE (acre-ft)

INITIATING EVENT

HIGH LEVEL FAILURE MODE

TYPE

INCIDENT YEAR

KEYWORD(S)

Click Here to Start a New Search

Obtained from http://npdp.stanford.edu
# Incident Details

<table>
<thead>
<tr>
<th>Incident Date</th>
<th>08/05/1978</th>
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</thead>
<tbody>
<tr>
<td>Initiating Event</td>
<td>Normal Reservoir</td>
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<tr>
<td>Failure Mode</td>
<td>Embankment Internal Erosion</td>
</tr>
<tr>
<td>Country</td>
<td>United States</td>
</tr>
<tr>
<td>Dam Type</td>
<td>Earth</td>
</tr>
<tr>
<td>Dam Height</td>
<td>305 ft.</td>
</tr>
<tr>
<td>Normal Reservoir Storage</td>
<td>288250 acre-feet</td>
</tr>
<tr>
<td>Incident Sequence</td>
<td></td>
</tr>
<tr>
<td>Incident Description</td>
<td>The dam was located in a deeply cut canyon in the Rexburg Branch, a plateau of volcanic origin. The rock in the canyon walls are of volcanic origin. At the dam site the the rock consists of layered and jointed rhyolite with some inclusions of basalt, breccia, and tuff. In the right abutment the bedrock joint system is open and generally flat upstream and vertical downstream.</td>
</tr>
<tr>
<td>Time of Day</td>
<td>11:57:00</td>
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<tr>
<td>Time to Failure</td>
<td>267 minutes</td>
</tr>
<tr>
<td>Structures/Components Involved</td>
<td></td>
</tr>
<tr>
<td>EAP Implemented</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>View All Incident Reference Documents</td>
</tr>
<tr>
<td>Photos</td>
<td>View All Incident Photos</td>
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</table>

Obtained from [http://npdp.stanford.edu](http://npdp.stanford.edu)
### Reference Documents

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<thead>
<tr>
<th>Full Citation</th>
<th>Document</th>
</tr>
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<tbody>
<tr>
<td>Greater Idaho Falls Chamber of Commerce presents Idaho East, 'The Teton Dam Flood,' Winter 1977. (This contains the names and circumstances surrounding those who died)</td>
<td></td>
</tr>
<tr>
<td>Saarnio, N. (no date), 'Lessons Learned from the Teton Dam Failure,' Presentation.</td>
<td>Download</td>
</tr>
<tr>
<td>Brigham Young University Library Special Collections, (2013). 'Teton Dam Collection,' Oral history reports and newspaper articles includes more than 50 oral history interviews of those living in the area when the disaster occurred.</td>
<td>Link</td>
</tr>
</tbody>
</table>

Obtained from [http://npdp.stanford.edu](http://npdp.stanford.edu)
## Incident Photos

<table>
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<th>Date Taken</th>
<th>Caption</th>
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<tbody>
<tr>
<td>08/05/1970</td>
<td>View looking at the right abutment approximately 10:30 and 11 AM. The leak can be seen running down the face of the dam.</td>
</tr>
<tr>
<td>08/05/1970</td>
<td>View looking at the right abutment approximately. The leak can be seen running down the face of the dam.</td>
</tr>
<tr>
<td>08/05/1970</td>
<td>View looking at the right abutment. The leak can be seen running down the face of the dam. Water is now ponding at the t</td>
</tr>
</tbody>
</table>

Obtained from [http://npdp.stanford.edu](http://npdp.stanford.edu)
Future Characterization of Events at Dams

Obtained from http://npdp.stanford.edu
Capturing & Transferring Lessons

• Dam engineering has advanced in large part to the lessons when trial and error was a large part of the evolution of how to design and construct dams.

• As we have seen in past dam incidents/failures, it is typically not one factor, but a number that collectively conspire to lead to the outcome we observed.
  – Focus on Financial Performance
  – Focus on Personal Safety, Not System Safety
  – Fixing Symptoms not Problems
  – Complacency, Arrogance, Ignorance
  – Poor Communications
  – Focus on Regulatory Requirements
  – Lack of Corporate Safety Culture

Obtained from http://npdp.stanford.edu
Capturing & Transferring Lessons (cont.)

• In 2009 at the CEATI workshop on dam incidents, Nate Snortland made this point when he spoke about the Teton Dam failure. (As did others at the same meeting.)

• His presentation and the message he delivered had relatively little to do about the ‘technical’ aspects of the dam and the failure. Rather he focused on the ‘organizational’ factors (think NASA and the Challenger disaster).
Capturing & Transferring Lessons (cont.)

• Some of Nate’s points/lessons:
  – Engineering and Geology - Aggressive Design with Poor Embankment Materials and Extremely Poor Foundation

• Communication
  – Investigations not Communicating with Design
  – Design not Communicating with Construction
  – Important Decisions Made in the Field
  – Failure Mode Known, but Not by Teton Design Team

• Hubris
  – Unwillingness to Learn and Adjust
  – Uncoordinated Confidence
Capturing & Transferring Lessons (cont.)

