

# **Brief Overview of DAM SAFETY LEGISLATION IN CALIFORNIA**

**J. David Rogers, Ph.D., P.E., P.G.**

**Karl F. Hasselmann Chair in Geological Engineering  
Missouri University of Science & Technology**

# **DAM SAFETY LEGISLATION**

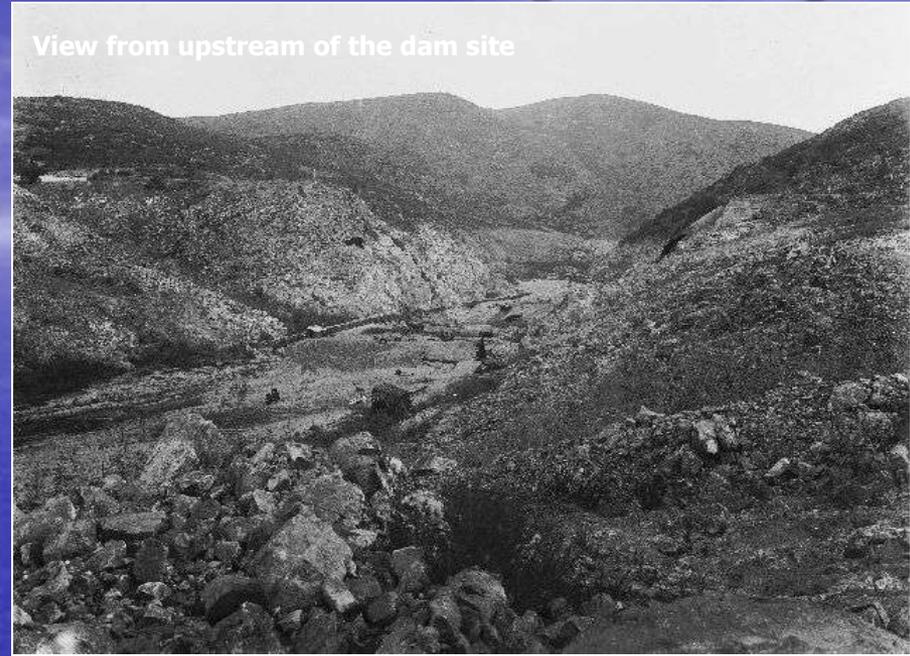
- **In 1915 the State legislature passed a law requiring all plans for dams and reservoirs to be submitted to the State Engineer for approval, but the act provided no penalty for failure to comply.**
- **Following a 2-year study, in August 1916 the State Reclamation Board issued a report recommending that the State Engineer regulate all storage reservoirs.**
- **No further action was taken by the legislature until after January 1916 floods in Southern California**

# FLOOD OF JANUARY 1916



- **Sweetwater Dam** was raised 15 feet in 1910-11, increasing the reservoir capacity by 70% (designed by James D. Schuyler).
- In January 1916, 8 to 20 inches of rain fell on the area, causing a peak discharge of 45,500 cfs for an hour, and an average flow of 20,000 cfs over 24 hours. The dam was overtopped to a depth of 3.66 feet, washing out the south abutment dike (shown here). 8 people were killed by the flooding. We would never build an arch dam in such fractured rock today.

# LOWER OTAY DAM FAILURE (1916)



- On January 27, 1916 the **Lower Otay Reservoir** rose 9.5 ft between 7AM and 5 PM, when the flow began to overtop the dam
- When the overflow reached 3,500 cfs it triggered severe erosion of the dam, causing it to fail within 5 minutes. All of the dam's rock fill was removed within 15 minutes, by 5:20 PM. 40,000 acre-feet of water was released, killing 30 people

# DAM SAFETY ACT OF 1917

Public outcry followed failure of the Lower Otay and Sweetwater Dams in January 1916 in San Diego Co



- The State Engineer was granted authority over all dams > 10 feet high or which impound > 9 acre-ft (3 million gallons), with exception of:
  - Dams for mining debris constructed by the California Debris Commission
  - Dams constructed by municipal corporations maintaining their own engineering departments
  - Dams and reservoirs that are part of water systems regulated by the State's new Public Utilities Act

