Learning from the Present & Past

An Industry Need and Supporting Resources

Martin W. McCann, Jr.
Stanford University

Patrick Regan
Risk-Informed Decision Making Group
Federal Energy Regulatory Commission

March 13, 2013

NPDP

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

Where are the Needs?

- Dam Safety
  - The forgoing list of activities and factors effecting the hydro industry is changing/expanding our vision of 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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

Success Story Example

Obtained from http://npdp.stanford.edu

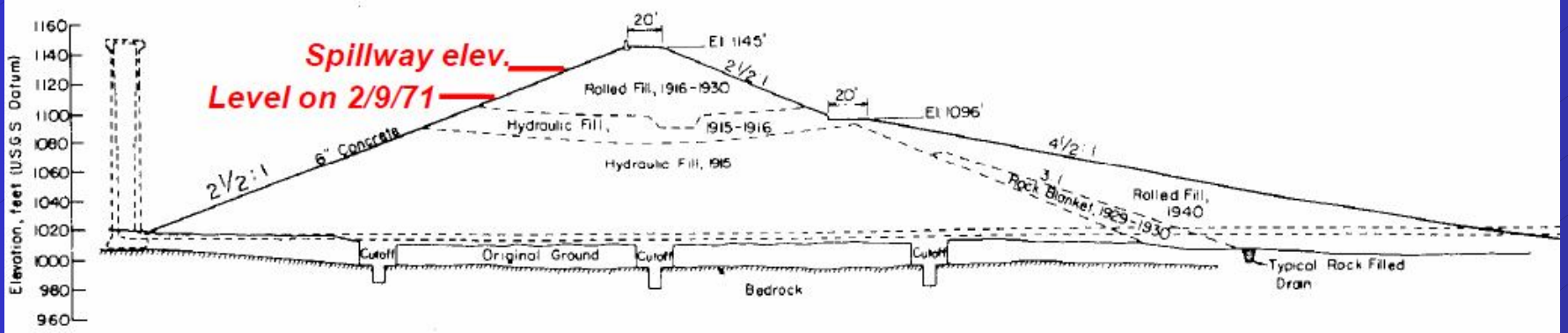


FIG. 2.—Cross Section of Lower San Fernando Dam (Los Angeles Department of Water and Power)

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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 PFMAs for hydropower projects
  - NPDP dam incident database
  - International dam incident database (ICOLD, etc.)

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

FERC Potential Failure Mode Data (cont.)

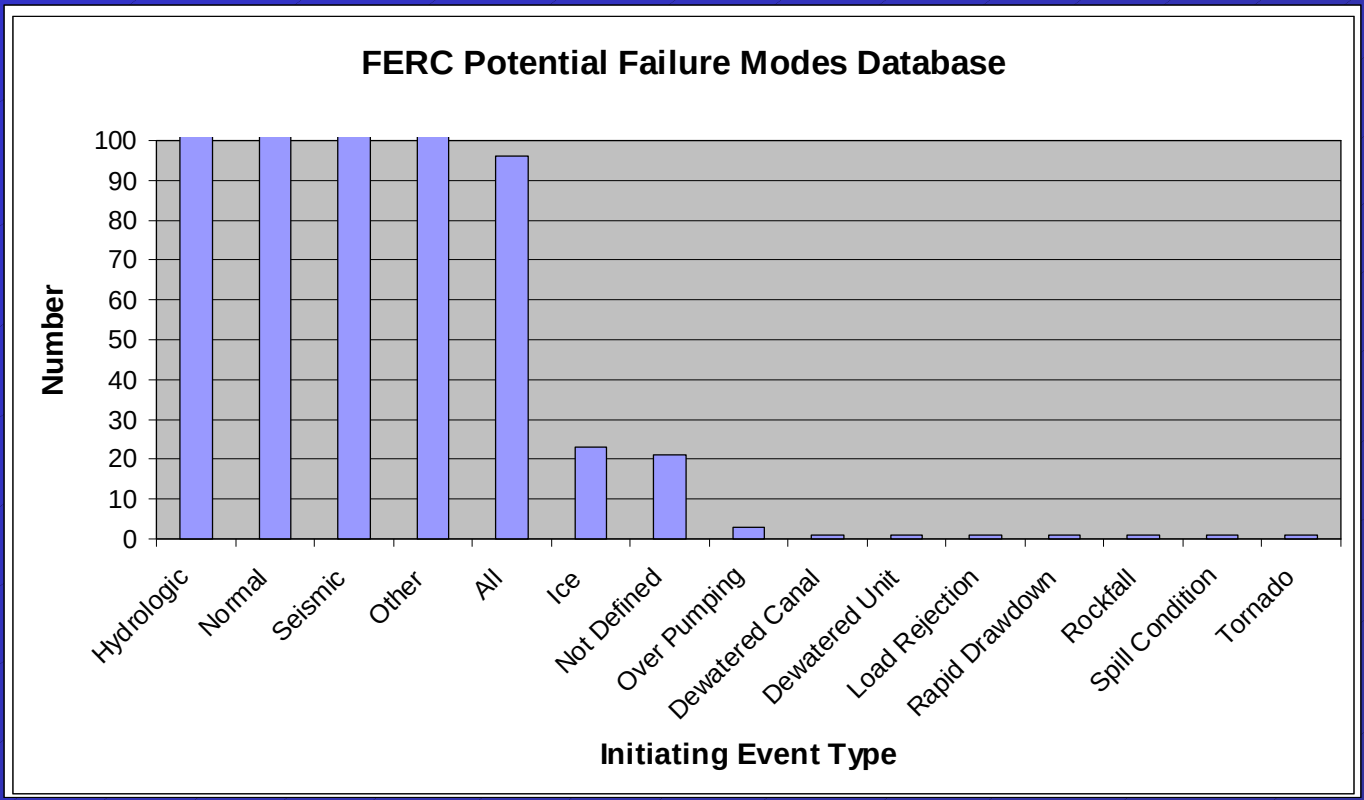
- There are 7,535 PFM that have been extracted
- At this point they have not been fully reviewed, filtered, etc.
  - There are replicates
  - Some are not well defined
- Expected that future Part 12 evaluations will improve the consistency and quality of this dataset.

