From Fame to Failure: The St. Francis Dam (Part 1)

This Month's History Lesson is the first of two parts, the second to be published in the September issue. In this part, we examine the construction and catastrophic failure of the St. Francis Dam in California. In September, we'll examine the causes and aftermath of the deadly event.

The 1928 Failure of the St. Francis Dam, north of Los Angeles, is one of the greatest civil engineering disasters of the 20th century, both because of its extensive human casualties (more than 400) and because of what seemed to be, at the time, its sheer improbability.

As Henry Petroski, P.E., Dist.M.ASCE, the Aleksandar S. Vesic Professor of Civil Engineering at Duke University, once wrote, the St. Francis Dam used the “latest engineering materials” and was overseen by an engineer “with an impeccable record of success.” (“St. Francis Dam,” American Scientist, March/Apr 2003, Vol. 91, No. 2, pages 114–118.) That engineer was none other than William Mulholland, the self-taught civil engineer who rose from supervising water ditches in frontier Los Angeles to overseeing some of the most colossal waterworks projects the world had ever seen. Mulholland, Los Angeles’s longtime chief engineer and head of its Bureau of Water Works and Supply (BWWS), now the Department of Water and Power, was the “only guy in human history who built the water supply infrastructure ahead of the people,” says J. David Rogers, Ph.D., P.E., PG, CEG, CHG, F.ASCE, a professor and the Hasselmann Chair in Geological Engineering at Missouri University of Science and Technology.

Mulholland had his critics and enemies, but “in the business of holding back vast quantities of water, he had been able to answer their fears,” Petroski wrote. “At least in the minds of those who were in the position to give the go-ahead for such great projects, a concrete dam built by Mulholland would certainly be stronger than the water that pushed against it.”

And that was true—until it wasn’t. Just before midnight on March 12, 1928, one of the most prominent engineers of his day was confronted in the most tragic way imaginable with how easily hubris and complacency can lead to disaster.

The need for, and promise of, water is at the heart of the history and mythos of Los Angeles. As the city grew, it became clear that the Los Angeles River watershed was capable of supporting only about 200,000 people, Petroski wrote. Its leaders faced the choice of limiting growth or finding new water sources. A drought in 1904 raised the issue to “crisis proportions.”

But what if water could be conveyed from the distant Owens Valley, more than 200 mi to the north? Such a distance was unprecedented. “The longest Roman aqueducts were less than 60 miles long, and New York’s Croton Aqueduct was even shorter,” Petroski wrote. But the Owens Lake was more than 3,000 ft higher than Los Angeles, “providing a much greater average gradient than existed in the successful Croton Aqueduct.”

The Los Angeles Aqueduct, which used...
inverted siphons and pressure tunnels to transport water over and through the mountains, was approved with a $23 million bond in 1907. Despite construction setbacks and ongoing enmity from Owens Valley ranchers, who claimed their land was being destroyed as water was siphoned away, the Los Angeles Aqueduct was an unprecedented success, ensuring the survival of the city.

When the project opened in 1913 and this new water started flowing into the city—with Mulholland famously declaring, "There it is. Take it."—water became Los Angeles's manifest destiny.

But the aqueduct, despite all the forward thinking that went into it, was simply no match for the explosive growth of Los Angeles in the early decades of the 20th century. While the aqueduct was being built, between 1902 and 1913, the city's population mushroomed by about 50 percent, from 284,000 to 425,000.

Compounding the population growth were two other factors: the massive cultivation of land in the San Fernando Valley, which increased by 567 percent between 1914 and 1923, and record-low rains in the area between 1918 and 1925, according to Rogers.

By 1922, Mulholland promised to build a reservoir system south of the San Andreas Fault that could store a year's supply of water in case the fault ruptured the Lake Elizabeth Tunnel, the longest in the aqueduct system. "He was fifty years ahead of anyone else," says Rogers. "He was the only civil engineer in the world in 1922 who recognized the threat posed by an active fault crossing a water supply system."

By now Mulholland was in his 60s and was one of California's most influential men, the respect for him no longer confined to engineering circles. "At the time," says Rogers, "he was both the highest-paid public official in California and the most popular person in L.A." Angelenos even wanted him to run for mayor.

