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Technical Paper

Dam Failure Investigation Approaches

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Co-Authored and Presented by: Mark Baker, P.E. mhbaker@do.usbr.gov, 303-445-2595
Wayne Graham, P.E. wgraham@do.usbr.gov, 303-445-2553

Provide comments to:
Bureau of Reclamation, Mark Baker, Dam Safety Office, 84-44000
303-445-2595
PO Box 25007
Denver, CO 80225

Summary

Dam failures represent critical opportunities to learn why dams fail and for improving dam safety across the industry. This paper describes the overall purpose of these investigations and how the information learned from the investigations is shared with others. The authors reviewed published dam failure investigation reports from seven of the larger past U.S. dam failures. They found significant variability in how dam safety regulators* respond to dam failures, how investigation panels are formed, and the resulting reports. Several organizations were contacted regarding the existence of policies or procedures for responding to dam failures. A summary of the mission and approach of the National Transportation Safety Board is included. From the above information, observations are made and a conclusion is provided.

** For the purposes of this paper, regulators are defined as the States or Federal entities that oversee the safety of dams either owned/operated by themselves or others.*

PART 1: Introduction and Background

Inquests, investigative teams, review panels, etc. are used by modern societies to evaluate problems and events ranging from why kids do not graduate from high school, why we have a national mortgage problem in 2008, to why the events of September 11, 2001 took place. These analyses are conducted to either document the event from an historical perspective, provide key findings so that improvements can be made, or to place blame or liability. The procedures for conducting evaluations can be formal or ad hoc. An example of a formal procedure is the National Transportation Safety Board's charge by Congress to investigate every civil aviation accident in the United States and significant accidents in the other modes of transportation – railroad, highway, marine and pipeline – and to issue safety recommendations aimed at preventing future accidents. An example of informal procedures would be a mayor asking his public works department to investigate why so many water mains have begun leaking in the last year.

There are typically two objectives in dam failure investigations. The first is to understand the cause of the failure and how to prevent similar failures from occurring in the future, and the second is to convey this information to the broad dam safety community so that similar deficiencies can be corrected at existing dams and avoided at new dams. The investigations are also used to determine liability in court actions.

Some dam failure investigations are simple and conclusions are unambiguous. For example, there were many dams that failed in the late 1800's and early 1900's due to dam overtopping caused by inadequate spillway capacity. It was easy to observe water flowing over the dam crest and conclude that the spillway should have been larger. Other dam failure investigations are more complicated. Sometimes a single cause of failure cannot be determined and a list of failure hypotheses is given.

It is important to share key findings from dam failure investigations with the broader dam safety community. This has been, and continues to be, done with journals, magazines, books, newsletters, conferences, and seminars. The Internet is in greater use to quickly, efficiently and inexpensively share information with others. However, there does not appear to be a single location/entity to learn about dam failures and major incidents industry-wide.

Investigations allow us to discover the reason or reasons a dam has failed. This improved understanding of dam construction, maintenance or operation may help prevent future dam failures. Investigations are sometimes needed by the judicial system in order to identify the party responsible for the failure. These investigations can help assure that victims are compensated. Investigations by impartial independent individuals or groups can also build trust with the public and provide some closure in the public's mind as to why the failure happened.

Investigations are often conducted by an independent team or with independent review. In the foreword of the St. Francis Dam failure report, the Governor wrote:

> *"California deplores the heavy loss of life and property that this disaster entailed. To prevent a recurrence of a like catastrophe, we believe it imperative that whatever lessons the failure of this dam may teach should be made public for the benefit of the people of our state. It was also our thought that the investigation into the causes of the failure of this dam should be made by an agency that was not in any way connected with the preparation of the plans, the construction, or the operation of the dam."*
>
> Causes Leading to the Failure of the St. Francis Dam, 1928, 79 pages

Dam failures can weaken the trust the people have in their government. A full and open review (with independent review) goes a long way in reestablishing this trust. Examples are shown in Part 2, where the public lost confidence in the investigation. Recent failure investigations have implemented coordinated strategies to communicate with the public and to foster confidence in the investigation.

Investigations can go beyond the cause of dam failure itself, and address the emergency response to the event. Were appropriate heroic actions taken to prevent dam failure, and did the warning and evacuation of downstream communities proceed optimally? Although many of the dams that have failed causing catastrophic losses were never rebuilt (Mill River Dam, South Fork Dam, Walnut Grove Dam, Austin Dam, St. Francis Dam, Baldwin Hills Dam, Laurel Run Dam, Kelly Barnes Dam, Teton Dam, and others), dam failure investigations should provide knowledge to allow a dam to be safely reconstructed at or near the site of the failed dam.

Dam failure investigations should review various dam safety aspects. These include: design, construction, operation, maintenance, periodic inspections, repairs, alterations and modifications. The investigations should also address ownership and regulatory responsibilities. Lastly, the investigations should provide information on emergency preparedness and response, i.e., what went right and wrong in last-ditch efforts to prevent failure and what actions could have reduced the loss of life or other adverse consequences that resulted from failure.

Dam failure investigations are often challenging. This is true even under the best of surveillance conditions, such as when Reclamation's Teton Dam failed on a bright and sunny day, in the presence of many people. Some dams fail at night, or in the case of Silver Lake Dam, during the day, but with no people nearby to observe or take pictures. Some evidence is washed away during dam failures. Sometimes dam owners or operators are uncooperative or are reluctant to fully disclose information. There may be conflicting stories as to what happened. Records and data may be unavailable or missing, especially for older dams.

