HOW GEOTECHNICAL ENGINEERING NEEDS SHAPED THE HISTORY OF CALIFORNIA

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for

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California: land of geologic contrasts and geohazards



- California is blessed with mineral wealth (gold, mercury, oil, gas, borate, gypsum, potash), and supports the largest agricultural output of any state in America.
- The state is also subject to torrential rainstorms that cause destructive floods, erosion/channel scour; debris flows and landslides; earthquake shaking and tectonic offset; wild fires; expansive soils, collapsing soils, many forms of ground settlement, delicate groundwater basins subject to depletion, pollution, and brackish water intrusion; the nation's largest sanitary landfills; and the list just goes on and on...

California sports the oldest dam and irrigation canal in the United States

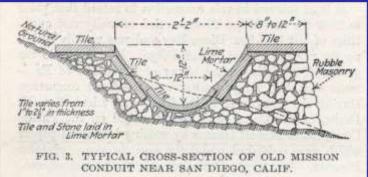


In 1814-15 a rubble masonry dam was constructed across the upper end of Mission Gorge in San Diego. It had a maximum height of about 13 feet, was 13 feet thick at its base, and was 244 ft wide. Water was released through gates and spillways into a six-mile long tile-lined flume, down Mission Valley, and terminating near the Franciscan Mission of San Diego de Alcala, estab in 1769. The dam gradually fell into disrepair mission after the missions were secularized in 1833. The lower left image shows the dam being

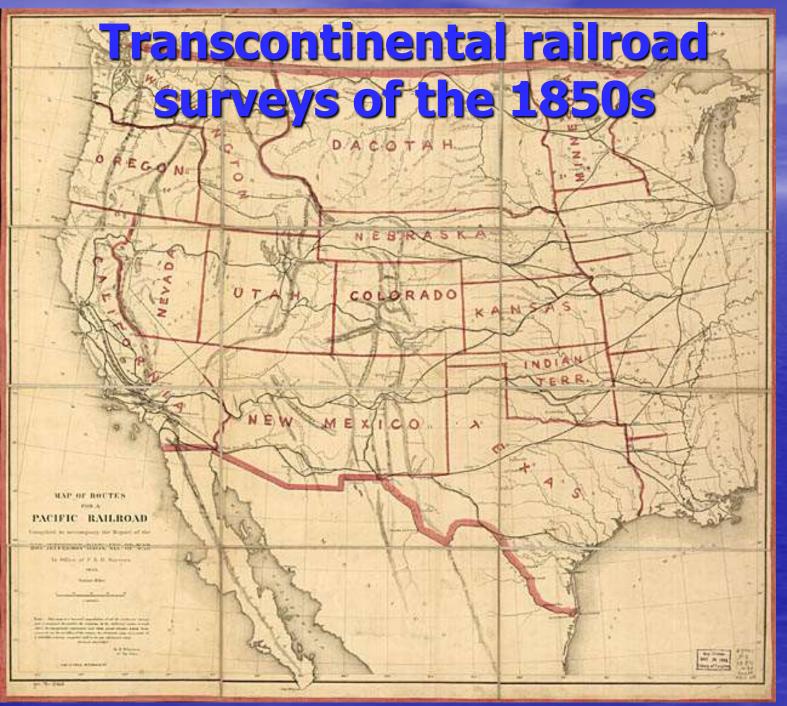
overtopped by the Flood of 1914 or 1916.

Today the Old Mission Dam is a nationally registered historic landmark and preserved within the Mission Trails Regional Park, along Father Junipero Serra Trail and the San Diego River





Left images are from ENR Feb 17, 1916 article on the dam and conduit (canal), which were remarkable feats of engineering for the early 19th century