NPDP

Obtained from http://npdp.stanford.edu

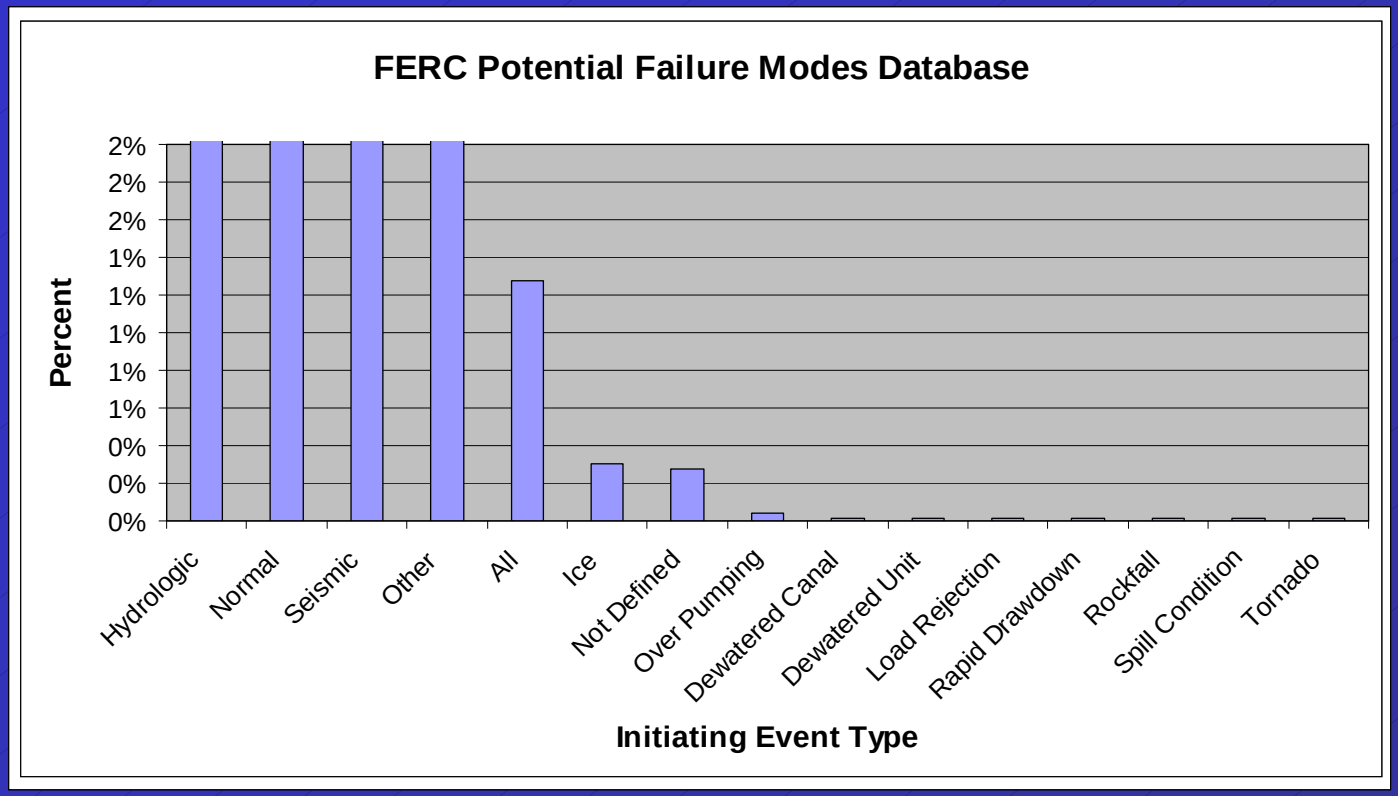
FERC FEDERAL ENERGY REGULATORY COMMISSION

FERC Potential Failure Mode Data (cont.)



Obtained from http://npdp.stanford.edu

FERC Potential Failure Mode Data (cont.)



Obtained from http://npdp.stanford.edu

Dam Performance Data (cont.)

- There are a number of resources we are utilizing:
  - ICOLD, USSD (USCOLD) reports, etc.
  - NPDP database
- Between us, we have colleted:
  - 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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

Dam Performance Data (cont.)