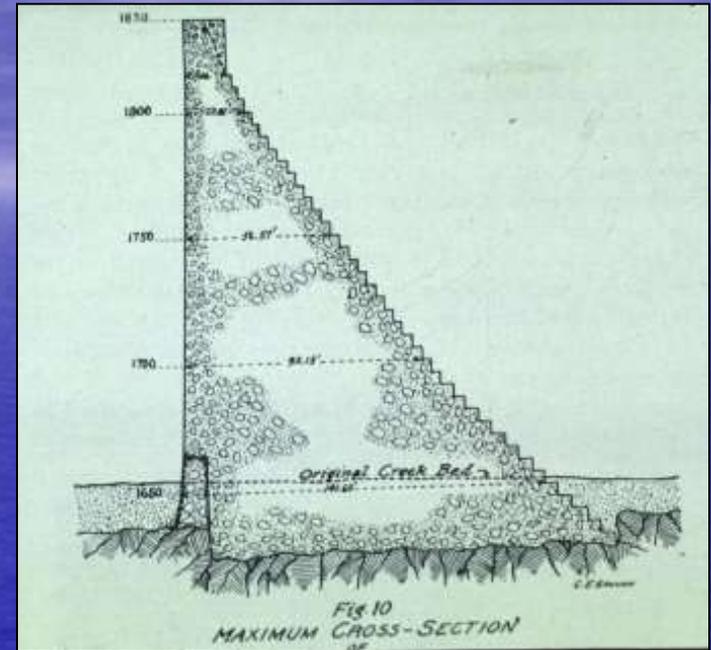
# **State Railroad Commission**

- **The Railroad Commission was given authority over all dams owned by public utilities, beginning in 1917**
- **The commission exercised some oversight on 46 of 140 dams built in California between 1917-1929**
- **Municipal water agencies, such as EBMUD and LACFCD, were exempt from State overview till August 1929**

# DAM SAFETY AUTHORITY BETWEEN 1917-1929

- From 1917-1929 the **State Engineer** was given authority to review plans for dams prepared by irrigation districts, private companies and individuals
- The **State Railroad Commission** was given authority to review dams and reservoirs **owned by public agencies** subject to the 1917 Public Utilities Act.
- In 1920 the **Federal Power Commission** began supervising dams for power projects involving the public domain.

# ST. FRANCIS DAM (1926)



- St. Francis Dam was designed and built by the City of Los Angeles in 1924-26, to contain a year's water supply for the city south of the San Andreas fault
- The dam was designed as a curved concrete gravity dam 185 feet high because there was no clayey material on site to construct an embankment structure

# Inquiries and a demands for justice



- **St. Francis Dam failed catastrophically on March 12/13, 1928. A flood wave 140 ft deep swept down the canyon, killing at least 430 people; of which 179 bodies were never recovered**
- **13 different panels investigated the St Francis failure**
- **Most blamed the failure on hydraulic piping along a ancient fault running beneath the dam's right abutment**
- **The City of Los Angeles paid out \$14 million in damages**