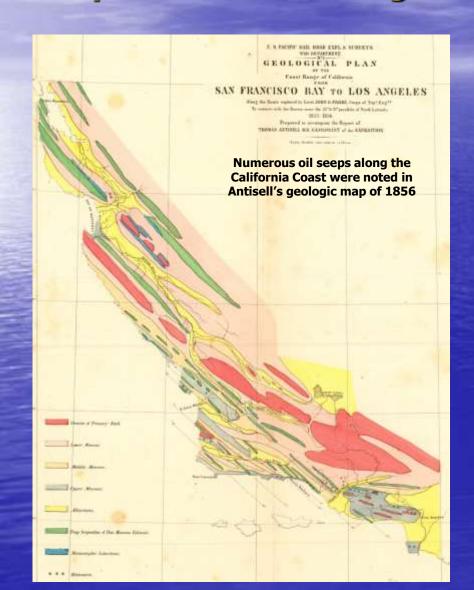


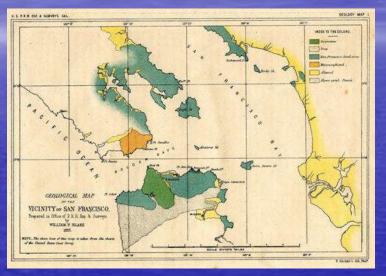
Congress
authorized a
series of
surveys
across the
continent in
hopes of
establishing a
rail link to
gold-rich
California

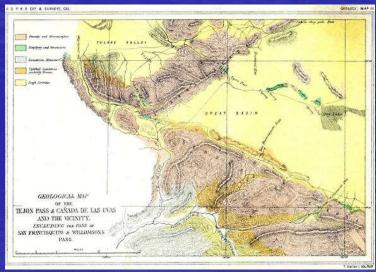
When silver was discovered in Nevada on the Comstock Lode and the Civil War erupted, the Pacific Railroad Act of 1862 was enacted

Our geotechnical story begins with

Transcontinental railroad surveys of the 1850s, which produced the first geologic maps of California

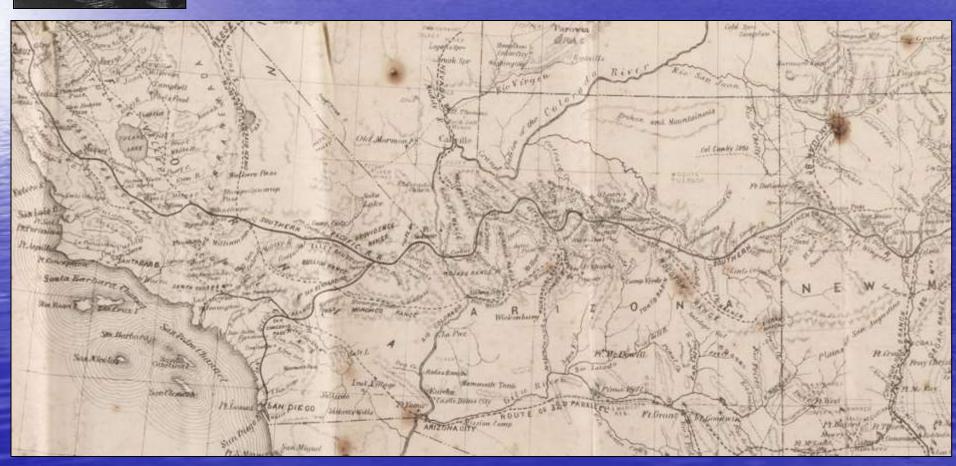






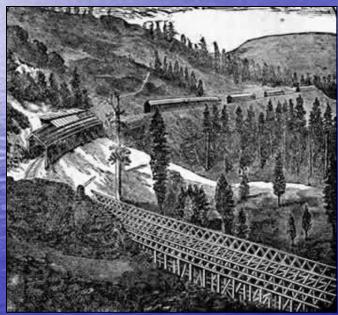


In 1867-68 civil engineer William Jackson Palmer directed the most thorough railroad survey ever carried out until that time, involving 116 men split into five crews surveying different routes along the 32nd and 35th parallels, leading to southern California