Dissemination of Information

Various journals, associations, organizations and conferences have provided a forum for analyzing, evaluating, tabulating, and categorizing dam failures. Investigating the cause of dam failure is important. More important is transferring knowledge to the dam safety community so that similar mistakes are not made in the future.

The American Society of Civil Engineers (ASCE) instituted in 1852, has been actively involved in dam failure investigations and in providing a forum for presenting information.

ASCE Transactions analyzed the 1889 South Fork Dam failure in the June 1891, in the *"Report of the Committee on the Cause of the Failure of the South Fork Dam*." ASCE published proceedings in 1932 of symposiums held in New York and Sacramento in 1930. A paper entitled, "*Necessity for, and Penalties for Lack of, Supervision [of dams]"* included reference to a tabulation and bibliography of the failure or partial failure of 293 dams. *Transactions* published in 1953, "*Earth-Dam Practice in the United States*," by T. A. Middlebrooks, contained a list of dam failures since 1914 and the reason for the unsatisfactory performance. ASCE holds conferences that include dam safety as a topic.

Engineering News, with a history dating back to 1874, provided initial reporting with probable cause of significant dam failures as well as overviews of dam failures. In 1902 it published "*A Classified Review of Dam and Reservoir Failures in the United States*." This provided an overview of the cause of dozens of dam failures. The journal also provided some in-depth coverage of individual failures. As an example, a dam at Oakford amusement park near Jeannette Dam, PA failed on July 5, 1903. The July 23, 1903 issue of *Engineering News* reported that the failure was caused by more than 5 inches of rain falling in a few hours which resulted in a flood in excess of spillway capacity and dam overtopping.

Engineering Record, with a history dating back to 1877, was similar to *Engineering News* in that it provided initial reporting with probable cause of significant dam failures as well as overviews of dam failures. In 1902, using the same source as *Engineering News*, above, published, "A List of Failures of American Dams." The cause of each failure was given. The journal provided in depth coverage of individual failures. The July 11, 1903, issue of *Engineering Record* stated that the dam near Jeannette gave way "as a result of a sudden downpour of rain" and "there are no new engineering lessons to be learned from this failure." It reported that the spillway could not handle the run-off and the dam was overtopped. *Engineering Record* carried another article about a year later, September 3, 1904, printing proceedings from a presentation made to the Engineer's Club of Philadelphia.

The *Engineering News and Engineering Record* were merged into one journal in 1917. *Engineering-News Record* continued the tradition of reporting on individual dam failures and periodically provided comprehensive assessments of dam failures. St. Francis Dam failed in California at midnight, March 12-13, 1928. *Engineering News-Record*'s March 22, 1928 issue contained, "*St. Francis Dam Catastrophe – A Great Foundation Failure*." More articles appeared between then and when the May 10, 1928 issued contained, "*St. Francis Dam Catastrophe – A Review Six Weeks After*." This article provided a summary of results from five investigating committees.

An unlikely source for dam failure data is *The Journal of Electricity* which in 1920 published an article, "*The Record of 100 Dam Failures*." The article provided a short description of when and why each dam failed.

The Bureau of Reclamation published a "*Catalog of Dam Disasters, Failures and Accidents,"* in 1968. The catalog listed several hundred events including the reason for the failure or accident. The source for the tabulated data, as with other tabulations listed above, is primarily *Engineering News, Engineering Record and Engineering-News Record*.

The Association of State Dam Safety Officials (ASDSO) was formed in 1984 in response to a decade-long period of significant dam failures. ASDSO provides a forum for the exchange of information through classes that it sponsors as well as regional and national conferences.

The National Performance of Dams Program (NPDP) was launched in 1994. Its mission is to be the "leading technical resource for information on the performance of dams, supporting dam safety, engineering, and public policy."

The National Dam Safety Program (NDSP), which is led by the Federal Emergency Management Agency (FEMA), includes dam safety training. An example of this training is a seminar given at FEMA's training facility in Emmitsburg, Maryland, "National Dam Safety Program Technical Seminar No. 15, Lessons Learned from Dam Failures and Incidents."

The United States Society on Dams (USSD) advances the knowledge of dam engineering, construction, planning, operation, performance, rehabilitation, decommissioning, maintenance, security and safety. It holds an annual conference and study tour. The society provides technology transfer to professionals throughout the United States and the world.

The International Commission on Large Dams (ICOLD), founded in 1928, provides a forum for the exchange of knowledge and experience in dam engineering. ICOLD publishes a newsletter, bulletins and books.

PART 2: A Review of Selected Dam Failure Responses and Investigations

Given the large number of historical dam failures and time/resource constraints the authors decided to research seven dam particular failures. Six dam failures from the past 38 years were selected. The New Orleans metro area levee failures were also included. These selected failures represent some of the more notable past dam failures and, in the authors' opinion, represented good opportunities for learning about how to investigate dam failures. References are cited in the section on each dam failure. These failures are listed chronologically. Part 5 of this paper presents observations based on the results of this research.

1972 Buffalo Creek Coal Waste Dam

February 26, 1972 (Date of failure)
On this date, this West Virginia coal waste impoundment dam failed. The dam was owned by a coal mining company. There were 131 deaths, $50 million in damages, and 546 homes were destroyed. The total settlement costs were $19 million.

March 1, 1972 (1 week post-failure)
The Governor appointed an ad hoc commission to investigate the failure and to determine if there are similar concerns with dams elsewhere in the state.