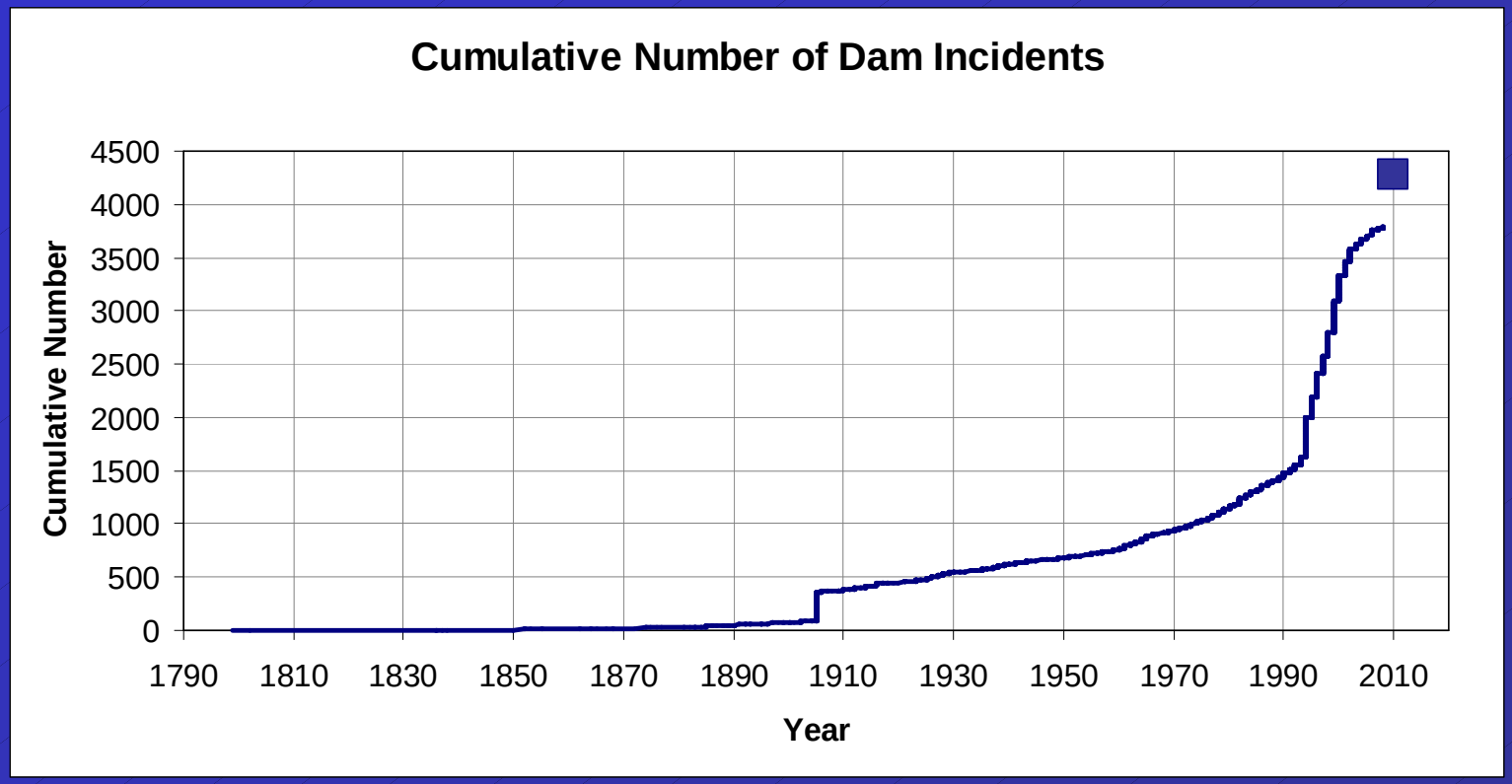
- Resources that we are bringing together:
  - 4,285 U.S. & international dam incidents
  - Approximately 4,500 U.S. incidents (beyond those in the above list).
- USCOLD (USSD) paper files gathered during the compilation of their 1975 book on dam incidents.
- Photographs – estimated to be over 8,000
- Initially starting with the list of international dam incidents (4,285 events)