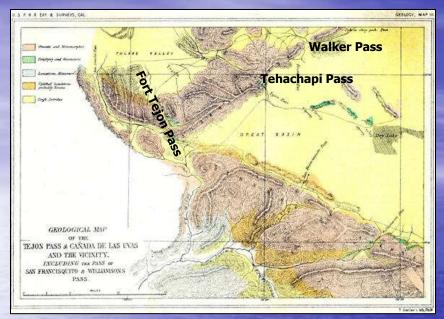


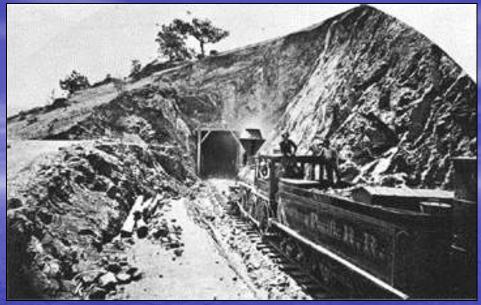
The first transcontinental rail link was completed by the Union Pacific and Central Pacific Railroads on May 10, 1869, between Council Bluffs, Iowa and Sacramento, California. It doesn't deviate more than 29 miles from a Great Circle Route between the two terminal points (see map at upper left).

FIRST RESERVOIR IN LOS ANGELES



Buena Vista Reservoir was constructed in 1868-69 using an earthfill embankment with riprap face, built to a crest elevation of 378 feet. It was located near what is now the southeastern tip of Elysian Park, in Los Angeles. It was owned by the Los Angeles Water Company as their first storage facility. This area is now part of Buena Vista Park, just off the Pasadena Freeway.







Using the railroad survey prepared by Lt. Williamson in 1853 (upper left), in 1875-76 the Southern Pacific Railroad constructed a new rail line across Tehachapi Pass (el. 4,025 ft), connecting Lathrop Junction (near present day Tracy) with Los Angeles. The line required a record 18 tunnels (shown above)and included the famous Tehachapi Loop, where the rail line loops back over itself, climbing the steep grade west of the summit valley. In the early days the principal freight revenue came from hauling ore from the Coso Mining District east of Owens Lake, which was brought by wagon to Mojave.

THE FRESNO SCRAPER

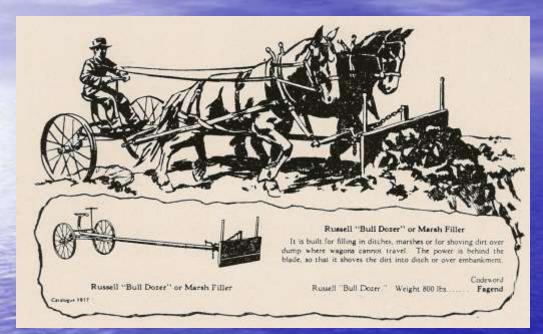






- Abajiah McCall invented the horsedrawn dirt bucket scraper in Fresno County, California in 1885.
- It became known as the "Fresno Scraper" and was widely employed as the prime earth moving device until the widespread advent of self-powered scrapers in the 1930s.

Bull Dozers





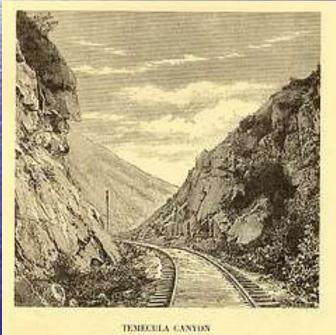
The Bulldozer was developed in the late 19th Century to grade railroad lines. Two bulls or horses (upper right), or up to 4 mules (lower right), could be employed to pull a wheeled caisson attached to a stiff arm connected to a flat iron blade, which extended out in front of the animals, as shown above. The advertisement at left is from the Western Wheeled Scraper Co., in 1917.

The California Southern Railroad



In 1881-83 a group of San Diego merchants organized a railroad that would connect them with the Atchison, Topeka & Santa Fe Railway owned by Boston interests.

Santa Fe agreed to cooperate, if the San Diegans constructed their connecting line from San Diego to Barstow, where the Southern Pacific was constructing a line eastward from Mojave to the Colorado River.