March 2, 1972 (1 week post-failure)
The U.S. Department of the Interior (DOI) Assistant Secretary established a commission (Task Force) consisting of 5 members from the Bureau of Mines and US Geological Survey.

March 10, 1972 (2 weeks post-failure)
The Chairman, U.S. Senate Committee on Labor and Public Welfare, requested the USACE to investigate the failure and the other coal waste dams in the region. The investigation included field sampling, questionnaires, lab testing, and the development of a hydraulic model.

March 12, 1972 (two weeks post failure)
Report Issued: *Preliminary Report*, U.S. DOI Task Force to Study Coal Waste Hazards, 29 pages

The report concludes that the causes of failure include: high water, saturated dam materials, poor stability, a "weak spot" due to previous dam repairs, piping along the drainage or overflow pipe, and a weak foundation.

May 1972 (3 months post failure)
Report Issued: *Investigation Report,* USACE

The USACE completes their investigation report for the U.S. Senate Committee on Labor and Public Welfare. The report concluded that the dam was unstable, but the USACE could not positively identify the controlling mode of failure. Failure could have been caused by piping/foundation stability/downstream slope failure/ or overtopping.

(Date uncertain)
Report Issued: *A Citizens Report on Criminal Negligence in a West Virginia Mining Community,* Citizens Panel, 1972, 31 pages

A citizens committee established itself after there were public concerns about the independence of the previously established investigations. The committee consisted of 12 members from environmental, church, miner advocacy, and union organizations. The citizens committee believed that the Governor-appointed investigation team members lacked independence and were beholden to the mining industry. The report stated that, "Any hope for objectivity and public disclosure of the truth vanished as membership of his (Governor's) commission was revealed." The goal of the citizens report were to disprove that the failure was an Act of God and to obtain knowledge of what really happened and why. The committee was initially denied access to the site. The report concludes with an accusation that the mine owners and others were guilty of violation of law, gross negligence and murder of 131 persons.

(Date uncertain)
Report Issued: *The Buffalo Creek Flood and Disaster – Official Report*, the Governor's Ad Hoc Commission of Inquiry

The report preface stated: "Public opinion already has placed the basic responsibility for this tragedy at the doorstep of [the mining company and their owner]." And "But the investigation indicated that responsibility must be shared by others . . .". The commission states that the mining industry, Federal, and state agencies also are responsible for the failure. Three minority opinions are made at the end of the report. Extensive recommendations are made for new dam safety legislation.

(Date uncertain)
Report Issued: The National Academy of Engineering inspection team produced a 15 page report plus photos. The team made recommendations for additional investigations.

February 1973 (1-year post-failure)
Report Issued: *Analysis of Coal Refuse Dam Failure*, U.S Bureau of Mines

This report was completed under contract with a private consultant. The investigation included field explorations and laboratory testing. A primary focus was to understand what happened so that the resulting data could be applied toward properly designing coal waste impoundments.

1976 Teton Dam Failure

June 5, 1976 (Date of failure)

This 305-high Bureau of Reclamation embankment dam failed due to seepage erosion during first filling. The dam failed within 5 hours from the time that the seepage was discovered. The failure was filmed, with both with still cameras and by video. Eleven people died and the government paid out over $300 million in claims. Several towns were inundated. Over 3000 homes were damaged. This was the largest dam failure in U.S. history.

June 8, 1976 (3 days post failure)

Interior established the Interior Teton Dam Failure Review Group (IRG) composed of 5 members, 1 member each from: the DOI Secretary's office, the Tennessee Valley Authority, the Soil Conservation Service, the U.S. Army Corps of Engineers (USACE) (ret.), and the USGS. DOI and the State of Idaho also established the "Independent Panel to Review Cause of Teton Dam Failure." The results of all investigations were shared by the two groups, but their analyses and conclusions were arrived at independently.

These groups visited the dam site, made preliminary examinations of available technical data, reviewed the design/construction/first filling, and collected eyewitness accounts of the failure. They inspected the geologic and post-failure conditions at the site. The IRG team focused on four failure modes related to seepage erosion through the dam/foundation/abutments. The IRG established three separate task groups: geology, grouting, and embankment construction.

July 14, 1976 (six weeks post failure)
Report Issued: *Interim Report on the Teton Dam Failure,* IRG.

August 5-7, 1976 (two months post failure)

Hearings were held before the subcommittee of the Committee on Government Operations, U.S. House of Representatives. Interviewees included the Reclamation Commissioner, other Reclamation design/construction/contract managers, geologists, a state water resource deputy director, a project construction engineer, a representative of the legal defense fund, a DOI deputy assistant secretary, and USACE representatives.

December 1976 (6 months post failure)
Report Issued: *Report to U.S. Department of the Interior and State of Idaho on Failure of Teton Dam,* Independent Panel.

The panel found that internal erosion caused the dam failure. Seepage control defenses were not adequately incorporated in the design. It stated that the dam was constructed in accordance with the design.

April 1977 (10 months post failure)
Report Issued: The *Failure of Teton Dam: A Report of Findings*, U.S. Department of the Interior Teton Dam Failure Review Group, 107 pages
This report included hundreds of pages of appendixes.

June 3, 1977 (1 year post failure)
Report Issued: *Actions Needed to Increase the Safety of Dams Built by the Bureau of Reclamation and the Corps of Engineers,* US General Accounting Office

Amongst its findings, the report found that Reclamation did not learn a valuable lesson from the near-failure of Fontenelle Dam 10 years earlier.

Reclamation performed a field investigation of the left side of the dam and the left abutment and foundation. The left side of the dam was removed.