# DAM SAFETY LEGISLATION of August 14, 1929

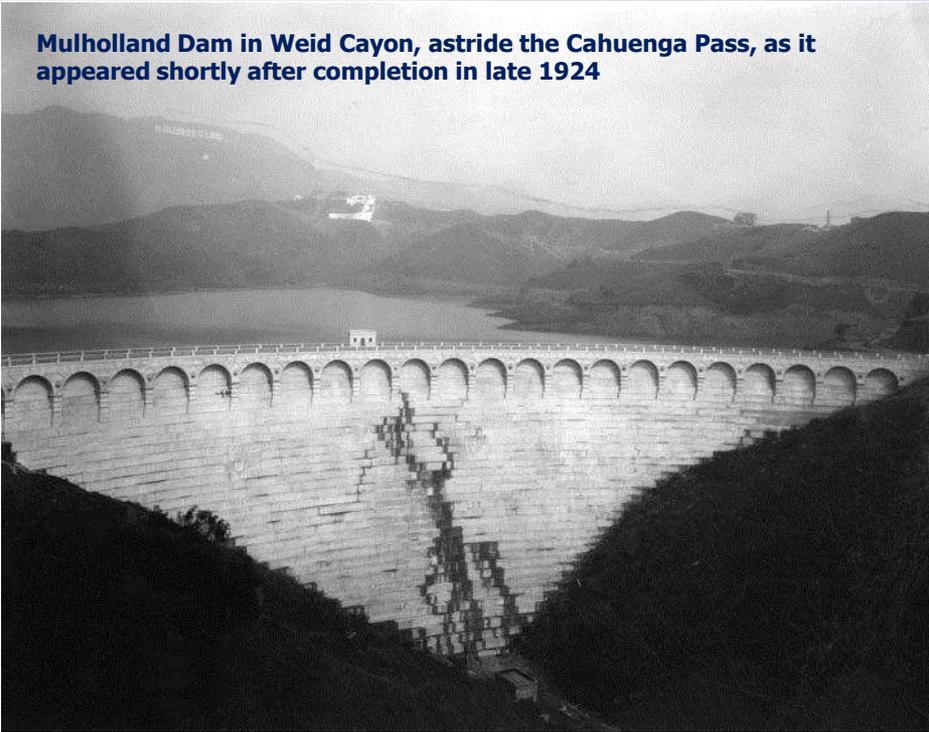
- In the wake of the St. Francis Dam failure, the State Engineer was given authority to review all non-federal dams > 25 feet high or which impound > 50 acre-feet of water
- The legislation allowed the State to employ consultants, as deemed necessary
- The State Engineer was given \$200K and asked to **examine all dams** in the State within three years and issue recommendations.
- The State was given full authority to supervise the maintenance and operation of all **non-federal dams**

# STATE INSPECTION of DAMS 1929-31

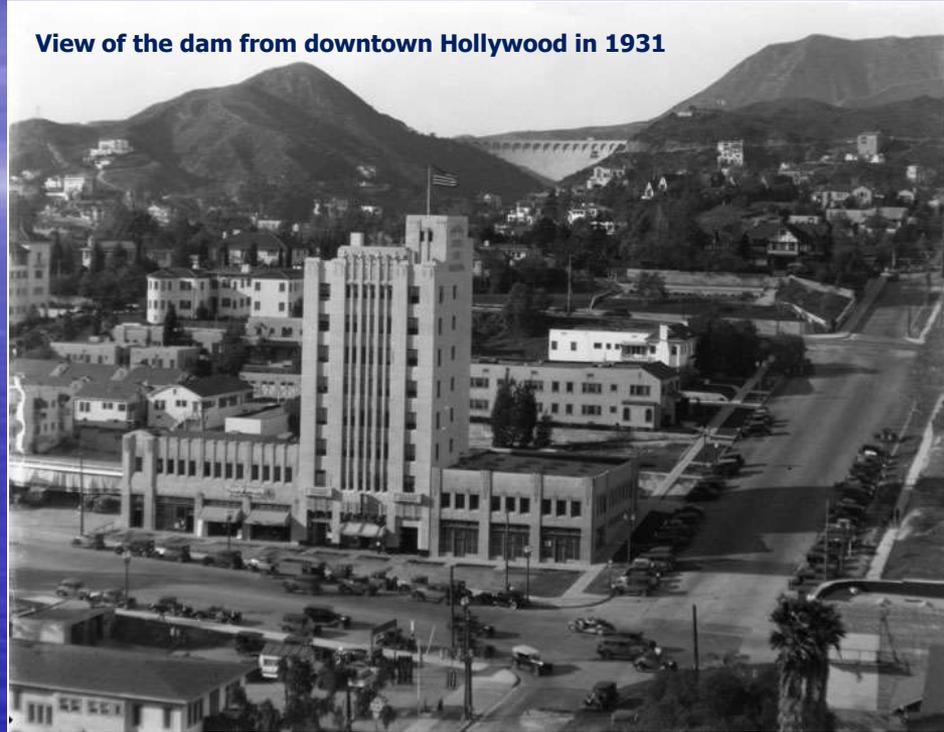
- Between August 1929 and November 1931 the State inspected 827 dams
- **One third** found adequate
- **One third** required further examination, such as borings or subaqueous inspection, before a determination could be made
- **One third** found to be in need of alterations, repairs or changes; frequently involving spillway capacity