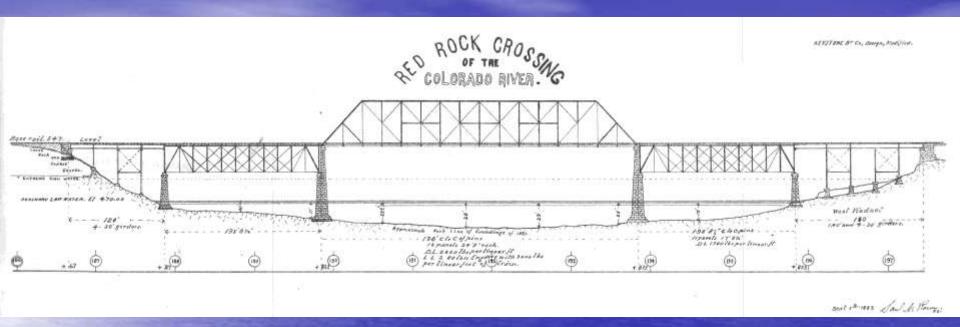




VIEW IN TEMECULA CANYON, ON THE GAL SOU. R. R.



 The recent flood history of the Colorado River between California and Arizona is recorded at Topock, 10 miles south of Needles. Six bridges have been constructed here since 1889.



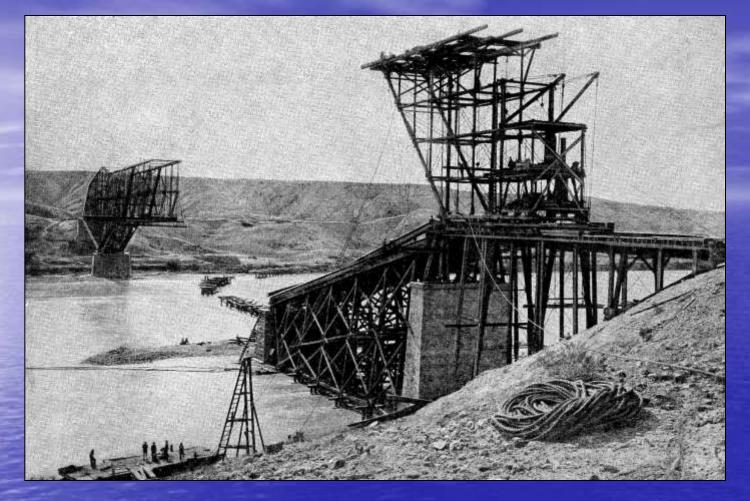
- This shows the original Red Rock Crossing over the Colorado River, designed by the Atlantic & Pacific Railroad in 1888, based upon soundings made by William Trainor of the Southern Pacific in 1881.
- The maximum depth to "bedrock" was believed to be about 40 feet below low water. That estimate proved to be in error by almost 100%...

