Dam Safety in the (Somewhat) United States

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SYNOPSIS. Dam safety laws for the more than 82,000 dams within the United States are as varied as the states and regions and people of our country. The individual autonomy of states, and their desire to establish their own rule of law, is the driving force behind nearly every aspect of life in the US, including dam safety. Currently, there is no federal law requiring individual states to have dam safety laws. One state, Alabama, has rebuffed efforts to establish these laws and currently has no formal dam safety laws. Even within the federal government there is disagreement with adopting standard dam safety laws. The US Army Corps of Engineers, National Resource Conservation Service, Bureau of Reclamation, Federal Emergency Management Agency, and Federal Energy Regulatory Commission all have their own unique dam safety standards. Determining regulation for an individual dam is a question of ownership, location, and use.

Dam safety regulation can create many conflicting issues. For example, a dam that provides both raw water supply and generates hydropower is regulated by both the individual state and the Federal Energy Regulatory Commission. With 49 states having individual dam safety laws, and the FERC having its own rules, there are 49 different scenarios that must be met for these types of dams. This can be a daunting challenge for any owner or consulting engineer.

This paper will look back at the history of dam safety rules and regulations within the US, discuss its current state, and provide recommendations for its continued improvement.

HISTORY OF DAM SAFETY IN THE US

As compared to the number of years dams have been designed and constructed in the United States, dam safety laws, rules, and regulations have only recently become a recognized area of concern. The first recorded dam failure involving fatalities occurred on 16 May 1874 with the failure of the Mill River Dam located at Williamsburg, Massachusetts. This failure, and the resulting flood, killed 139 people. Since then there have been over

150 notable dam failures, which have directly or indirectly caused the deaths of over 5,000 individuals.

Dam safety in the US has improved dramatically since the late 1800s. The following summarizes the number of dam failures and the number of dams constructed by time period in the US (for dams over 50 feet high).

1900 – 1930:	27 of 600 dams failed (1 in 22)
1930 – 1960:	3 of 1050 dams failed (1 in 350)
1960 – present:	3 of 3137 dams failed (1 in 1,046)

Failure modes for these failures can be attributed to these general categories.

One-third:	Overtopping
One-third:	Seepage and piping
One-third:	Foundation and geotechnical issues

NOTABLE US DAM FAILURES

Johnstown Flood (1889)

A contemporary illustration of the broken South Fork Dam from Harper's Weekly.

Figure 1. Artist's Drawing of Breached South Fork Dam

The Johnstown Flood (Johnstown, Pennsylvania) of 1889 was one of the first significant dam failures in the United States and it remains the largest loss of life dam failure, with over 2,200 people perishing as a result of the flood caused by the failure. The Western Reservoir dam was located 14 miles upstream of Johnstown and was owned and maintained by the South Fork Hunting & Fishing Club, whose membership included Andrew Carnegie, Andrew Mellon and many of Pittsburgh's most elite and wealthy individuals. The embankment dam was 72 ft (22m) high and retained approximately 14,700 acre-feet (18Mm³) of water. From its initial construction in 1852, to provide water for local canals, it was poorly maintained. This poor maintenance included the construction of fish screens across the spillway to inhibit fish from being washed out of the reservoir, but which trapped debris and significantly reduced the spillway capacity. The dam was also lowered to permit two carriages to pass each other at the same time, but which also reduced critical freeboard. The difference between the spillway crest and the dam crest at the time of the failure was only four feet. Lastly, and most critically, the original owner of the dam removed the low level outlet works, selling them for scrap metal, and these were never replaced.

The people standing on the rooftops in this striking image are likely sightseers who have come to see the flood destruction.

Fig

On 31 May 1889 a large rain storm moved into the area, dropping between 6" and 10" (150mm to 250mm) of rain in 24 hours, and most people in Johnstown went indoors to wait out the storm. At 3:00 pm the dam overtopped and a 40 ft (12m) high wall of water travelling at 40 mph (65 kph) raced down the valley. When it was over 2,209 people were dead including 99 entire families; 396 children had been killed, 322 lost either their wife or husband, 98 children lost both their parents, and one third of the victims were never identified.

Lawsuits were filed in the aftermath of the tragedy, but even though the dam was privately owned by a club with some of the wealthiest people in the US, these lawsuits were unsuccessful and the failure of the dam was deemed an "Act of God" by the courts.