# MULHOLLAND DAM DILEMMA

Mulholland Dam in Weid Canyon, astride the Cahuenga Pass, as it appeared shortly after completion in late 1924

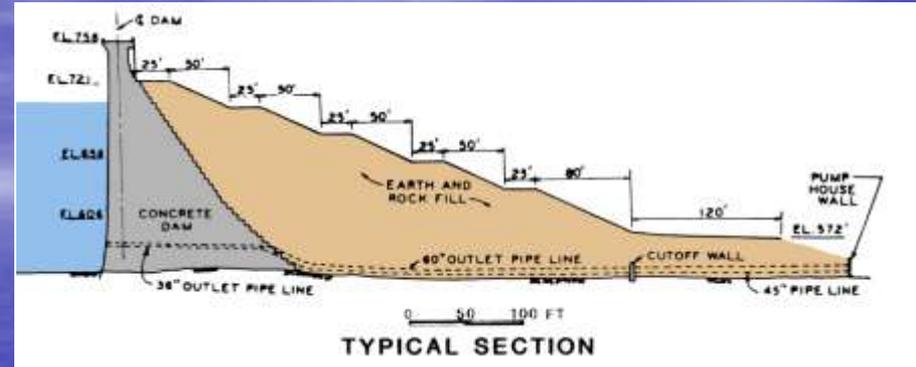


View of the dam from downtown Hollywood in 1931



- **Weid Canyon Dam** was a 195 ft high concrete gravity arch dam built in 1923-24 by the City of Los Angeles, and re-named **Mulholland Dam** when it was dedicated in December 1924, retaining **Hollywood Reservoir**
- It was virtually identical to the ill-fated St Francis Dam, causing the citizens of Hollywood, living beneath the structure (upper right) to clamor for its drainage or removal after the St Francis failure in March 1928
- Between 1928-31 the City appointed three different panels to investigate its stability

# MOST PEER-REVIEWED DAM IN AMERICA



In 1933-34 the City of Los Angeles placed 330,000 yds<sup>3</sup> of fill against the downstream face of Mulholland Dam, making it one of the most conservative dams in the state

Soon after the failure of the St. Francis Dam a **Committee of Engineers & Geologists to Assess Mulholland Dam** was appointed to reviewed the safety of the sister structure to St. Francis. This was followed in January 1930 by the **External Review Panel to evaluate the Mulholland Dam**, convened by the State of California. In March 1930 the City of Los Angeles Board of Water & Power Commissioners appointed their own **Board of Review for Mulholland Dam**. A fourth panel, the **Board of Engineers to Evaluate Mulholland Dam**, was appointed in 1931 to examine the feasibility of abandoning Mulholland Dam. This was followed by an external **Geological Report of the Suitability of Foundations for Mulholland Dam** in late 1931, appointed by the Board of Water & Power Commissioners.

The decision was eventually made to permanently draw down Hollywood Reservoir, from 7437 ac-ft to no more than 4000 ac-ft (the reservoir is usually maintained around 2800 ac-ft), and to place an enormous buttress fill in lower Weid Canyon, to bolster the dam's resistance against hydraulic uplift and earthquake forces, and screen it from public view. This work was carried out in 1933-34, shown above left.