NPDP

Obtained from http://npdp.stanford.edu

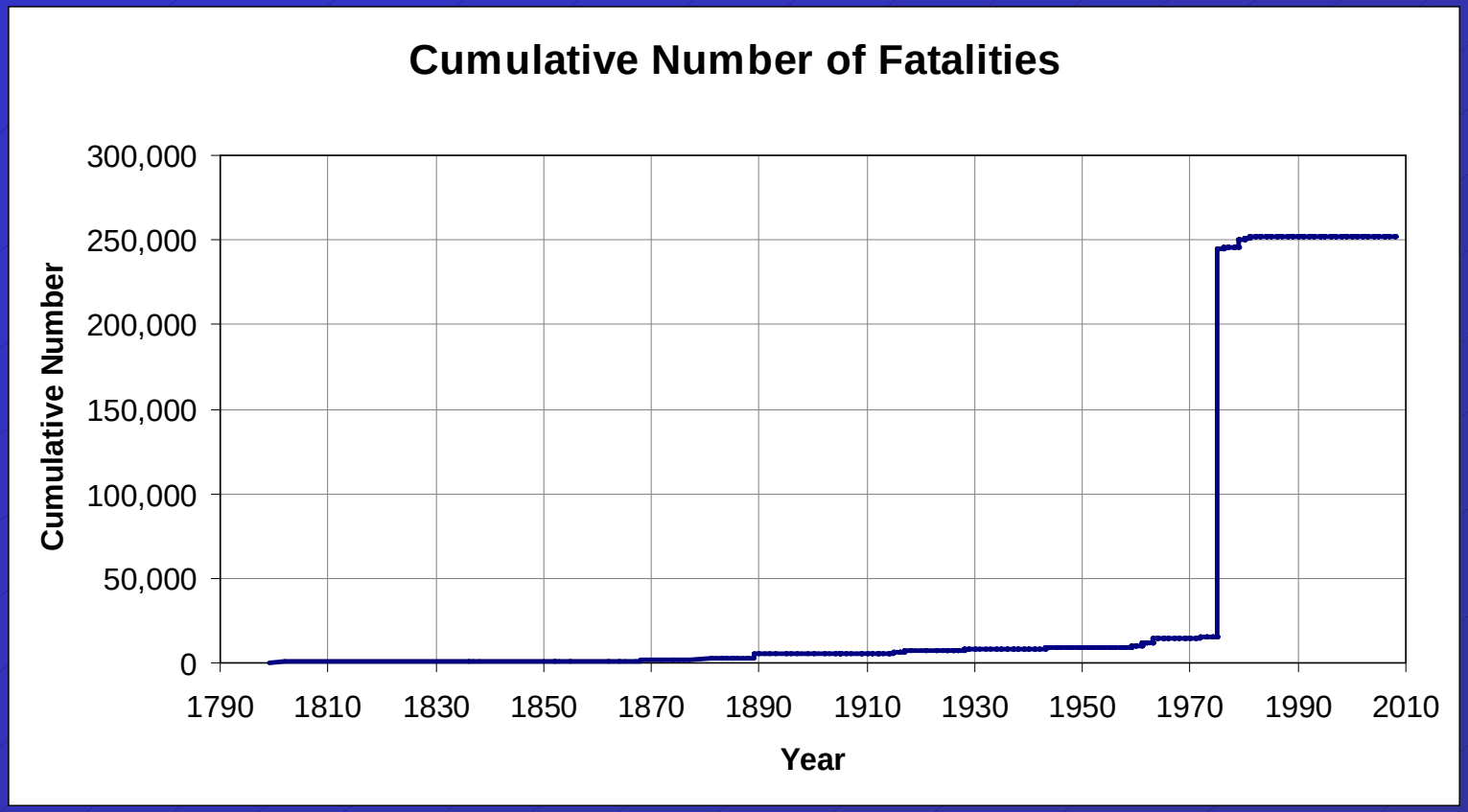
FERC FEDERAL ENERGY REGULATORY COMMISSION

Dam Performance Data (cont.)



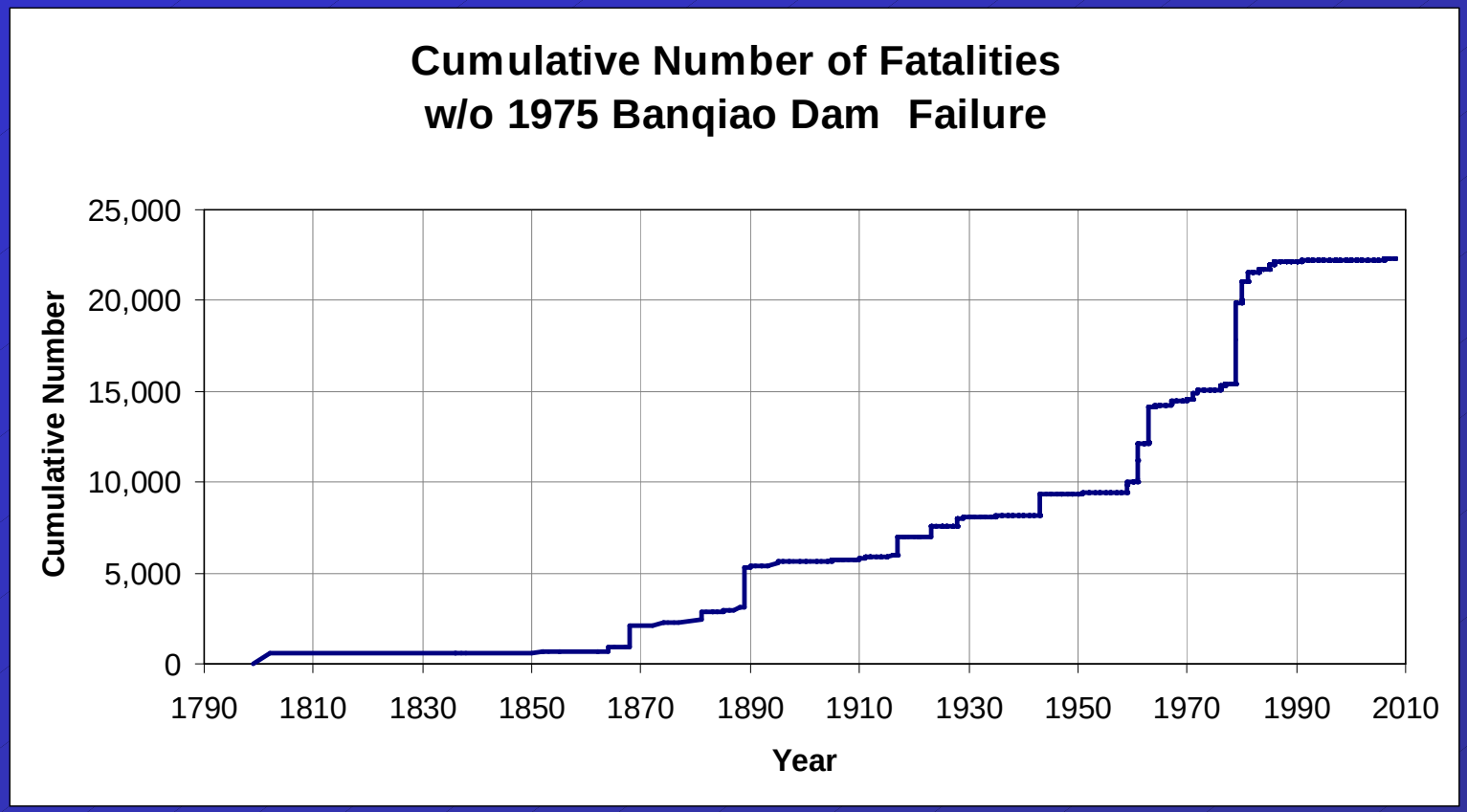
Obtained from http://npdp.stanford.edu

Dam Performance Data (cont.)