St. Francis Dam (1928)

The St. Francis Dam was designed and constructed by William Mullholland, a self-taught engineer and general manager of the Los Angeles Department of Water and Power. Mullholland was a visionary and primarily responsible for creating the water supply scheme for Los Angeles which captured water in the Owens Valley, approximately 200 miles (320km) north of Los Angeles, and stored it in reservoirs in and around Southern California. The St. Francis Dam created one of these terminal storage reservoirs.

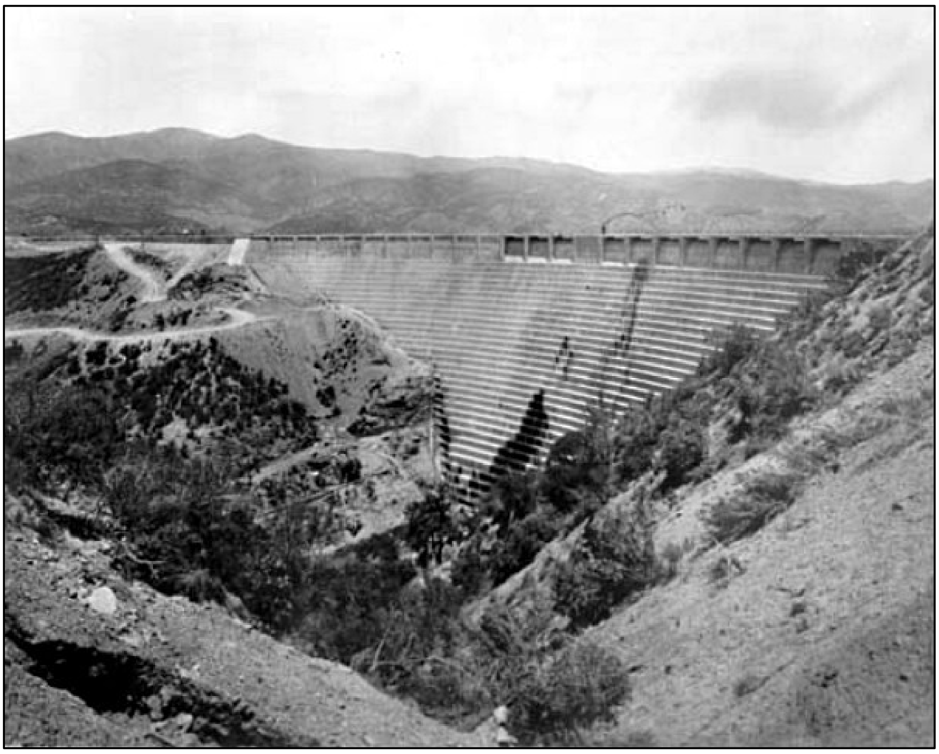

Figure 3. St. Francis Dam Days before Failure

The St. Francis Dam was built on the San Francisquito Creek near present day Santa Clarity, California. The dam, completed in 1926, was an arch-gravity dam 196 ft (60m) high at its maximum section, which stored approximately 32,000 acre-feet (40Mm³) of water. Nearly immediately after its completion it began to have problems in the form of a large cracks and seeps, which were visible on the downstream face of the dam. These issues were inspected and immediately denounced by Mullholland as being minor and having no negative impact on the safety of the dam. The reservoir was completely filled on 7 March 1928. Nearly at the same time, a road near the east (left) abutment began to show significant signs of settlement.

Figure 4. St. Francis Dam Immediately After Failure

Figure 5. St. Francis Dam Left Abutment

By 12 March portions of this road had settled as much as a foot. Also on 12 March the dam tender again called Mullholland to inspect a new leak that had developed and once again Mullholland pronounced the dam safe. Just before midnight on 12 March the St. Francis Dam failed. The resulting flood wave killed approximately 500 people, many of them itinerant individuals and families that lived in inexpensive housing along the Santa Clara River, a tributary of San Francisquito Creek.

The failure of the St. Francis dam ruined Mullholland both personally and professionally, and he took sole responsibility for the disaster. In the aftermath of the failure he never fully recovered and died in 1935, at the age of 79, a broken man. However, one positive aspect of the failure occurred in the formation of the California Division of Safety of Dams (DSOD), which is today considered one of the leading state dam safety agencies in the US.

<u>Teton Dam (1976)</u>

The Teton Dam was located on the Teton River in rural Idaho, near the town of Rexburg, Idaho. The dam was designed and constructed by the Bureau of Reclamation. The Teton Dam was 305 ft (93m) high, was a zoned embankment dam, and stored approximately 230,000 acre-feet (284Mm^3) of water. The rock at the dam site was predominately rhyolitic tuff, which was formed from ancient volcanic ash flows. This material was highly fractured and quite permeable in places and to address these issues an extensive grouting program and deep and narrow cut-off trench were designed.