The reservoir that he planned at the St. Francis Dam would be the largest of nine reservoirs built or enlarged between 1920 and 1926, according to Rogers. In 1923, Mulholland and his
staff at the BWWS studied the viability of the fateful location of the dam: the San Francisquito Canyon (now roughly 5 mi northeast of the Six Flags Magic Mountain amusement park in Santa Clarita, California). The dam would follow the course of the steepest section of the Los Angeles Aqueduct.

In an essay published as part of a book, Rogers described it this way: "About three miles beyond the south portal of the Elizabeth Lake Tunnel, the aqueduct drops almost 900 feet into upper San Francisquito Canyon at what later became Powerhouse No. 1. The aqueduct’s path then entered a series of tunnels excavated within the Pelona Schist beneath the south slope of the canyon, several hundred feet above the valley floor. At Powerhouse No. 2, the aqueduct drops another 485 feet, again into the floor of San Francisquito Canyon." (The St. Francis Dam Disaster Revisited, “A Man, a Dam and a Disaster: Mulholland and the St. Francis Dam,” Historical Society of Southern California, Ventura County Museum of History and Art, 1995).

The dam to be built there was modeled after another dam under construction, the Weid Canyon Dam, the city’s first concrete dam. “The new dam would also be a stepped concrete gravity-arch structure,” Petroski wrote. “Its downstream face was constructed like a wide set of steps, its material was mass (unreinforced) concrete, and the structural principle by which it held back the water was through its sheer weight pressing down on the ground, aided by an arched plan that took advantage of the water pressure behind it to compress or wedge the dam between the sides of the canyon, which served as abutments.”

The St. Francis Dam was impressive and deeply problematic. And the problems started with Mulholland himself.

"In studying him, [I learned] he was a brilliant construction engineer, a great leader of men, and a very clever problem solver," says Rogers. "But he was also something of a penny-pinching tightwad."

Worse, he wasn’t used to being second-guessed. Nicknamed “The Chief,” Mulholland may have completed everything on time and on budget, “but he didn’t make use of outside expertise to review his agency’s work,” Rogers explains. “Nobody questioned him within the agency at all. ... The old man had the first say and the last say.”

Construction began in 1924. Originally the dam was meant to impound 30,000 acre-ft, but that amount was later increased to 32,000, and ultimately to 38,168. “This increase may have been to account for the inflation in population and yearly water consumption then being experienced,” Rogers says.

To accommodate the larger volume of water, the dam was raised from 175 ft to 205 ft, but critically, its base was not widened to compensate. “This was a potentially dangerous action in a gravity dam, which is a retention structure that derives its stability through simple dead weight to resist the force imposed by the reservoir water,” wrote Rogers. Not widening the base increased the chance that the dam could overturn.

Additionally, there were no contraction joints to “allow concrete to crack in a controlled manner as it cools,” wrote Petroski. “No doubt the arched nature of the dam was expected to close as much as possible any cracks that did develop.”

Furthermore, the dam’s internal drainage was inadequate; there were no cutoff walls or grout curtains to reduce seepage. “These measures [would have reduced] the possibility of water infiltrating under a dam and exerting upward hydrostatic pressure, thus making the structure somewhat buoyant,” wrote Petroski.

Still, the dam was largely deemed a success when it opened in 1926. But even as its reservoir was being filled, the first of four transverse contraction cracks appeared on its downstream face, caused by “the thermal stresses associated with the curing of the mass concrete,” says Rogers.

The cracks revealed another warning sign. The 130,000 cu yd of concrete used to build the dam wasn’t good enough. It was too porous and too light—its average mass density of 140 lb per cubic ft was below the industry standard of 150, making the dam 7 percent lighter than it should have been. “Most concrete has a porosity of half a percent,” says Rogers. “Samples we have tested of the St. Francis Dam exhibit porosity values of 13 percent.”

And Mulholland’s builders used declining troughs, which lift concrete very high and allow it to descend in diagonal, zigzag fashion. It was a common technique at the time but led to an inconsistent mix. “When you have wet concrete sliding down troughs, you get segregation; the fine material with more water moves faster, while the rocky portion of the mix moves slower. You end up with a lot of aggregate segregation,” Rogers explains.

On the morning of March 12, 1928, the dam keeper, Tony Harnischfeger, telephoned Mulholland, reporting that a large new leak had appeared and was discharging dirty water, a sign of a type of internal erosion known as hydraulic piping. But they realized the water was being muddied as it washed over an access road that was being regraded. After two hours, Mulholland, along with his assistant chief engineer and right-hand man, Harvey Van Norman, deemed the dam stable and left the site.