January 1980 (2-1/2 years post failure)
Report Issued: *Failure of Teton Dam Final Report,* U.S. Department of the Interior Teton Dam Failure Review Group.

The reasons for failure were modified to incorporate findings from the left embankment excavation.

2003 Silver Lake Fuse Plug Spillway Failure

May 14, 2003 (Date of failure)

During a flood, the Silver Lake Dam (in Michigan) fuse plug activated and the foundation of the fuse plug eroded causing uncontrolled release of the reservoir. The dam is owned by an electric utility. A downstream dam owned by the City of Marquette, Michigan also failed. Both dams are under Federal Energy Regulatory Commission (FERC) regulation. The dam failures occurred during the day time. No one was onsite at Silver Lake to observe the failure.

A power plant that provided electrical service to the county and two mines was closed due to flooding and siltation of the water intake. Several roads and bridges were washed out. More than 1700 people were evacuated. Direct and secondary costs due to the failure were estimated to exceed $100 million. There was no loss of life or injuries.

There is a website that includes the reports developed as a result of the failure. It can be found at: http://www.ferc.gov/industries/hydropower/safety/projects/silver-lake.asp

Circa May 14, 2003
FERC issues Project and Incident Description

May 16, 2003 (2 days after accident)

FERC Developed an Incident Action Plan. The action plan was distributed via press release and included the following items for how FERC was responding to the event:

- Staff engineers were immediately dispatched to the site to obtain initial information concerning fuse plug failure and assist in any necessary emergency response.
- A review was to be completed of the design report, construction plans and specifications, and construction records for fuse plug.
- Hydrologic data of rainfall event and the record of reservoir elevations throughout the event would be evaluated and analyses performed to determine why the fuse plug activated. In addition, runoff characteristics and affect on reservoir elevation would be assessed to extrapolate to larger rainfall events.
- A forensic evaluation of the failure of the fuseplug would be performed, including an evaluation by geotechnical consultants to determine the fuse plug performance.
- A foundation exploration program would be developed to obtain data and information for remedial action.
- A re-assessment of the Silver Lake Dam and spillway Inflow Design Flood (IDF) would be made under the current rainfall event.
- The forensic evaluation will include a critical review of the effectiveness of the Emergency Action Plan (EAP).
- The results of the evaluation and analysis would be used to undertake a program wide review to apply knowledge gained to other Commission dams.

(Date uncertain)

FERC established their investigative team. The members consisted of:

- 6 FERC engineers
- 1 FERC fishery biologist
- 1 State of Michigan fishery biologist
- 1 State of Michigan dam safety staff
- 1 County emergency operations manager

Their objective was to gather all available information on the design and construction of the fuse plug; the events leading to the fuse plug activation; and the subsequent impacts affecting downstream lives, property, infrastructure, and the natural environment.

June 1, 2003

A team called the "Independent Review Board" was assembled by FERC, Division of Dam Safety and Inspections. The board consisted of 3 members, one from academia and two

private consultants. The team reviewed data from May 26 to June 3. On June 4, the team met with officials, visited the site and requested additional information. They also requested interviews with designers, the dam inspector, and the owner.

June 7, 2003 (three weeks post failure)
Report Issued: *Report No. 1: Field Investigation Report,* FERC Independent Review Panel, 5 pages plus attachments

The report documented their investigative activities, recommended additional geology mapping of fuse plug foundation, and created a list of data sources

June 19, 2003 (1 month post failure)
The panel interviewed the designer of the fuse plug in Chicago.

July 24, 2003 (10 weeks post failure)
Report Issued: *Initial Report of Findings, Draft*, FERC Investigation team, 40 pages.

This draft document described FERC team's initial investigation findings, including: The fuse plug foundation was erodible. The stop logs were not removed prior to flood. The operators contended that they did not know they were supposed to remove the stoplogs. The fuse plug acted as the principle spillway for flood events but was not designed with the features of a principal spillway.

July 31 – August 1, 2003 (11 weeks post failure)
The panel met in Washington DC.

October 6, 2003 (5-1/2 months post failure)
Report Issued: *Root Cause Report on the May 14, 2003 Operation of the Fuse Plug Spillway and Subsequent Channel Erosion Resulting in the Uncontrolled Release of Silver Lake - Owners Consultant Report*, Washington Group International (WGI), 40 pages

The Upper Peninsula Power Company hired the Washington Group to perform an evaluation of events leading up to and following the breach of the Silver Lake fuse plug spillway. The report presented the root causes of the operation of the fuse plug spillway and the release of Silver Lake. Their investigation method included reviewing of project documentation (including design drawings, studies and inspection reports), inspecting the site, a site survey, a subsurface exploration program (drill holes, test pits, surface geologic mapping, in situ/laboratory soils testing), hydrologic review of conditions/modeling, and erosivity studies. Key findings include: 1. The fuse plug and pilot channels where designed and constructed too low. 2. The fuse plug foundation and spillway channel materials were highly susceptible to erosion.

October 24, 2003, (5 months post failure)
Designer's Response: *Silver Lake Reservoir Fuse Plug Release, Marquette County, Michigan, May 2003: Facts, Observations and Discussion,* Montgomery Watson Harza (MWH) Americas, Inc., Engineering Consultant
Pages: 26 Pages
The designer disputed the Owners Consultant WGI Report above.