# Out of sight, *out of mind....*

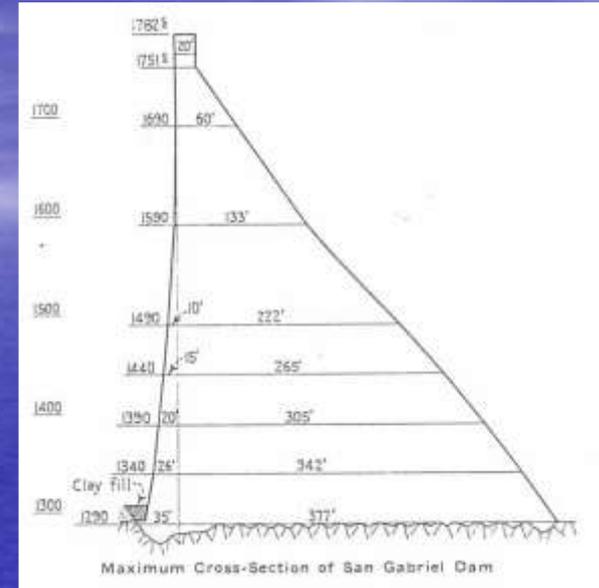
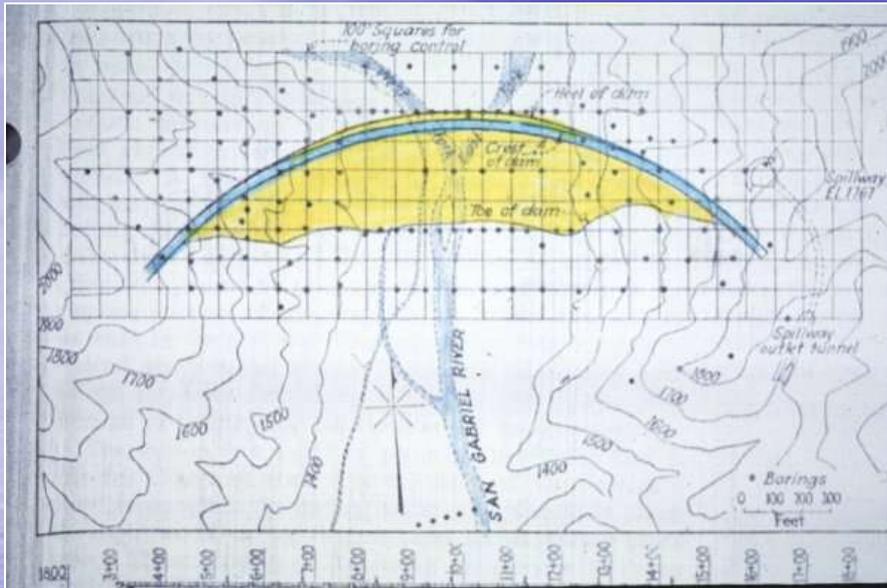


LADWP undertook a vigorous program of re-vegetation on the new buttress fill (lower left), which succeeded in screening the dam from most everyone's consciousness

# 6-Year Program of Dam Safety Inspection 1931-36

- In July 1936 the **second series** of inspections were concluded by the State
- **950 dams** were inspected; with **588** of these dams being under the State's jurisdiction
- **One third** of these dams were found in need of repairs
- New dam construction was under State observance from August 1929 forward.