Figure 6. Teton Dam Days Before Failure

Figure 7. Right Abutment Seepage One Hour Before Failure

Initial filling of the dam began in the Spring of 1976 before the spillway and outlet works were completed and fully operational. Idaho is in an arid climate and there was pressure to store spring runoff water for the upcoming irrigation season, with the reservoir rising at a rate of approximately four feet (1.2m) per day. Even with the outlet works and gated emergency spillway being non-operational, the reservoir was near the normal maximum pool elevation on 3 June when the first small seeps near the downstream toe and right groin area of the dam first appeared. These seeps were small, approximately 2 cfs (55 l/s), and were not considered problematic. At 7:30 a.m. on 5 June these seeps had increased and the water was very muddy, however engineers on site were still not concerned. At 9:30 a.m. a seep on the downstream face of the dam began producing water at a rate of 20 to 30 cfs (0.55m^3/s to 85m^3/s) and two bulldozers were dispatched to try and fill a sinkhole that had formed. By 10:30 a whirlpool was observed in the reservoir, the bulldozers were withdrawn and the order was given to evacuate as many people as possible downstream. At noon the Teton Dam failed and it took only 6 hours to completely drain the reservoir. Because the disaster occurred during the day, the death toll was minimized and only 11 people died. The population impacted by the flood was estimated to be around 10,000 and, had the failure occurred at night, it is believed the majority of these people would have been killed.

Figure 8. Teton Dam Minutes After Full Breach

The cause of the Teton Dam failure is still debated. Initially it was believed the core material, a loess with collapsible properties, fractured due to concentrated seepage forces moving through the fractured bedrock. This in turn caused an internal erosion, or piping, failure of the embankment. Recent analyses have evaluated the possibility of arching within the core material of the deep cutoff trench on the right abutment that created areas of low density soils. Similar to the initial fracturing theory, these low density soils were unable to resist the high seepage forces, which resulting in a piping failure.

As a result of this failure, the Bureau of Reclamation created one of the most rigorous and comprehensive dam safety programs in the US. This program includes the Safety and Evaluation of Existing Dams (SEED), the Potential Failure Mode Analysis (PFMA) process, and the Comprehensive Facility Review (CFR) process. This risk based program performs a thorough evaluation of each Reclamation dam every six years. Decisions on making changes or upgrades to dams are made after performing a complicated and thorough risk analysis evaluating the likelihood of the loss of life of the population at risk downstream of the dam. Any loss of life risk greater than 1 in 10,000 per year triggers action by the Bureau of Reclamation.

It was not until the 1960s and 70s that dam safety rules and regulations began to be established. These laws were enacted at both the individual state and the Federal levels. The first Federal law was the 1972 National Dam Inspection Act, which tasked the Corps of Engineers with regularly inspecting the dams under their control, as well as establishing a national inventory of dams. In 1989 this responsibility was transferred to the Federal Emergency Management Agency (FEMA). It is important to note that while the Corps of Engineer and FEMA maintain this inventory of dams, they have no authority for regulation for the majority of dams within the US. The responsibility for regulating and ensuring dam safety within the US rests predominately with each individual state.

Taum Sauk Dam (2005)

The upper dam of the Taum Sauk pumped storage hydroelectric project was built as an asphalt-faced rockfill dam in the early 1960s. In the early morning hours of 14 December 2005 (at approximately 5:20 a.m.) the upper dam of the Taum Sauk pumped storage project was breached due to overfilling. The dam had no spillway. The entire reservoir (approximately

Figure 9. Taum Sauk Dam Before Failure

5,400 acre-feet (6.7Mm³) of water) emptied in 30 minutes. A 20 ft (6m) high wall of water rushed down the mountainside and obliterated the home of Jerry Toops, the caretaker for the Johnson's Shut-Ins State Park, approximately 2 miles (3km) from the dam. Mr. Toops, his wife, and their three children were swept downstream by the flood but survived by managing to grab onto the branches of trees inundated by the flood and remain there until the floodwaters subsided. The Toops attribute their survival to their infant child. Mrs. Toops was awakened by their crying infant only minutes before the flood hit their house and she was able to awaken the entire family just as the flood hit.