December 18, 2003 (7 months post failure)
Report Issued: *Report No. 2 Technical Reasons for the Release of Silver Lake Reservoir on May 14-15, 2003, 52 pages,* FERC Independent Review Panel

February 2, 2004 (8-1/2 months post failure)
Responses to Panel Report No. 2
- From Designer, 8 pages
- From Wisconsin Public Service on behalf of Upper Peninsula Power Company, 4 pages
- From City of Marquette, 1 page

March 10, 2004 (10 months post failure)
FERC Investigation Panel Response to Responses of February 2, 2004

April 13, 2004 (11 months post failure)
Summary of Conclusions, FERC Investigation Panel, 2 pages

2004 Big Bay Dam

This Mississippi dam failed on March 12, 2004. The owner had created the lake to increase shoreline property land values. The failure resulted in one the largest volumes of water (22,100 acre-feet) released from a U.S. dam failure. It failed during the daytime from seepage erosion/piping. The Emergency Action Plan was implemented and there were no lives lost. The property loss was estimated to be $8.5 million.

Following the failure, the private dam owner employed the firm of Timothy R. Burge, P.A., Inc., Consulting Engineers to conduct a study into the failure of the dam. This firm had maintained a professional association with the dam and its owner since shortly after completion of construction of the dam.

April 27, 2004 (6 weeks post-failure)
Report Issued: *Big Bay Dam – Evaluation of Failure,* Burge Consultants, 17 pages.

The purpose of the report was to "present the results of this firm's investigation and evaluation of the failure of the Big Bay Lake Dam directed toward determining the most probable cause of failure." The primary cause of failure was given as: "The development of rapid piping of soil and water from below the foundation structure of the dam, and not through the embankment or foundation sections." It was restated as follows: "It is my conclusion that the most probable cause of failure development was the combined mechanisms of the initial unexpected collapse of the ground structure around the seep point, leading to the critical shortening of the seepage path beneath the cut-off wall. The result of which was the erosion and collapse of the embankment structure from within."

January 13, 2005, (8 months post-failure)

106 plaintiffs asserted a claim against the Mississippi Department of Environmental Quality for damages.

2005 New Orleans Levees

August 29, 2005 (Date of failure)

The levees failed on August 29, 2005, as a result of flooding from hurricane Katrina. About 1200 people were killed. Thousands of homes were destroyed. Costs have been estimated as high as $28 billion. Nearly half of the region's people before the hurricane have not returned.

The performance of the New Orleans levee system during and following hurricanes Katrina and Rita is perhaps the most investigated civil water infrastructure failure.

Following the disaster, the USACE formed the Interagency Performance Evaluation Task Force (IPET). The team consisted of 23 members: 12 members from the USACE, 5 from academia, 2 members from water districts, 1 member from the US Dept of Agriculture, 1 member from the Bureau of Reclamation, 1 member from National Oceanic and Atmospheric Administration and 1 consultant. Their work was peer reviewed on a weekly basis by an external review panel of the American Society of Civil Engineers and independently reviewed by the National Research Council on New Orleans Regional Hurricane Protection Projects.

An independent investigation was also performed by a team led by the University of California at Berkley and sponsored by the National Science Foundation. The team consisted of 35 members. The members were mostly from academia and consultants.

July 31, 2006 (11 months post-failure)
Report Issued: *Investigation of the Performance of the New Orleans Flood Protection Systems in Hurricane Katrina on August 29, 2005*, Independent Levee Investigation Team, two vols. Volume 1 is 690 pages long.
Ref: http://www.ce.berkeley.edu/%7Enew_orleans/

The purposes of the investigation were threefold: what happened, why, and what changes are needed to prevent a recurrence. These questions were answered through field study, review of the history of the system, studies of the system, studies of the institutions involved, observations of repairs underway, and development of findings and recommendations. The causes were: (1) the hurricane itself, (2), the poor performance of the system, and (3) more global institutional problems.

March 26, 2007 (1-1/2 years post-failure)
Report Issued: The IPET produced a draft final nine-volume report entitled *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System,* IPET*,* 9 vols. The executive summary and overview volume is 147-pages long.

This investigation was to address five principal areas: the system pre-Katrina, the storm characteristics, the system performance, the consequences and the risks (both before the storm and following repairs). Findings include: (1) the system did not perform as a system, (2) the storm created record storm surge and loadings, (3) most of the major breaches were caused by overtopping and subsequent erosion, (4) [a description of consequences], and (5) [risks were described/quantified]. Lessons learned were presented for each of these five areas. In a section entitiled "Looking Forward", lessons for the future were provided in the areas of: strategy, systems, standards, sustainability, resilience, responsibility, risk, research and change.

Ref: https://ipet.wes.army.mil/

2007
Report Issued: *The New Orleans Hurricane Protection System: What Went Wrong and Why,* IPET External Review Panel (ASCE), 84 pages

The work of this ASCE panel was reviewed by the National Research Council of the National Academies. The report identifies two direct causes for the levee breaches and seven contributing factors. The panel ". . . strongly urges that organizations responsible for critical life-safety facilities be organized and operated to enable, not to inhibit, a focus on safety . . .". Eight recommendations are made to increase the safety of levees and hurricane protection systems.
Ref: http://www.asce.org/files/pdf/ERPreport.pdf

Other Investigations
Other investigations were also performed, including the *Team Louisiana Forensic Evaluation.* This investigation was performed by the Louisiana State University and sponsored by the Louisiana Department of Transportation and Development.

