FAMOUS FAILURES: REVISITING MAJOR DAM CATASTROPHES

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Failure of a dam is something we hope never happens. But if a failure occurs, it's important to study the circumstances in order to expand our knowledge base, and then apply what we learn to other structures. Today's dams, in most instances, are carefully designed, constructed, operated, maintained, and monitored by competent engineers. Yet, we still have much to learn from the past. Most people would agree that for every dam failure, there are many lessons to be learned.

In order to identify some of these lessons learned, Hydro Review has researched some famous dam failures, and gathered information regarding the circumstances around the failures and the theories that abound on their cause. This paper highlights a few of these famous failures:

-- Teton Dam;
-- Baldwin Hills Dam and Reservoir; and
-- Buffalo Creek Dam.

Historically, 216 significant dam failures have occurred throughout the world, according to data from the International Commission on Large Dams. Of these, only 54 were total failures, like Teton. The other 162 failures caused major structural damage, but the dams were successfully repaired and placed back into operation.

Teton Dam

One of the most publicized dam failures in recent history was the dam break at the Bureau of Reclamation's Teton Dam project in Idaho on June 5, 1976. Teton Dam on the Teton River, 3 miles northeast of Newdale, Idaho, failed during initial filling of the reservoir. A large leak near the right abutment in the dam -- about 130 feet below the crest -- washed away the embankment and caused the dam breach. Deaths of 11 people were reported, with property damage of about $400 million.

Teton Dam was a zoned earthfill dam with a low-permeability central core. It rose 405 feet above its foundation and 305 feet above the riverbed, and was about 3,000 feet long. It would have formed a 288,250 acre-foot reservoir. The spillway was a gated chute structure on the right abutment. Low-level reservoir releases were to be controlled by a river outlet works in the left abutment and by an auxiliary outlet works in the right abutment, with maximum capacities of 3,300 cubic feet per second (cfs) and 850 cfs, respectively.

An Account of the Failure

By March 1, 1976, the reservoir water surface was at Elevation 5164.7 and the auxiliary outlet works was discharging nearly 300 cfs. The reservoir water surface was rising approximately 2-1/2 inches a day. On March 23, the allowable per-day filling rate was increased to 2 feet -- runoff from the Teton River was abnormally high and Reclamation wanted to fill the reservoir so that the water could be used for irrigation that summer. From May 11 through June 5, the average rate of water rise was 3 feet per day.

Prior to June 3, no seepage conditions of any type were noted upstream or on the downstream face of the dam. On June 3, two small spring areas leaking clear water at approximately 40 and 60 gallons per minute developed on the right abutment. The next day, another small spring developed 150 feet downstream from the toe of the dam on the right abutment. Workers examined the abutments and downstream face of the dam and found no other seepage conditions.

On the morning of June 5, though, 20 to 30 cfs of water was flowing from the right abutment rock near the toe of the dam and above the embankment-abutment contact. In about an hour, the flow from the leak had doubled, and another leak from the rock of the right abutment, approximately 130 feet below the crest of the dam, had developed. Several minutes later, a wet spot developed on the downstream face of the dam, which rapidly developed into seepage. Workers operating dozers tried to push material into this hole, but the larger of the two machines began sliding into the hole! By 11:30 a.m., both dozers were lost in the eroded embankment hole. The crest of the embankment fell into the water at 11:55 a.m., and the dam was breached 11:57 a.m. -- only about two hours after the first embankment seepage was observed.

The reservoir contained 251,000 acre-feet of water. When the dam was breached, a wall of water surged through the opening. The reservoir was essentially emptied in five hours. About 40 percent of the dam embankment was lost, and the powerhouse and warehouse structures were completely submerged in debris.

Investigating the Failure

The Secretary of the U.S. Department of Interior and the Governor of Idaho appointed an independent panel of experts outside the government to review the cause of the dam's collapse. A review group representing federal agencies conducted a separate review.

During their intensive investigations, these groups concluded that the failure was caused by a combination of geologic factors and design decisions that did not adequately take these factors into account. The primary geologic factor that caused problems was the existence of numerous open joints in the abutment rocks. The material used for the embankment core, because it was available, was a highly erodible windblown silt. The engineering of the dam did not adequately take these factors into account and, as a result, water was able to seep under the dam at its right abutment and wash it out at that point, causing the disaster. Specific design deficiencies include:

-- Complete dependence for seepage control on a combination of deep key trenches filled with windblown soils and a grout curtain;

-- Geometric configuration for the key trench that encouraged arching, cracking, and hydraulic fracturing in the brittle and erodible backfill;

-- Reliance on special compaction of the impervious materials as the only protection against piping of materials into open joints; and

-- Inadequate provisions for collection and safe discharge of seepage, which inevitably would occur through the foundation rock and cutoff systems.

Baldwin Hills Dam and Reservoir

The Baldwin Hills Dam and Reservoir, atop one of the highest hills in southwest Los Angeles, was completed in 1951. The Los Angeles Department of Water and Power built the reservoir to supply water to the south and southwest sections of the city. The reservoir failed 12 years later, following a sudden displacement in its foundation. Experts in the dam safety community point to the failure at Baldwin Hills as an example of subtle changes that can occur at dams to threaten their safety.

The main dam at Baldwin Hills was 232 feet high and 650 feet long. The reservoir consisted of compacted earth dikes on three sides; the fourth (north) side was closed by the dam. The embankment design required that an impervious reservoir lining and an underdrainage system be installed to ensure that the phreatic line would not rise into the embankments and impair their safety. The lining was comprised of compacted earth, and topped with 3 inches of asphaltic paving.