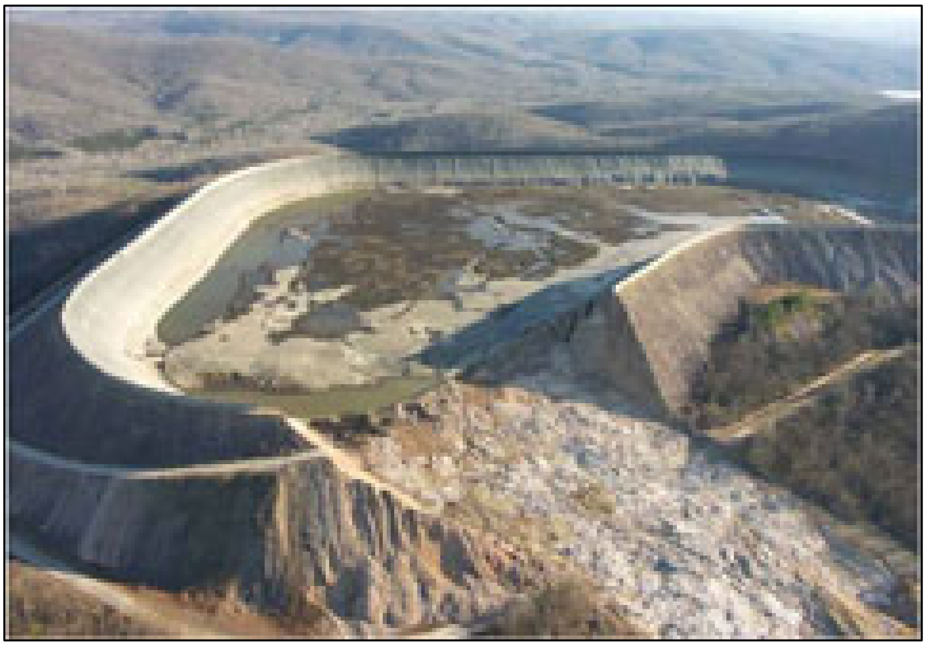

Figure 10. Taum Sauk Dam Break Immediately After Failure

The failure of the dam was attributed to a faulty water level sensor that had become dislodged from its location at the inlet/outlet pipe used to drain and fill the reservoir. The operators viewed the data from the dislodged water level sensor as they filled the reservoir, which showed the reservoir to be well below the maximum normal pool elevation even as it was overtopping the embankment. A roller compacted concrete dam is being constructed as a replacement dam and is nearly completed. The costs of the new dam are in the range of US$400 million.

DESCRIPTION OF DAMS IN THE US

According to the National Inventory of Dams (NID) there are 82,642 dams that are currently regularly monitored and inspected within the United States and Puerto Rico. Of these, only 4% of these dams are federally owned and regulated. Dam ownership within the US breaks out as follows:

Federal	4%	Public Utility	2%
State	5%	Private	65%
Local Government	20%	Unknown	4%

The majority of these dams are considered low hazard dams, meaning their failure would not likely result in loss of life. The hazard classification of these dams breaks out as follows:

High:	14%
Significant:	16%
Low:	70%

Most of these dams were constructed after 1950, which is considered the start of the modern era of dam design and construction. While in many cases construction documentation is unknown, the era of construction of the dams where data exist breaks out as follows:

Pre-1900:	2,503
1900 to 1950:	16,584
1950 to 1990:	50,350
Since 1990:	6,015

DESCRIPTION OF SOME FEDERAL DAM SAFETY REGULATING AGENCIES

<u>USACE (Flood Control and Navigation)</u>

US Army Corps of Engineers

The US Army Corps of Engineers is the oldest engineering organization in the US. It was established in 1802 to support both military and civil works, with the early years of the Corps spend developing coastal structures, lighthouses and water navigation channels. These activities continued until the late 1800s and early 1900s, when increased waterway navigation and hydropower generation began to rapidly expand. The Corps took an active role in this expansion, and designed and constructed lock and dam projects throughout the eastern portion of the US. Nearly simultaneously the need for effective flood control also became a large issue and the Corps again took a leadership role with the design and construction of flood control dams. These functions continue to this day. The Corps is organized as regional districts as well as nationally; however individual project decisions are made at the district level. Today the Corps is responsible for maintaining 569 dams.