2005 Taum Sauk Upper Reservoir Failure

December 14, 2005 (Date of failure)

Taum Sauk (Upper) Reservoir is located in Missouri. The dam is part of a pump storage project owned by an investor-owned utility and regulated by FERC. A total of 4300 ac-ft of water was released. The upper dam failed at night from excessive pumping of water into this mountaintop reservoir which caused overtopping and erosion. The loss of life was adverted by chance, although 4 people were injured. The utility paid settlements totaling $195 million.

FERC has a website that includes the main investigation documents at:
http://ferc.gov/industries/hydropower/safety/projects/taum-sauk.asp

Circa December 14, 2005 (Date of failure)

Staff engineers were immediately dispatched to site to ensure the safety of the lower dam and obtain initial information concerning the breach of the upper reservoir embankment dam.

December 15, 2005 (1 day post-failure)

FERC issued a letter to licensee utility directing the utility to submit a detailed report which includes the details of the incident and information needed to assess the cause of the incident and the appropriate remedial action.

December 16, 2005 (2 days post-failure)
Action Plan: *Action Plan for Dam Breach Incident*, FERC

This action plan documents FERC's initial response to the failure, describes overall plan for investigation, identifies teams/panels established or to be established, commits to stakeholder involvement and states that results will be shared with the Interagency Committee on Dam Safety.

December 21, 2005 (1 week post-failure)
News Release: *Commission conducts investigation of Taum Sauk Dam breach,* FERC

The new release explained that there would be two teams investigating the failure: one team is the FERC team of dam safety engineers the other team would be a panel of outside experts working independently. It would be a fact-driven forensic examination to determine what factors contributed to the dam breach. It would be an open and transparent process to learn from the event.

The FERC Chairman stated in the release: "Our investigation will determine the factors that caused this event, and the timing of any conclusion to our investigation will be driven by the facts. We will determine what details must be addressed in order to restore the upper reservoir and ensure the safety of the structures. Until the Commission's investigation is completed, we urge against speculation as to what contributed to this breach."

FERC established an investigative team consisting of 9 members, all from FERC: 5 civil engineers, 1 engineering geologist/security specialist, 1 geotechnical engineer, 1 fisheries biologist, and 1 energy infrastructure and cyber security advisor.

April 7, 2006 (4 months post-failure)
Utility submits their Consultant Report to FERC:
Forensic Investigation and Root Cause Analysis December 15, 2005 Incident Upper Reservoir Dike Taum Sauk Dike Taum Sauk Plan FERC Project No. 2277, 130 pages, 7 appendixes

From the conclusion: "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."

April 26, 2006 (4-1/2 months post failure)
Report Issued: *Report of Findings on the Overtopping and Embankment Breach of the Upper Dam – Taum Sauk Pumped Storage Project,* FERC Taum Sauk Investigation Team FERC No. 2277, 168 pages, 5 appendixes

The executive summary included that the instrumentation/sensor contributions to failure. The dam was operated with little freeboard. The upper reservoir parapet had overtopped previously. There were major problems with the reservoir sensors and instruments.

May 25, 2006 (5 months post-failure)
Report Issued: *Taum Sauk Upper Dam Breach FERC No. P-2277 Technical Reasons for the Breach of December 14, 2005,* Independent Panel of Consultants (IPOC) 36 pages, 3 appendixes

The report concluded, "It is the Panel's opinion that the cause of the December 14, 2005 failure was overtopping of the parapet wall and embankment." And, "…the primary root causes of failure on this particular date were those factors which caused the overtopping to

occur. The secondary root causes or contributing factors are those factors which combined to make this embankment more vulnerable to failure by overtopping."
Factors contributing to overtopping included:

- Pressure transducers became unattached and gave erroneous water level readings
- Emergency backup probes were set above the lowest points along the parapet wall.
- The normal operating high water levels of 1 ft. below the top of the parapet wall was too near the top of the wall to allow for any mistakes of misoperation.
- Visual monitoring of the upper reservoir was almost nonexistent
- There was no overflow spillway

May 25, 2006 (5 months post-failure)
News Release: FERC seeks comment on Independent Panel Report

July 20, 2006 (7 months post-failure)
News Release: *Close of Comment Period for Taum Sauk Independent Panel of Consultants Report,* FERC

Fourteen comments were received and no technical issues were raised.

October 2006 (10 months post-failure)
Agreement Signed: *Stipulation and Consent Agreement,* FERC and Utility, 13 pages and 6 appendixes

The agreement alleged license violations leading up to dam failure. The utility did not admit or deny the allegations and agreed to pay FERC a $10 million penalty, establish a $5 million escrow for enhancements to the project, and agrees to a documented dam safety program

January 9, 2008 (2 years - 1 month post failure)

The utility agreed to pay $180 million in cash and property to compensate the state due to losses related to the dam failure.

2006 Kaloko Dam

March 14, 2006 (Date of failure)

This Hawaiian dam was privately owned and regulated by the state. The dam failed at night after weeks of heavy rain. The spillway may have been altered causing failure. There were 7 deaths, damage to several structures and roads, and environmental damage to land and coral reefs. The dam had been rated as having a low-hazard potential classification.

April 10, 2006 (1 month post-failure)

A citizens group from the island of Kauai launched "DAM MAD", a petition drive for an independent investigation of the dam failure. The group and victim's families believed that the state attorney general, who had the responsibility for investigating the failure, had a conflict of interest.

Circa June 2006 (3 months post-failure)

The Hawaii House of Representatives passed a concurrent resolution "Requesting the state attorney general to appoint a special deputy attorney general to independently and impartially investigate the Kaloko reservoir dam collapse."