Three known faults lay under the reservoir. In addition, land subsidence in the vicinity had been in evidence for many years. Possible causes of the earth movements are earthquakes, ground water extraction, oil and gas production, and tectonic activity. Consequently, LADWP undertook design and construction of the project with extreme care, and the completed work had been kept under very close and continuous surveillance from the time it was put into service.

An Account of the Failure

At about 11:15 a.m. on December 14, 1963, during a routine daily inspection, the project's caretaker heard running water in the spillway discharge pipe at the reservoir and subsequently noticed water running freely from the drains under the asphalt-paved bottom of the reservoir. Within 30 minutes, the caretaker and the operating system engineer had opened discharge lines to lower the reservoir level. (It would have taken nearly 24 hours to empty the reservoir.) Anticipating potential danger, the Department of Water Resources asked police to institute an evacuation procedure. By 3:20 p.m., about 1,600 people had left the area.

Soon after the reservoir began to drain, muddy water was discovered emerging downstream from the east abutment of the dam. Workers attempting to control the outflow tried to clear debris from the inlets to the storm drain system, examined the inspection chamber under the reservoir, and hung by ropes on the upstream face of the dam -- all to no avail. At 3:38 p.m., a huge gush of water blew mud and debris through the lower face of the dam, and poured down the steep ravine leading to a residential street about 900 feet away. In a little over an hour, the reservoir was empty. Only then could a crack in the asphaltic lining extending all the way across the bottom of the reservoir could be seen.

In the resulting flood, five people died and 41 homes were destroyed (nearly 1,000 more were damaged). Had it not been for LADWP's recognition of the danger, more lives would have been lost.

Investigating the Failure

In its investigation, the State Engineering Board of Inquiry determined that the rupture of the reservoir lining -- which ultimately caused the collapse -- was the result of slow earth movement, concentrated at one of the fault lines. This rupture allowed water to escape into the loose partially consolidated sandy soil under the reservoir and the dam. According to Robert Jansen, a premiere consulting civil engineer, the foundation of the reservoir had been subjected to progressive horizontal stretching, concentrated at the steep fault planes in the soft rock. The foundation blocks under the reservoir literally tended to pull apart and drop down in a staircase, and then rebound. This action formed gaps between the blocks that became ready conduits for leakage once the lining was destroyed.

Buffalo Creek Dam

Buffalo Creek in West Virginia flooded on February 26, 1972, after heavy rains in the area, causing the collapse of Buffalo Creek Dam. This flood was one of three major ones that occurred in '72, sometimes referred to as the "year of the floods." The collapse of this dam spewed 132 million gallons of mixed sludge and water into Buffalo Creek

Valley, killing 125 people and destroying the town of Saunders as well as all or parts of 16 other small communities or mining camps in southeastern West Virginia, about 40 miles from Charleston.

Buffalo Creek Dam was one of a non-engineered series of three embankments of coal-mine waste, which had accumulated over 25 years. The reservoirs behind the embankments served as settling basins for waste water from the mining operations. The uppermost and newest embankment, erected in the soft sediment of the next lowest settling basin, was about 44 feet high and 500 feet long. It had no spillway or outlet works at all except a 24-inch steel overflow pipe. This pipe was installed only a few months before the embankment collapsed.

An Account of the Failure

Heavy rain had fallen during the three days before the failure, and consequently, water in the reservoir had risen. Four hours before the collapse, the water level was within a foot of the crest. Early on the morning of February 26, water rose onto the crest and washed through waste that had been previously dumped. The mining company reportedly considered excavating an emergency spillway, but that never occurred. Longitudinal cracks soon appeared in the soggy fill; the crest dropped and accelerated the overflow. The dam broke at 8 a.m. About 400 acre-feet of sludge and water was discharged within 15 minutes. During the next three hours, a flood wave estimated as high as 20 feet moved down the valley, leaving 4,000 people homeless.

Occasional slips and breaks had occurred in the embankments. A year before the failure, a mining company worker said that he had seen black water coming up from the bottom of the middle pool, indicating leakage through or under the uppermost dam.

Investigating the Failure

When federal inspectors visited Buffalo Creek Dam six years before it failed, they indicated that the three embankments were in poor condition. The washout of the uppermost embankment was the result of a staircase of poorly built embankments, with the upper two founded on the soft sediment in the settling basins.

West Virginia was not the only state in the U.S. to experience devastating floods in 1972. Altogether, floods in 13 states resulted in casualties and property damage that year. However, studies conducted afterward have contributed to an improved understanding of the potential disasters.

A Lesson behind Every Failure

Statistics covering dam failures and the causes of these failures have been gathered and quoted by several different authors. One of the best sources of dam failure data is the International Commission on Large Dams.

Based on studies of past dam failures, many in the dam safety community contend that there is a relationship between failure, and the age, height, and date of construction of a civil structure. For example, most failures have occurred in dams less than ten years old. Among failures occurring in the first ten years, a large percentage occurred in the first year of operation. Also, the greatest number of recorded dam failures have occurred at dams less than 20 meters in height. The largest single group of failures occurred in dams between 15 and 20 meters high. Finally, the percentage of dams that have failed has decreased dramatically in the last 40 years -- from 2.3 percent in 1950 to 0.09 percent in 1986.

Although we can learn much from past accidents and reduce the risk of failure, no structure, device, or dam can be built such that operation is foolproof and failure impossible. However, the risk of dam failure can be greatly reduced to well within acceptable limits, provided that current engineering practice is applied during the investigation, design, construction, operation, maintenance, and monitoring phases of the dam.

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