That was the last time Mulholland’s dam was to remain intact.

That very night, at 11:57:30, the dam gave way—the time is known precisely because Southern California Edison’s power lines at the dam failed along with the dam. Harnischfeger and his girlfriend, Leona Johnson, may have been investigating the dam right before it collapsed because Johnson’s body was discovered between the dam and Powerhouse No. 2. Harnischfeger, his 6-year-old son, and Johnson were likely the first victims of the dam failure.

In her book, Rivers in the Desert: William Mulholland and the Inventing of Los Angeles (New York: HarperCollins Publishers, 1993), writer Margaret Leslie Davis described the harrowing experience of engineer Ray Rising, who had been living with his family near Powerhouse No. 2, just 1.5 mi downstream from the dam. She wrote that he awoke to a “deafening roar,” and when he opened the front door of his cottage, he “stared in awe at a seventy-eight-foot wall of water crashing towards him. Rising yelled for his wife and three small children to run for their lives. Before they could escape, the water engulfed the concrete powerhouse and Rising’s adjoining cottage, collapsing the wood-frame house like a box of matchsticks and drag-
ging it along in its chaotic path down the valley. The force of the deluge smashed the power plant into ten-thousand-ton pieces of concrete and carried them along on its wild ride.”

Rising tried to grasp his wife’s arm but failed. “Then he felt himself enveloped in blackness and choking with mud, his lungs filling with water. Tossing him on his back, and then head over heels, stripping his body of all clothing, the raging water propelled him down the valley. Then, miraculously, caught in the swirl of a freakish eddy, Rising managed to grab hold of a section of rooftop, pull himself up on it and ride it spread-eagled until it smashed up against a hillside and hurled him to safety. Through it all, he shouted in vain for his wife and children. Vomiting water and dazed, all he could do was helplessly watch as the ten-story wall of death rolled on.”

Mulholland arrived on the scene and was devastated by the tragedy unfolding around him. “Every stick, stone and nail of the powerhouse, including its adjoining houses, had been demolished,” wrote Davis. In all, 64 of 67 Bureau of Power and Light employees and their families were killed at Powerhouse No. 2. Downstream, 84 of 184 men sleeping at the construction camp drowned.

The Chief helped in the search efforts and directed pilots to survey the damage from the air. One pilot, as Davis recounted, offered this report: “It is just one great scene of devastation.... It stretches clear to the sea. Thousands of people and automobiles are slushing through the mud and debris looking for the dead. Bodies have been washed into the isolated canyons. I saw one alive stuck in the mud to his neck.”

Davis herself noted that the water laid waste to everything in its path, “engulfing automobiles, bridges, locomotives. ... One-hundred-ton blocks of concrete rode the water like rubber ducks. Ranch houses were crushed like eggshells, their cement foundations pulverized. Steel bridges were smashed like tin cans, and acres upon acres of citrus and nut trees were uprooted, their groves wiped clean of all vegetation. When it was over, parts of Ventura County lay under a seventy-foot thick blanket of slimy debris.”

Roads were washed out; rescuers and volunteers struggled through quicksand-like conditions to search for survivors. Pack horses and mules dragged bodies—some of which had been impaled on trees, others crushed between chunks of concrete—to dry land. Some bodies were so disfigured they could not be identified.

Animals were not spared either; many died in the deluge—so many that health officials worried about an outbreak of typhoid—and thousands more livestock had to be slaughtered because they couldn’t be transported through the mud.

The flow of water was amazingly powerful—about 1.7 million cu ft per second at the point at which the dam burst. By the time the flood wave had reached the Pacific Ocean—54 mi away—it was about 5:30 a.m. The path of devastation had grown to 2 mi in width, claimed the lives of at least 450 people, destroyed 8,500 acres of farmland, and caused approximately $15 million in damage (the equivalent of roughly $220 million today). Bodies were recovered from the ocean as far away as the border with Mexico.

It was the beginning of the end of Mulholland’s legendary career. But the subsequent investigation into the causes of the dam’s failure—which will be explored in part 2—had momentous consequences not only for the fate of other major dams, including the Hoover Dam, but for improving civil engineers’ understanding of the forces, both natural and human, that make dams vulnerable to failure.

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