August 2006 (6 months post-failure)

The new Hawaii Special Deputy Attorney General (also an engineer) began an independent investigation. He also consulted with three experts from the meteorology, engineering, and the geospatial imaging fields.

January 10, 2007 (10 months post-failure)

Report Issued: *Report of the Independent Civil Investigation of the March 14, 2006, Breach of Ka Loko Dam,* State Special Deputy Attorney General, 216 pages

The investigation objective was to determine culpability of several entities, make legislative recommendations and other recommendations. The investigator traveled to site and interviewed witnesses. Comments were solicited from the public via an Internet web site. He used aerial photos and current and historical satellite imagery. He also developed an animation that showed three dimensionally the dam changes over time. Other states were contacted for how they regulated dams. The report describes the historical context of these types of dams in Hawaii.

The report describes the legal implications of a dam failure investigation.

> *"For all these reasons, the report does not attempt to come to conclusions regarding legal blame. It does not shy away from the facts, however, or from conclusions regarding their significance to the consideration of appropriate government action in the future. An impartial examination of the facts is essential to the investigation's goal of identifying those conditions and practices that may have contributed to the breach of the dam, and the results of the investigations are set out in the findings. The report attempts to set out the most significant of those conditions and practices in its conclusions, and – based upon those conclusions – to make recommendations to minimize the chance of any similar tragedy in the future*." Ref: Page 6

Contributing causes to the failure were: lack of maintenance, a filled-in spillway (probably leading to overtopping), and lack of government dam safety regulation. The existing Hawaii dam safety law/regulations were reviewed and improvements were recommended.

Two engineering firms, the dam owner, and the state are being sued as a result of the failure. A Phase II investigation is being considered.

PART 3: Dam Failure-Related Investigative Requirements of Selected Organizations

The States

The Association of State Dam Safety Officials (ASDSO) model state dam safety program has no requirements for investigation and reporting of dam incidents and failures.

A cursory review of two state dam safety program's statutes and regulations found no requirements for investigation of incidents and failures.

U.S. Army Corps of Engineers (USACE)

Although the USACE has no existing policy or procedure for formally investigating dam failures, it performed an intensive investigation of the New Orleans levee failures.

For dam incidents (or distress), the USACE has implemented regulation ER 1110-2-101 *Reporting of Evidence of Distress of Civil Works Structures*. The purpose is to describe the responsibilities and procedures for the immediate notification to higher authority of evidence of distress or potential failure of civil works projects (in construction or operation). The intent of the regulation is to keep the USACE chain of command informed by ensuring the immediate reporting, inspection and follow up evaluation of conditions that demonstrate evidence of distress or potential hazard. The regulation includes a long list of "distress signals" such as changes in seepage, sandboils, etc. that would warrant notification to higher authorities.

Incidents and equipment-type failures are documented in Engineering and Construction Bulletins which are publicized across the USACE. The bulletins include purpose, background, discussion and guidance. The USACE is increasing the use of these bulletins as a way of promoting awareness of these issues.

Federal Energy Regulatory Commission (FERC)

Project licensees are required to promptly report incidents in writing and verbally. Once an incident is terminated/resolved, the licensee prepares a written report of the incident and provides it to the FERC Regional Office. The report includes an assessment of the efficiency of the response and procedure revisions needed. The report includes:

- Causes of the condition
- Unusual occurrences or operating circumstances preceding the incident
- Measures taken to prevent worsening of the condition
- Description of damages, deaths, injuries
- Status of repair
- Anything else necessary to describe the incident and response

FERC Hydropower Safety Guidelines Section 12.10 Reporting safety-related incidents

An effort is made to coordinate the lessons learned within FERC and with other state/Federal agencies.

The FERC dam safety program also regularly emails staff to disseminate dam incident information.

FERC formally investigates dam failures using FERC staff or consultants. The Taum Sauk Dam and Silver Lake Dam failures were investigated (see previous descriptions); however there are no established failure-related policies or guidelines.

Bureau of Reclamation

Independent investigations of dam incidents and the failure of Teton Dam have been performed. A contractor performed an independent review of the 2006 A-V Watkins Dam near failure incident.

There is currently no policy to perform dam failure or major incident investigations. A recent Dam Safety Program independent review made a recommendation to develop a formal process to investigate, report, review, and evaluate major incidents and failures.

PART 4: Other Industry Approaches

National Transportation Safety Board (NTSB)

The NTSB is an independent Federal agency charged by Congress with investigating and establishing the facts, circumstances, and cause or probable case of civil aircraft, railroad, highway, marine and pipelines accidents. For example, the NTSB investigated the recent Minnesota bridge collapse.

To ensure that NTSB investigations focus only on improving transportation safety, the NTSB's analysis of factual information and its determination of probable cause cannot be entered as evidence in a court of law. The NTSB has priority over any investigation by another department, agency or instrumentality of the United States Government. The results of the investigation are to be made public. The NTSB maintains a database of accidents and conducts special studies of transportation issues of national significance. For air transportation, the NTSB has authority to establish a Special Board of Inquiry into an accident. They have the authority to enter the accident area and "do anything necessary to conduct and investigation." No person, (including a State or political subdivision) may impede the ability of the NTSB to perform the investigation. The accident investigators may test equipment. No attorney may make an unsolicited communication to the NTSB concerning a personal injury or wrongful death before the 45th day following the date of an accident. The NTSB budget in FY2008 was $92,625,000.

At the core of NTSB investigations is the "Go Team." The purpose of the Go Team is simple and effective: begin the investigation of a major accident at the accident scene as quickly as possible, assembling the broad spectrum of technical expertise that is needed to solve complex transportation safety problems.