The Colossal Flood of 1884



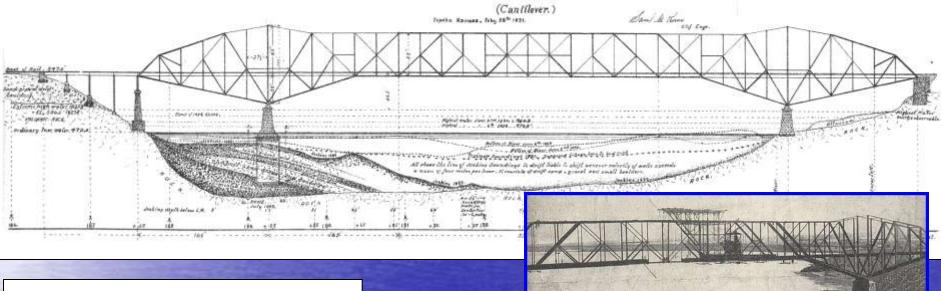


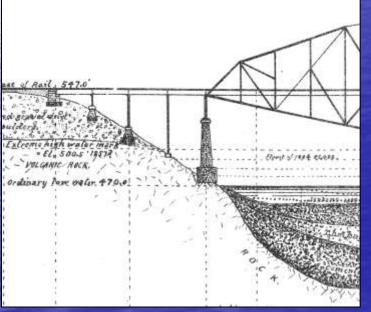
- Heavy rains and flooding during Jan-Feb 1884 destroyed every railroad bridge between Santa Fe, NM and Santa Barbara, CA
- During the flooding at Needles, W.A. Drake, Chief Engineer of the Atlantic & Pacific Railroad, made a number of important measurements
- He recorded a maximum flow of 384,000 cfs at Topock, almost double that of the "record" 1902 flood, recorded at Yuma
- He estimated that 7,900,000 cubic yards of sediment was transported in 24 hours, after measuring silt concentrations of 1.56 grains per cubic inch of water
- River silt deposited by the flood had a dry density of 59.95 pcf



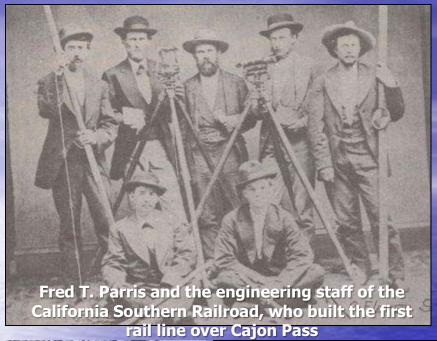
Following the 1884 floods that destroyed their bridge at Topock, the Santa Fe railroad made new soundings (borings) at the site in 1888. They discovered that the river bed was now 80 feet deep! This necessitated some major design changes.

Atlantic & Pacific Railroad .





- The railroad was forced to build the longest cantilever span bridge in the United States, so the caissons could be constructed above the low water surface.
- They ran into lots of surprises on the Arizona side, which precluded this footing from being founded on bedrock.









The rail line
through
Temecula Canyon
was destroyed by
the 1884 flood

With Santa Fe's financial help, Chief Engineer Fred T. Parris rebuilt the line through Temecula Canyon, but Santa Fe took the precaution of purchasing a short line between Los Angeles and East Pasadena, which they extended to Colton and later named it the "Los Angeles Division." This forever changed the respective destinies of Los Angeles and San Diego.



Railroad Fare War brings real estate bonanza to Los Angeles County



- For several years the Southern Pacific (SP) tried to prevent the California Southern and the Atlantic & Pacific (Santa Fe) Railways from serving the California freight market.
- SP built a connecting line from Mojave to Needles, then charged the Santa Fe for trackage rights to use it. Santa Fe wanted to connect to San Diego and Los Angeles to access freight from Pacific ports.
- In August 1884 SP fell on financial hard times while trying to acquire other railroad lines. In desperate need of cash, they agreed to sell the Mojave to Needles line to Santa Fe.
- The two railroads then got into a spirited fare war, competing for riders between St Louis/Kansas City and Los Angeles...the fare eventually dropping to just \$1 each way in September-October 1885. A lot of people purchased tickets...
- During the next 2-1/2 years, 75% of the cities in Los Angeles county were incorporated and more than 65% of the real estate subdivided, marking the greatest real estate speculation episode of the 19th Century.
- San Diego had the dream of being a major Pacific Coast port, and the foresight to construct a transcontinental rail connection, but they were defeated by flood damage in Temecula Canyon in 1884 and 1889, when the line was abandoned.



- In 1871 jetties were constructed to scour out Wilmington Slough and provide a deep draft shipping channel inland of San Pedro, which was unprotected during winter storms.
- In Dec 1898 the Los Angeles District of the Army Corps of Engineers was established after passage of the River & Harbors Act of 1896. In late April 1899 the Corps began dumping rock into San Pedro Bay off Point Firmin. The granite for this breakwater was quarried on Catalina Island and this initial breakwater was completed between 1902-05.

Lessons learned, and forgotten...

1906 San Francisco Earthquake and Fire











In 1906 the city's fire mains were destroyed by liquefaction near the corner of 6th & Howard Streets

In 1989 the city's fire mains were destroyed by liquefaction near the corner of 6th & Howard Streets....