Obtained from http://npdp.stanford.edu

Dam Performance Data (cont.)



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 mutli-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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

First Steps

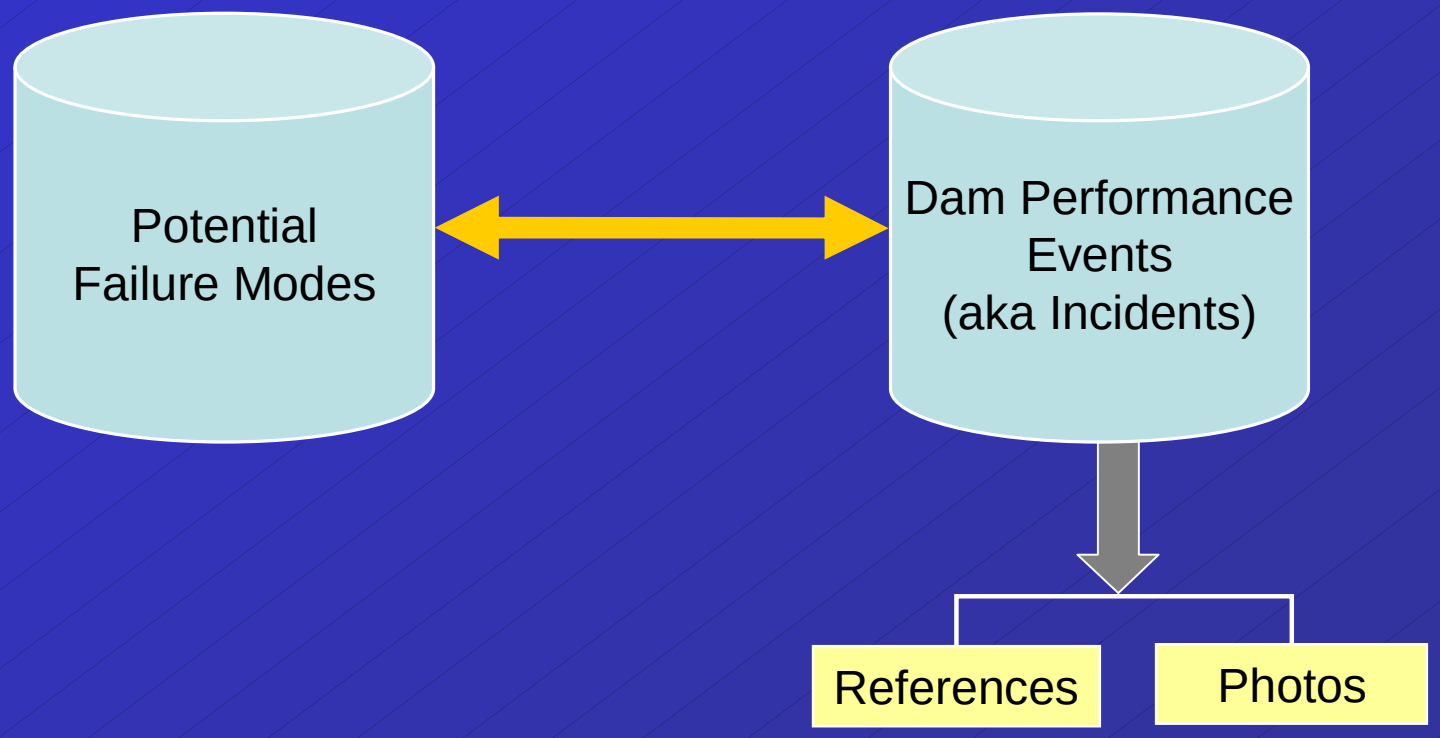
- Database on PFMs
  - The result of a prospective assessment of dams
  - Support an initial understand of the potential vulnerabilities of dams
- Dam performance
  - Give a retrospective view of events that have occurred.
  - Realization of how the 'whole' dam system performed under certain circumstances
- Our initial database developments efforts:
  - Getting the PFMs online,
  - Getting the international incidents online, and
  - Relating the two of these; the prospective to the 'real'