# SAN GABRIEL DAM at THE FORKS

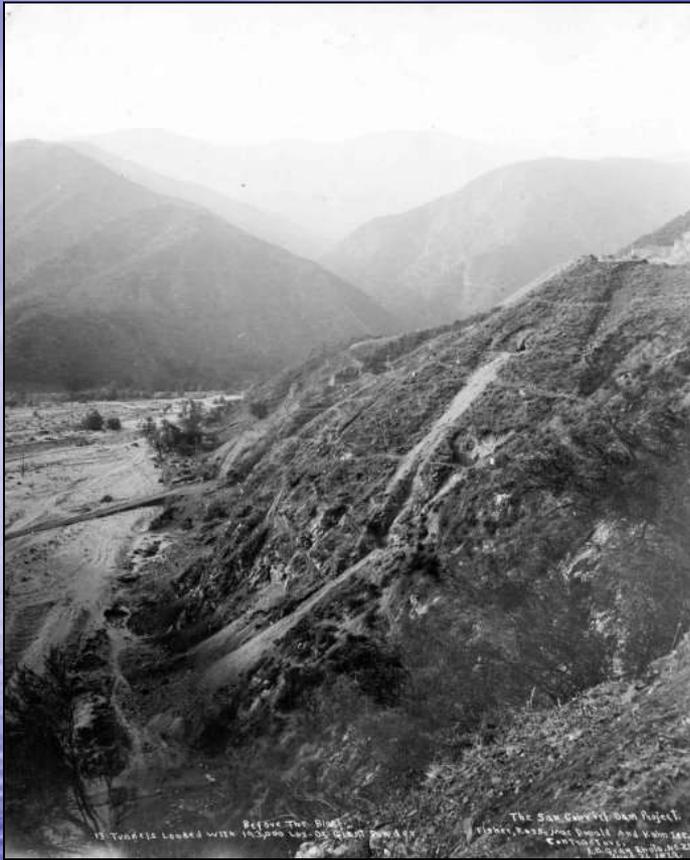


- A \$26 million bond was approved by voters in LA Co in 1924 for construction of flood control structures
- The kingpin feature of this program was the **San Gabriel Dam**, a concrete gravity arch dam 512 feet high and 2,500 ft long, with volume of 3.8 million yds<sup>3</sup>
- When designed in 1927-28 it was the highest and largest concrete dam ever conceived

# 700,000 yds<sup>3</sup> of abutment excavation



- Construction began in Sept. 1928, 6 months after the St Francis failure. A rail line and contractors village for 500 men was built by the dam site (left view)
- By February 1929, abutment stripping began, removing 100,000 yds<sup>3</sup> per month (right view)



- On June 26, 1929 the contractor detonated 193,000 lbs of Giant Powder, distributed in 13 “coyote tunnels” excavated into the right abutment, bringing down 160,000 yds<sup>3</sup> of rock
- On September 16, 1929 a massive landslide occurred in the same area, involving 200,000 yds<sup>3</sup> of additional rock debris

# FIRST PROJECT CANCELLED BY THE STATE

- Acting under newly legislated authority in August 1929, the State Engineer convened an independent inquiry of the problems at San Gabriel Dam in early November 1929
- The panel included Jack Savage, George Elliot, M.C. Hinterlider, George Louderback, Ira Williams and Charles Berkey
- On Nov 26<sup>th</sup> the panel issued a report stating that the proposed dam “cannot be constructed without creating a menace to life and property”
- As a supplemental suggestion, the board recommended an earth and rockfill dam of “conservative design” might be employed in San Gabriel Canyon
- LACFCD subsequently built a record height rockfill dam one mile downstream, in 1934-38

# ELECTED OFFICIAL SENT TO JAIL

- After the County rescinded their construction contract on Dec 8, 1929, the contractor filed a lawsuit to recover damages for breach of contract, claiming 773,646 yds<sup>3</sup> had been excavated
- A Grand Jury was appointed in Feb 1930 to investigate the validity of the claims, finding that 83,433 yds<sup>3</sup> were outside the "pay line"
- Nevertheless, the contractor was paid an additional \$831K in 1930, for "additional excavation" at \$2.95 per yd<sup>3</sup> (they were paid \$1.85 million in total)
- In the summer of 1933 former County Supervisor Sydney T. Graves was found guilty of accepting a \$80,000 bribe from the contractor to hasten the boards approval of their claims

# LIVE NEWS COVERAGE



KTLA Channel 5 employed the world's first television-equipped news helicopters. Their live coverage helped publicize the evacuations ordered by the Los Angeles Police Department.