Construction of the first Los Angeles Aqueduct 1906-13





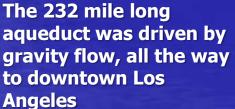


First use of Caterpillar tractors in heavy construction

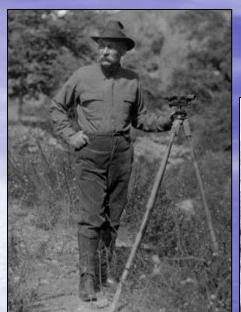


By constructing hydroelectric plants along the aqueduct, Los Angeles became the largest public owned utility provider in the world

The City also built the largest cement calcining plant in the world at Monolith



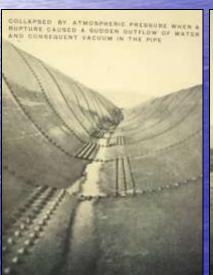


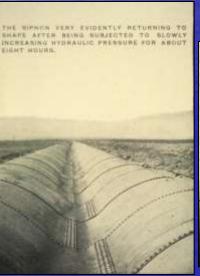


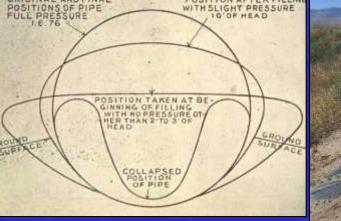
Big Bill Mulholland — born problem solver











Mulholland's novel repair of the Antelope Valley Siphon was an engineering triumph, and the original section still conveys water today (as shown at far right)



Earthmoving for water supply

Above left: 10-horse team pulling an elevating grader to load hopper dumping wagons during construction of the Central Reservoir for the People's Water Co. in Oakland, California in 1909.

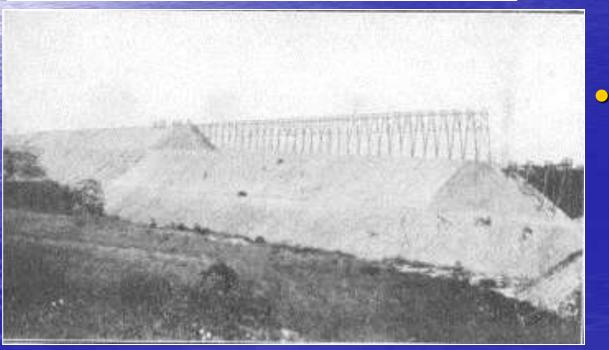


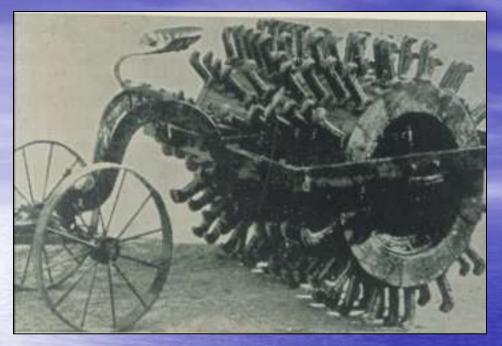
Note the old Buffalo-Springfield steam roller compacting the dam's embankment, in left background. Below Left: Marion shovel loading a hopper dumping wagon at the San Pablo Dam site of the East Bay Water Company in 1920, near Richmond, California. At 220 ft high with a volume of 2.2 million yds³, it was the highest and largest earth dam in the world when completed in 1922.



"Load Compaction" of Trestle Fills

- In the early days large embankments were constructed by side-dumping rail cars or wagons from temporary wooden trestles, as shown at left.
- Engineers assumed that, after placement and infiltration by rain, the soil would 'compact' under its own dead load.