- The factors that play a role in an event (success and failures) are often:
  - Inter-related
  - Difficult to identify
  - Evolve on time scales that are very different than the event itself

- ‘Traditional’ characterizations were often provided in a form that was motivated by less-is-more; limited words, abbreviations or codes.

Obtained from http://npdp.stanford.edu
A Vision for the Characterization of Dam Performance

- The issue, looking ahead is, how can we capture the insights and lessons from past and future events in a database so they are retrievable, clearly convey the inter-relationships of these factors, the lessons learned, etc.

- A question arises as to how can we characterize events in a way that ‘better’ captures the many varied elements and factors that contribute to the initiation and evolution of an event.

- How do we do this in a way that ‘better’ captures information about incidents, can be retained and queried in a database, and ultimately displayed for the user.
<table>
<thead>
<tr>
<th>No.</th>
<th>Dam</th>
<th>Incident Type</th>
<th>Dam Failure</th>
<th>Success</th>
<th>Seismic</th>
<th>Piping</th>
<th>Flood</th>
<th>Landslide</th>
<th>Intrinsic/Normal Conditions</th>
<th>System Operational</th>
<th>Operator Action</th>
<th>Organizational / Management</th>
<th>Fatalities</th>
<th>DS Economic Impact</th>
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<td>X</td>
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</tr>
<tr>
<td>17</td>
<td>WAC Bennett</td>
<td>Sinkhole</td>
<td>X</td>
<td></td>
<td>X</td>
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<td>X</td>
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</tr>
</tbody>
</table>
A Vision for the Characterization of Dam Performance

• Our vision for the characterization of dam incidents is founded on a number of key ideas, attributes:

• These include:
  – The temporal evolution (memory) of factors that lead to incidents,
  – Variation in time scales
  – The organizational and system level factors that are inter-related and effect how dam engineering is carried out, operations are performed, and events are managed.

• We will look at two examples that illustrate these points.

• Our next step is to develop a database structure that captures these attributes that is query-able and easily displayed.
Managing the Risks of Organizational Accidents

James Reasons (2000)

Obtained from http://npdp.stanford.edu
A Teton Dam Timeline

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Prior to Consideration of a dam at the Site</th>
<th>During Planning of Dam</th>
<th>Alternative Evaluation Design Selection</th>
<th>During Design</th>
<th>During Construction</th>
<th>During Filling</th>
<th>During Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>The eastern Snake River Plan is almost entirely underground by basalt erupted from large shield volcanoes</td>
<td>Test core showed that the rock at the dam site was highly fissured and unstable, particularly on the right side of the canyon. The wall structures were</td>
<td>Original concept was for a compacted rockfill dam</td>
<td>Single-line curtain</td>
<td>- Zone 1: the blast placed against rock in the cliff face without an intervening layer</td>
<td>- Zone 2: did not meet criteria with Zone 1</td>
<td>Filling halted prior to completion of cofferdams to facilitate FH testing (and to avoid a possible contractor claim)</td>
</tr>
</tbody>
</table>

 Obtained from [http://npdp.stanford.edu](http://npdp.stanford.edu)
# Event Involving Operation of A Sluice Gate

## Timeline and Events

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Pre-Event Condition</th>
<th>Initiating Event</th>
<th>Event A</th>
<th>Event B</th>
<th>Event C</th>
<th>Final Outcome (failure, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12pm</td>
<td>Reservoir at Normal Pool</td>
<td>Sluice Gate Raised to Make Required Releases</td>
<td>Static &amp; Dynamic Stresses on Lift Bolts</td>
<td>Higher Stresses on Remaining Bolts</td>
<td>Lift Bolt Sheared</td>
<td>Remaining Bolts Sheared</td>
</tr>
<tr>
<td>12pm</td>
<td>12:23pm</td>
<td>Sluice Gate Experiences Significant Vibrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:31pm</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>12:35pm</td>
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<tr>
<td>12:36pm</td>
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</tr>
</tbody>
</table>

## Pre-Existing Factors

<table>
<thead>
<tr>
<th>Category</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>Operators failed to recognize the ongoing vibration</td>
</tr>
<tr>
<td>Procedural (Inspection: Maintenance)</td>
<td>Inspections were incomplete; failure to recognize deteriorated bolts</td>
</tr>
<tr>
<td>Design</td>
<td>Bolts were not designed to handle the load if one of more bolts failed or had deteriorated crosssections</td>
</tr>
<tr>
<td>Management</td>
<td>Failure to institute a culture of safety &amp; reliability</td>
</tr>
<tr>
<td>Environmental</td>
<td>Bolts were deteriorated; failed bolt had lost 67% of its crosssection.</td>
</tr>
</tbody>
</table>
Final Thoughts

• The world in which the dam safety community operates is changing. These changes are compromising reliability (i.e., aging) and safety, remote operations, business pressures, etc.

• These changes and demands must be met with better informed technical professionals, owners and management.

• To support these demands we need the means (data, evaluations, etc.) that improves our understanding of dam and hydropower system performance.

• Understanding system performance meets to principle owner objectives: reliable generation capability and safe operation.
Thank You