The team can number from three or four to more than a dozen specialists from the Board's headquarters staff in Washington, D.C., who are assigned on a rotational basis to respond as quickly as possible to the scene of the accident. Go Teams travel by commercial airliner or government aircraft depending on circumstances and availability.

During their time on the "duty" rotation, members must be reachable 24 hours a day by telephone at the office or at home, or by pager. Most Go Team members do not have a suitcase pre-packed because there is no way of knowing whether the accident scene will be in Florida or Alaska, but they do have tools of their trade handy -- carefully selected wrenches, screwdrivers and devices peculiar to their specialty. All carry flashlights, tape recorders, cameras, and lots of extra tape and film.

The Go Team's immediate boss is the Investigator-in-Charge (IIC), a senior investigator with years of NTSB and industry experience. Each investigator is a specialist responsible for a clearly defined portion of the accident investigation. In surface accident investigations, teams are smaller and working groups fewer, but the team technique is the same. Locomotive engineers, signal system specialists and track engineers head working groups at railroad accidents. The specialists at a highway crash include a truck or bus mechanical expert and a highway engineer. The NTSB's weather, human performance and survival factors specialists respond to accidents of all kinds.

At least once daily during the on-scene phase of an investigation, one of the five Members of the Safety Board itself, who accompanies the team, briefs the media on the latest factual information developed by the team. While a career investigator runs the inquiry as IIC,

the NTSB's board member is the primary spokesperson for the investigation. A public affairs officer also maintains contact with the media. Confirmed, factual information is released. There is no speculation over cause.

The individual working groups remain as long as necessary at the accident scene. This varies from a few days to several weeks. Their work continues at Washington headquarters, forming the basis for later analysis and drafting of a proposed report that goes to the Safety Board itself perhaps 12 to 18 months from the date of the accident. Safety recommendations may be issued at any time during the course of an investigation.
Reference: Code of Federal Regulations, Title 49 – Transportation, website: http://www.ntsb.gov/

American Society of Civil Engineering (ASCE)

ASCE has a policy for assisting others in the investigation of the failure of civil structures.[see *http://www.asce.org/pressroom/news/policy_details.cfm?hdlid=6]*

The ASCE will cooperate with federal, state and local government and non-profit organizations in the investigation. Their policy recommends/requires that "… ASCE should execute a formal written agreement concerning the investigative effort to protect all parties involved defining the scope of services and other elements of the engagement."

By participating in these investigations, ASCE helps to fulfill their role in providing expertise and leadership in failure investigations. It also has a role in disseminating technical information on the lessons learned from the failure.

The policy recommends that an initial meeting with the parties be held to discuss the expectations for ASCE's participation. Items in the discussion should include: role of ASCE (peer review, advisory or leadership, to lead an investigation), objectives of the review, access to the site, schedule, deliverables, dissemination of results, and appointment of qualified individuals without conflicts of interest. A fee for services should also be discussed. Following the meeting, an Agreement or Memorandum of Understanding should be executed.

Part 5: Observations and Conclusion

Observations

All of the investigations described had a goal of learning the causes of dam failure. The dam failures in this paper were found to have been caused by one or more environmental, technical or human factors. The combination of these factors can lead to primary and secondary factors. Often there are no witnesses to the failure itself and often substantial evidence can be washed away leading to informed speculation as to the cause of failure.

Unlike the transportation sector, there is no national organization responsible for investigating dam failures. It appears does not appear that most dam safety regulators have established policies and procedures for responding to and investigating dam failures.

There is significant variation in the regulator approaches to investigating the dam failures. Because dam failures are rare and geographically diverse, the regulator may have had little experience in responding to and investigating dam failure events. Some failures resulted in several investigations. The number of people on these investigations and their disciplines varied. The length and content of the reports also varied. The extent of the investigation (and

the media attention) appeared to be proportional to the magnitude of the loss of life and other damages.

Dam failure investigations are often used by courts or the parties themselves to determine damages and cost settlements. The motivations of the regulator, dam owner, and the damaged parties are different. Settlement costs can be very large (hundreds of millions).

Regulators are under a great deal of pressure at the time of failure. These failures receive a great deal of near-real time press coverage. In addition to communicating with the media, the regulator needs to be responding to the unfolding events in the field. Investigations need to be initiated quickly and information collected.

Dam failures can damage the public's confidence in government generally and in the regulator specifically. It is in this potentially charged atmosphere that the regulator responds to the failure and conducts an investigation. Should the public believe that there is any conflict of interest there can be concerns raised in the public and media, leading to further deterioration in confidence.

Strategies for establishing or strengthening the public's trust in the regulator and in the investigation include:

- Communicating with the media and the public very early in the failure event
- Expressing appropriate concern for losses/injuries/loss of life
- Issuing a press release stating that the regulator's objective is to have an open and transparent investigation using experts and fully independent review
- Establishing a web site and posting information, and issuing press releases.
- Structuring the investigation to have either a fully independent investigation or an independent review of the regulator's investigation. The independent team/independent review members should be recognized experts in their field and have no conflicts of interest.
- Holding public hearings and solicit information from the public.
- Allowing for public review of draft documents.

All of these actions could be planned early in the event and documented as an action plan.

Conclusion

Dam failure investigations are challenging. These investigations receive much scrutiny from the public and the press. There are significant technical factors to be considered covering many different technical disciplines. Matters of law are often involved. Consideration of how regulators of past dam failures met these challenges can help us prepare for dam failures in the future.

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