<u>Bureau of Reclamation (Water development and power generation in the Western US)</u>

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

The Bureau of Reclamation was created to develop water, mainly irrigation water, throughout the Western US. Reclamation, as it is commonly called, was formed in 1902 to “reclaim” the lands of the Western US through irrigation projects. Since this time they constructed over 600 dams and currently operate and maintain 476 dams, 348 reservoirs, and 58 hydropower facilities. These facilities are used by over 140,000 farmers to irrigate over 10 million acres of land. Reclamation also produces 17 percent of the hydropower in the US.

The failure of Teton Dam in 1976 helped establish one of the best dam safety groups of any organization in the US. This risk based programme involves regular inspections for safety deficiencies, analyses the use of current technologies and designs, and corrective actions if needed based on current engineering practices and risk evaluations. This is primarily done through the Safety Evaluation of Existing Dams (SEED) program, which consists of regular on site inspections of each dam, a review of the downstream population at risk and any changes to that population that may have occurred after the last inspection, any changes within the engineering practice (e.g. flood hydrology or seismically induced ground motions), and then to quickly evaluate whether or not corrective measures are required. Typically, any loss of life risk greater than a 1 in 10,000 per year is considered justifiable to undertaking corrective action.

Federal Energy Regulatory Commission (Energy production)

The Federal Energy Regulatory Commission (FERC) regulates all power generation activities within the US, including hydropower dams. Dam owners licensed to own and operate hydropower dams must comply with all FERC safety regulations. The predominate means for FERC to regularly inspect dams is through regular Part 12 inspections, which include a Potential Failure Mode Analysis (PFMA) procedures pioneered by the Bureau of Reclamation in the aftermath of the Teton Dam failure. Part 12 inspections are performed by an engineer who has been previously approved by FERC. Until recently it was common for the same engineer to lead these regular inspections; however FERC recently adopted rules prohibiting an individual engineer from performing the Part 12 inspections more than twice for the same dam. The Silver Lake Dam spillway failure in 2003 and the Taum Sauk Dam failure in 2005, both regulated by FERC, underscored the tremendous importance of vigorous dam safety practices and inspections. FERC inspects and regulates 3,036 dams. Over 2,000 of these dams are older than 50 years old.

Natural Resource Conservation Service (Rural water development and flood control)

The Natural Resource Conservation Service's (NRCS) natural resources conservation programs help communities reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters. Regarding dams, the NRCS has historically been tasked with creating reservoir and flood control projects in small communities, rural and agrarian areas with limited financial resources. However, as communities have grown and converted farmland into residential housing complexes, NRCS dams have recently become more visible role. The NRCS typically become involved in a dam project as a financial partner with a community or organization, bringing with them their own specific design and dam safety standards. At the completion of construction the ownership and operation and maintenance of individual dams is typically turned over to the project sponsor. Safety regulation and regular inspections then become the responsibility of the individual state. The NRCS is organized as both individual state agencies, as well as national headquarters, which is responsible for overall oversight and funding of projects. The NRCS has helped design and build over 11,000 dams in 47 states since 1948.

In all, 18 Federal agencies are involved in one way or the other in the regulation of dams within the US and Puerto Rico.

INDIVIDUAL STATES

With roughly 95% of the dams in the US non-Federally regulated the dam safety movement within the US has been primarily championed by individual states. As previously discussed, 49 of the 50 states have adopted dam safety rules and regulations, with Alabama being the only state without a formal dam safety program. In the mid-1980s the leaders of several states with active dam safety programs formed the Association of State Dam Safety Officials (ASDSO) that serves to promote dam safety at the state and Federal levels.

ASDSO has compiled dam safety data from all states with dam safety programs and it is estimated that, of the 82,000 dams regulated at the state level, nearly 4,100 are considered deficient in some form. Approximately 45% of these dams are high hazard, meaning there is a high probability for loss of life in the event of a failure. To date only 341, a small fraction of the number of deficient dams, have been remediated or improved.

SUMMARY

Dam safety in the US will continue to be a challenge. There has been, and will continue to be, a great deal of support for individual states to establish their own rules and regulations, and laws. This attitude remains especially prevalent in the Western US, where a majority of the large dams and water projects are located.

Consulting engineers are regularly asked to work on a wide range of dams that can have anything from stringent regulation, with prescribed rules and procedures, to dams that have little to no regulation. Further complicating this issue is the possibility of more than one regulatory agency becoming involved in an individual project. It is not uncommon to be working simultaneously with FERC and an individual state dam safety program on the same project because the dam provides both municipal water and hydropower.

Looking forward, it is unlikely for this scenario to change drastically in the future.

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