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

Vision for Online Access



Obtained from http://npdp.stanford.edu

A Short Tour

Obtained from http://npdp.stanford.edu

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

International Incidents and Failure Mode Data Access

Home » 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

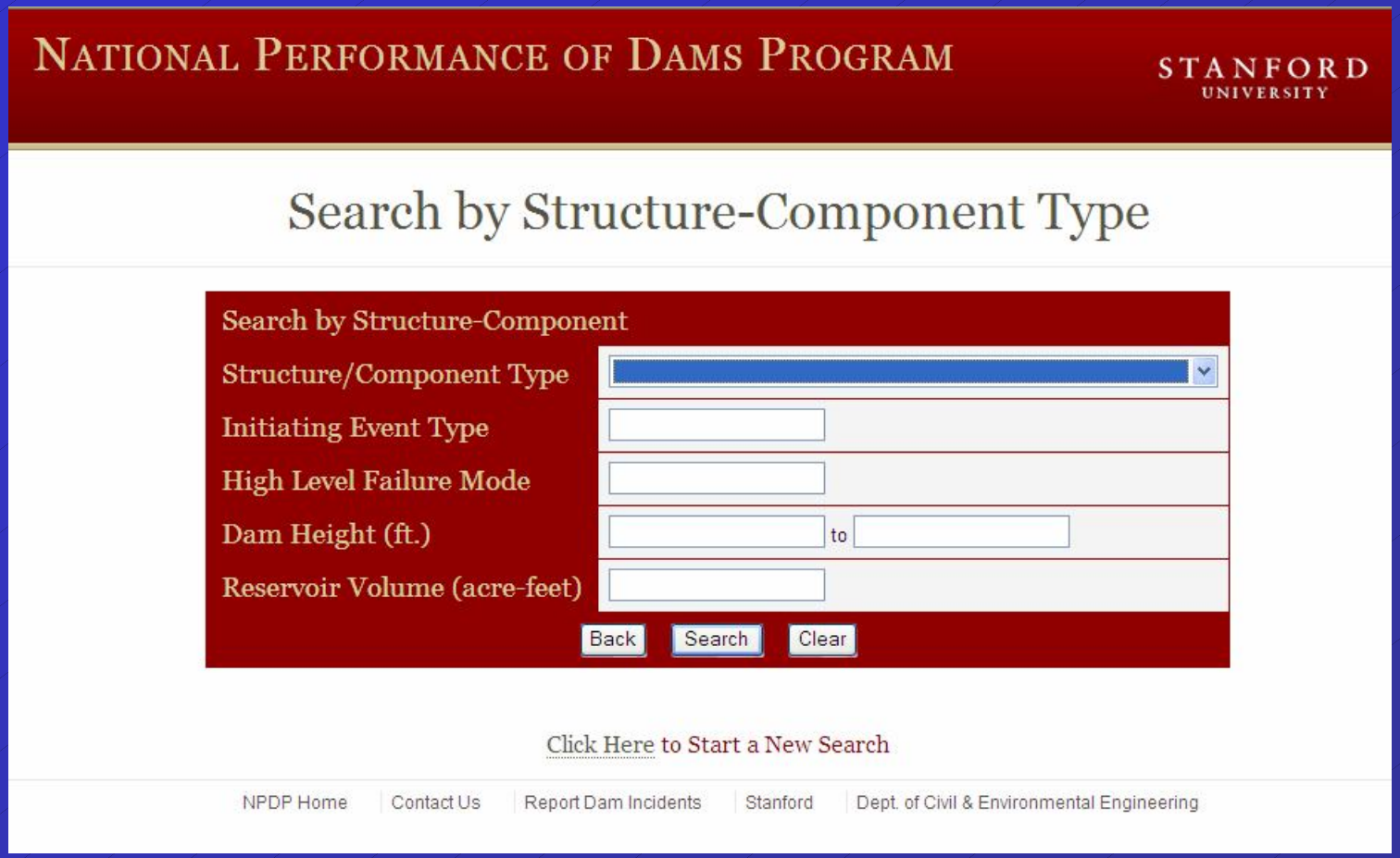
- Search All Incidents
- Search Success Stories
- Search Incident Reference Documents
- View a Map of all Dam Incidents by Country

NPDP Home | Contact Us | Report Dam Incidents | Stanford | Dept. of Civil & Environmental Engineering

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION



Obtained from http://npdp.stanford.edu

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

Results for Search by Structure/Component Type

Found 1383 record(s)

Show All | Search | First Page | Previous | Next | Last Page | Bottom

Display 10 record(s) | Export [Choose a Format]

Initiating Event Type	High Level Failure Mode	Failure Mode Description	More...
all	Internal Erosion	piping through foundation of concreite spillway	
All	Internal Erosion	piping through foundation of concrete spillway	
all	Internal Erosion	piping or internal erosion fails embankment leading to the potential uncontrolled release of the reservoir.	
All	Internal Erosion	Piping Failure through main embankment - Normal Pond up to PMF	
All	Internal Erosion	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.	
All	Internal Erosion	Failure of Right Abutment due to Piping	
all	Internal Erosion	spillway fails due to piping of foundation or crib resulting in an uncontrolled release of the reservoir.	
all	Internal Erosion	piping of spillway foundation fails the spillway, leading to the potential uncontrolled release of the reservoir.	
Any	Internal Erosion	Failure of the Main and Wing Dikes due to piping from seepage flow under normal pond or flood conditions	
Any	Internal Erosion	Failure of the Main Dam, Canal Dike and Middle Dike due to piping from seepage flow under normal pond or flood conditions.	

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

Search the Incident Database

Country	-ANY-	System Performance	ALL
Dam Type		Structure/Component Type	
Dam Height (ft.)	to	Reservoir Storage (acre-ft)	to
Initiating Event Type		High Level Failure Mode	
Incident Year	to	Keyword(s)	

Back Search Clear

Click Here to Start a New Search

NPDP Home | Contact Us | Report Dam Incidents | Stanford | Dept. of Civil & Environmental Engineering

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

Incident Details

Incident Date	06/05/1976
Initiating Event	Normal Reservoir
Failure Mode	Embankment Internal Erosion
Country	United States
Dam Type	Earth
Dam Height	305 ft.
Normal Reservoir Storage	288250 acre-feet
Incident Sequence	
Incident Description	The dam was located in a deeply cut canyon in the Rexburg Bench, 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.
Time of Day	11:57:00
Time to Failure	267 minutes
Structures/Components Involved	
EAP Implemented	
References	View All Incident Reference Documents
Photos	View All Incident Photos