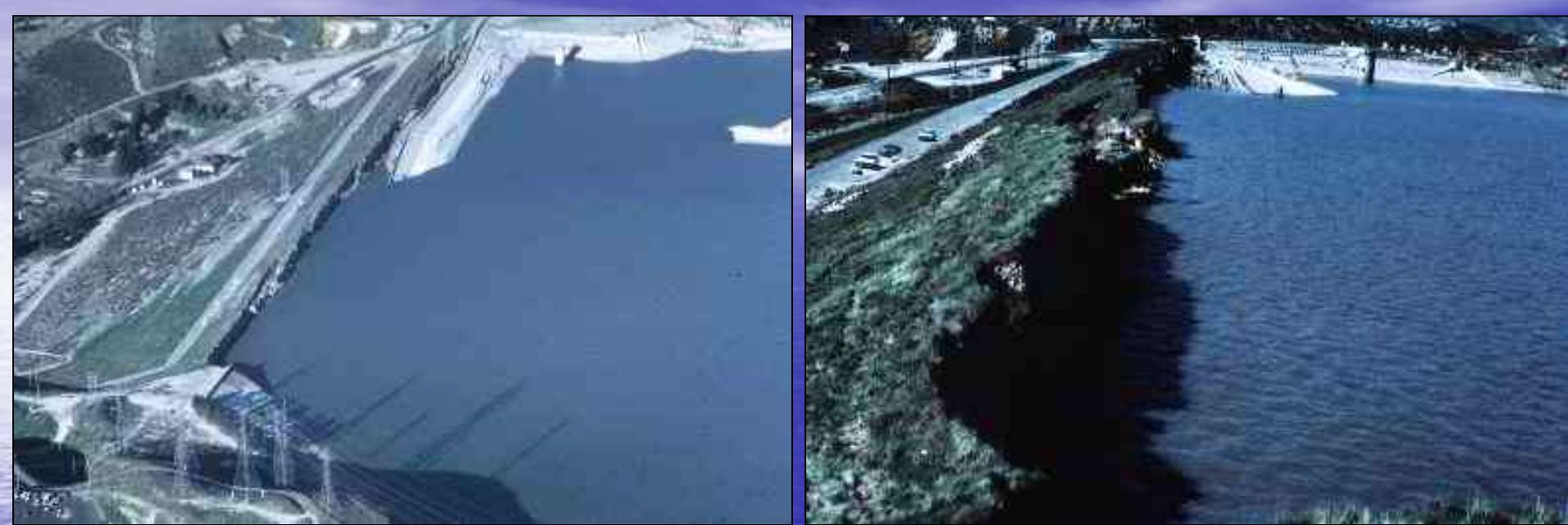
- Public outcry was enlivened by the real time simulcasting of the entire event, beginning around 12:30 PM.

# Public Outcry stimulates political reaction

## DAM SAFETY LEGISLATION of September 17, 1965

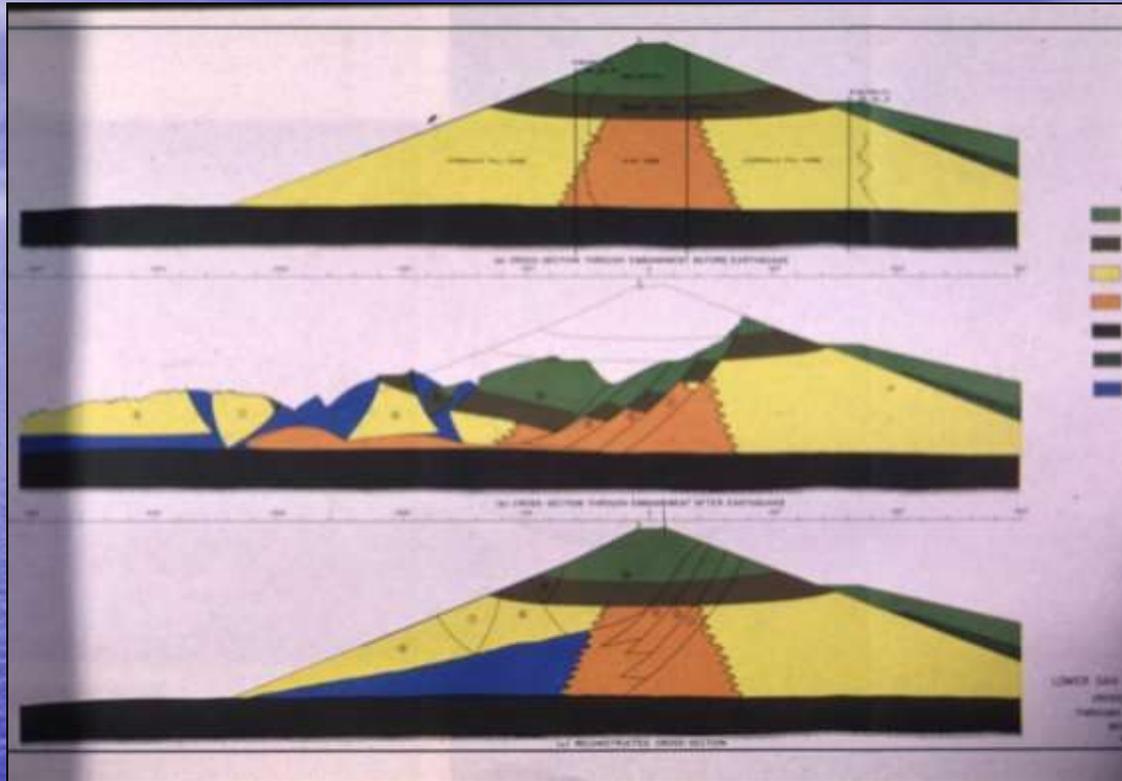
- Passed in wake of the December 1963 failure of the Baldwin Hills Reservoir, covered live on television.
- Jurisdiction for State overview of dams expanded to include *offstream storage facilities*, such as municipal reservoirs.
- Dams > 25 feet high which impound >15 ac-ft of water and dams >6 ft high which impound >50 ac-ft of water