Back

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

Reference Documents

Found 16 record(s)

Search | First Page | Previous | Next | Last Page | Bottom

Display 10 record(s)

Full Citation	Document
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).	
Thomas, J., Thomas, M. Tingey, M. (editors). (1977) "That Day in June – Reflections on the Teton Dam Disaster," Ricks College Press, Rexburg, Idaho, 1977.	
94th Congress, 2nd Session, "Teton Dam Disaster Assistance Act of 1976," Report No. 94-963.	
Independent Panel to Review Cause of Teton Dam Failure, (1976). "Report to U.S. Department of Interior and State of Idaho on Failure of Teton Dam," U.S. Department of the Interior, Idaho Falls, Idaho, December 1976.	Download
U.S. Department of the Interior Teton Dam Failure Review Group, (1977). "Failure of Teton Dam – A Report of Findings," U.S. Department of the Interior, Bureau of Reclamation, Denver, CO.	Download
Ray, H.A. and Kjelstrom, L.C. (1977) "The Flood in Southeastern Idaho from the Teton Dam Failure of June 5, 1976," USGS Open-File Report 77-765.	
Snortland, N., (no date). "Lessons Learned from the Teton Dam Failure." Presentation.	Download
Congressional Budget Office, (1976). "Teton Dam Disaster Assistance Act of 1976 : Report Including Cost Estimate of the Congressional Budget Office to Accompany S. 3542.	
Stene, E.A. (1996). "The Teton Basin Project." U.S. Bureau of Reclamation History Program, Denver, CO.	Download
Brigham Young Univeristy 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, http://abish.byui.edu/specialCollections/Manuscripts/Collections/CollMss2.htm.	Link

Search | First Page | Previous | Next | Last Page | Top

Click Here to Start a New Search

NPDP Home | Contact Us | Report Dam Incidents | Stanford | Dept. of Civil & Environmental Engineering

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

NATIONAL PERFORMANCE OF DAMS PROGRAM

STANFORD UNIVERSITY

Incident Photos

Found 40 record(s)

First Page | Previous | Next | Last Page | Bottom

	Date Taken	Caption
	06/05/1976	View looking at the right abutment approximately 10:30 and 11 AM. The leak can be seen running down the face of the dam.
	06/05/1976	View looking at the right abutment approximately. The leak can be seen running down the face of the dam.
	06/05/1976	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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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).

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

					Initiating Event					Incident Attributes			Consequences		
No.	Dam	Incident Type	Dam Failure	Success	Seismic	Piping	Flood	Landslide	Intrinsic/ Normal Conditions	System Operational	Operator Action	Organizational / Management	Fatalities	DS Economic Impact	Major Owner Economic Impact
1	Teton Dam	Failure on First Filling	X			X			X			X	X	X	X
2	Lower San Fernando	Embankment Liquefaction		X	X						X				X
3	Gibson Dam	Overtopping		X			X								
4	Folsom Dam	Gate Failure; Trunion Friction	X				X		X			X			X
5	Buffalo Creek	Flood	X				X						X	X	X
6	Lyman Dam	Flood and piping	X				X						X	X	X
7	South Fork Dam	Hydrologic Event	X				X					X	X	X	X
8	Austin Dam	Sliding	X										X	X	X
9	Lower Crystal Springs Dam	Earthquake Ground Shaking		X	X										
10	San Andreas Dam	Earthquake Ground Shaking and Fault Movement		X	X										
11	Fountonelle Dam	Embankment Piping		X					X						X
12	St. Francis Dam	Structural	X						X				X	X	X
13	Taum Sauk	Mechanical & Overtopping	X						X	X		X			X
14	Orienta	Flood and Debris		X			X				?	?			?
15	Palenedra	Flood and Debris		X									X		
16	Viant	Landslide		X				X					X		
17	WAC Bennett	Sinkhole		X					X			X			

Obtained from http://npdp.stanford.edu

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.

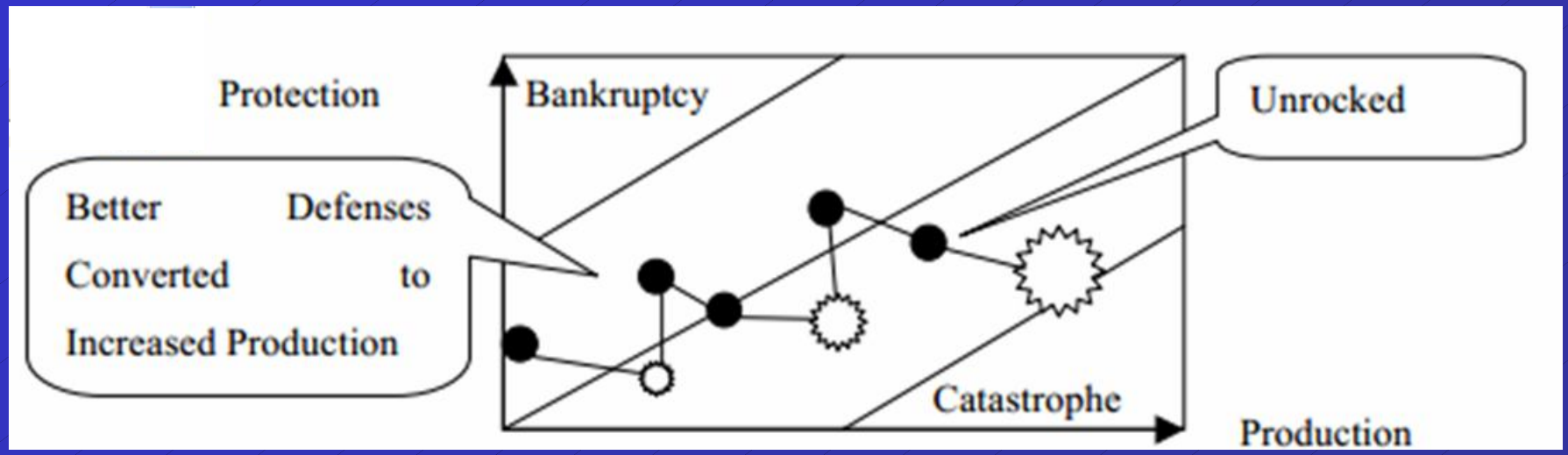
- Our next step is to develop a database structure that captures these attributes that is query-able and easily displayed.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

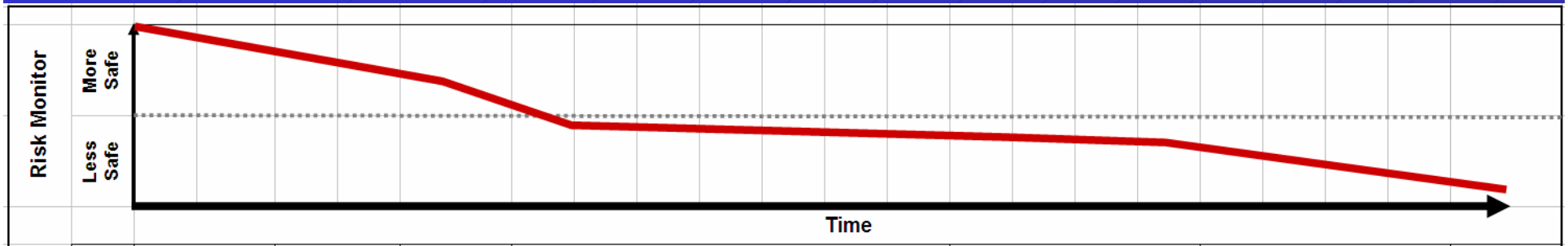
Managing the Risks of Organizational Accidents



James Reasons (2000)

Obtained from http://npdp.stanford.edu

A Teton Dam Timeline



Timeframe	Description
Prior to Consideration of a dam at the Site	The eastern Snake River Plain is almost entirely underlain by basalt erupted from large shield volcanos on top of rhyolitic ash-
	Aeolian silt deposits, up to 30 feet thick, cover the highlands above the river canyon.
During Planning of Dam	Test cores showed that the rock at the dam site was highly fissured and unstable, particularly on the right side of the canyon. The widest fissures were
Alternative Evaluation Design Selection	Original concept was for a compacted rockfill dam. This was changed to an earthfill dam "due to the environmental consideration of defacing the upstream reservoir abutment area."
During Design	Single Line grout curtain
	Cutoff trench in abutments
	Use of aeolian silt for impervious core
	Zone1 (the silt) placed against rock in the cutoff trech without an intervening filter
	Zone 2 did not meet filter criteria with Zone 1. Nearly as impervious as core.
	Cutoff trench described as "deep, narrow and steep-sided" - potential for arching and cracking of Zone 1 in trench
	Only instrumentation was to be settlement monuments
During Construction	Extensive grouting (over twice estimated quantities). Post-Failure testing indicated "that in the critical key-trench areathegrout curtain was not
	Testing of fill placement was, at times including a key period in 1975, less than the specified 1 test per 2,000 cy fill. (7,000 cy w/ no tests, 12,000 cy w/2
	Discovery of latge fissures in key trenches, some of which extended a100' or more upstream and downsream of dam axis.
	Design engineers seldom visited the site
During Filling	Filling initiated prior to completion of outletworks to facilitate PH testing (and to avoid a possible contractor claim)
	Filling rate exceeded specs
	Not all survey monuments installed
	Daily inspections - data sent monthly to design engineers for review - Critical data arrived in Denver the day after the failure
During Operation	Failed prior to "normal: operations

Obtained from http://npdp.stanford.edu

Event Involving Operation of A Sluice Gate

	Pre-Event Condition	Initiating Event	Event A	Event B	Event C	Final Outcome (failure, etc.)
Timeline	12pm	12pm	12:23pm	12:31pm	12:35pm	12:35pm
Outcome or Consequence			Static & Dynamic Stresses on Lift Bolts	Higher Stresses on Remaining Bolts		
Events	*Reservoir at Normal Pool*	*Sluice Gate Raised to Make Required Releases*	*Sluice Gate Experiences Significant Vibrations*	*Lift Bolt Sheared*	*Remaining Bolts Sheared*	*Sluice Gate Dropped, Closing the Outlet*

Pre-Existing Factors

- **Operational**: Operators failed to recognize the ongoing vibration
- **Procedural (Inspection; Maintenance)**: Inspections were incomplete; failure to recognize deteriorated bolts
- **Design**: Bolts were not designed to handle the load if one of more bolts failed or had deteriorated crossections
- **Management**: Failure to institute a culture of safety & reliability
- **Environmental**: Bolts were deteriorated; failed bolt had lost 67% of its crossection.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

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.

NPDP

Obtained from http://npdp.stanford.edu

FERC FEDERAL ENERGY REGULATORY COMMISSION

Thank You