# LOWER VAN NORMAN RESERVOIR FAILURE



- **Lower San Fernando Dam** was built by the City of Los Angeles as part of the Los Angeles Aqueduct between 1916-18 using the puddled hydraulic fill. A rolled fill addition seven feet high was placed in 1924-25.
- The embankment failed during the Feb 9, 1971 M. 6.7 San Fernando Earthquake, but no water was released

# SUSEPTIBILITY TO LIQUEFACTION



- Careful forensic evaluations by the geotechnical engineering group at U.C. Berkeley unraveled the dam's failure by liquefaction of a zone of low density sandy hydraulic fill, shown in blue in the above sections
- The State subsequently slated **30 other hydraulic fill dams for retrofitting between 1973-75**

# Impacts of the 1971 San Fernando earthquake on dam safety

- In the wake of the Lower San Fernando Dam (Van Norman Reservoir) failure, the State Division of Safety of Dams (DSOD) joined with the Los Angeles Dept of Water & Power and the National Science Foundation to support research by Professors H.B. Seed (Berkeley) and K.L. Lee (UCLA) to determine the cause of the liquefaction. These studies were summarized in a series of articles by Seed, Lee, Idriss, and Makdisi that appeared in 1975.
- In December 1971 DSOD identified 29 hydraulic fill embankment dams in California for dynamic analyses. These dams were subsequently evaluated using the new Seed & Idriss approach.
- By 1975 DSOD requested new dynamic analyses of 59 dams, 14 of which were placed in the highest rank of urgency (six of these were already under evaluation).
- Between 1975-80 DSOD, nine more dams of the 59 were evaluated, while owners initiated reassessments of 19 more dams on their own.
- By 1983 53 of the 59 dams had undergone through reevaluations. Satisfactory performance was predicted for 28 of these dams, eight required additional freeboard, and seven were earmarked for extensive alteration or replacement. These included: Upper and Lower San Fernando, Upper San Leandro, Chabot, San Pablo, Fairmont, Lake Arrowhead, Silver Lake, Lower Franklin, Dry Canyon, and Sheffield Dams.
- Upper and Lower San Fernando, Upper San Leandro, and Lake Arrowhead were rebuilt; San Pablo and Chabot were extensively retrofitted; and Sheffield was abandoned.



- **Matilija Dam** is a 190-ft high constant angle arch dam designed by the Donald R. Warren Co. of Los Angeles in 1946. The designers recognized the need for using low alkali Portland Type II cement and imported coarse aggregate from over 100 miles away (Irwindale) to better resist abrasion than onsite materials.
- Extreme case of cracking distress caused by alkali aggregate reaction because of glassy andesites and chalcedonic chert, which somehow found their way into fine aggregate fraction of the upper 40 feet. After studies in 1965, 1975 and 1977, the central crest was lowered by as much as 40 feet.

# ALKALAI AGGREGATE REACTION



- **Alkali aggregate reaction** was discovered in the early 1940s, as concrete structures began to experience expansion cracking.
- 40 years would pass before the precise mechanism was discovered; that being a chemical reaction between opaline quartz and the cement paste

# SLATED FOR REMOVAL



- **By 1966 Matilija Reservoir had filled with 6 million cubic yards of sediment. Matilija Creek used to support steelhead trout, migrating up Ventura River from Pacific Ocean**
- **Current plans call for complete removal of the dam, after funding is secured from state and federal agencies**