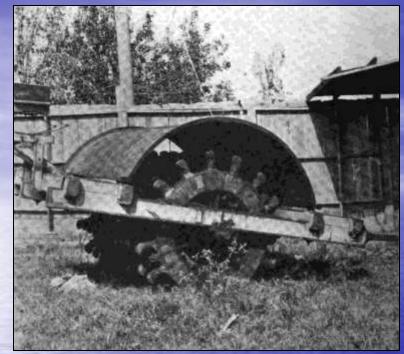


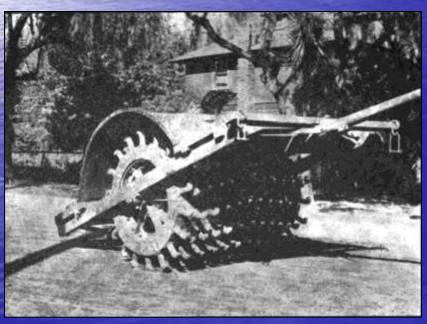




The first sheepsfoot rollers

- The first sheepsfoot roller was built in Los Angeles in 1902, using a 3-ft diameter log studded with railroad spikes protruding 7 inches, distributed so the spikes were staggered in alternate rows.
- This layout was soon modified to increase weight and efficiency, initially, by increasing its length to 8 ft.
- Note the leading wheels on the early models shown here, absent later.
- The roller's weight was then increased to about 5000 lbs by filling them with sand and water (drained when moved).
- The 7-in spikes were enlarged to a contact of area of 4 sq inches. This increased the load bearing on each spike to 300 lbs, or about 75 psi contact pressure
- Marketed as the "Petrolithic Paving Tamper," it was built by the Killefer Manufacturing Co. of Los Angeles.

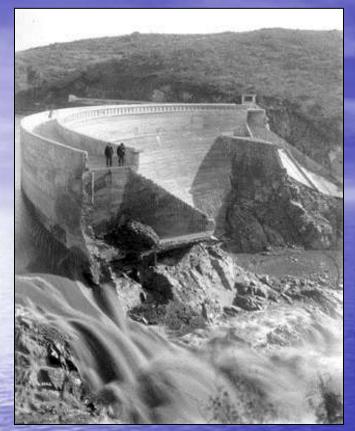




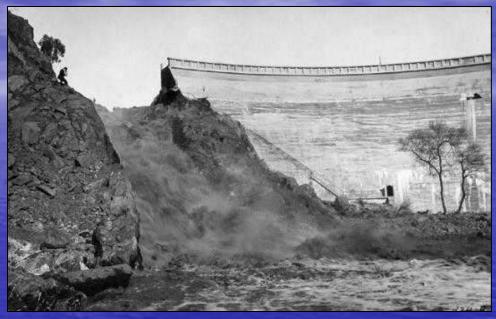
"Fitzgerald Rollers" 1906-23

- The roller was patented by John W.

 Fitzgerald in 1906, who worked for
 Walter and Harbert Gillette, owners of
 the Petrolithic Paving Co. of Los Angeles
- It was modified with a counter-balanced tow frame and hemispherical fender, and manufactured by the Killefer Mfg. Co. of Los Angeles and marketed nationally as the "Fitzgerald Roller."
- The number of spikes was reduced to either 10 or 11 per row, to bring the contact pressure up to 100 psi.
- It was first used to compact an embankment dam by Bent Bros Construction in El Segundo, CA in 1912.
- Numerous imitations soon appeared, and when the patent expired in 1923, it was not renewed.



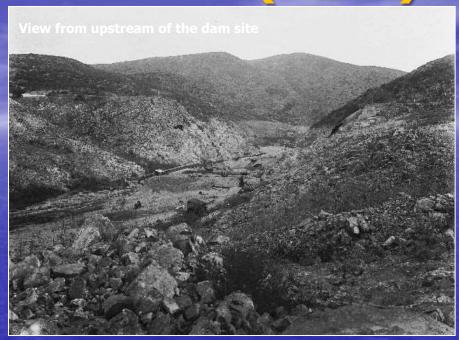
RIGHT ABUTMENT FAILURE OF SWEETWATER DAM (1916)



- In 1910-11 James D. Schuyler prepared plans that raised Sweetwater Dam 15 feet, increasing its capacity by 70%.
- In January 1916, 8 to 20 inches of rain fell on the area, causing a peak discharge of 45,500 cfs for an hour, with 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 five 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.

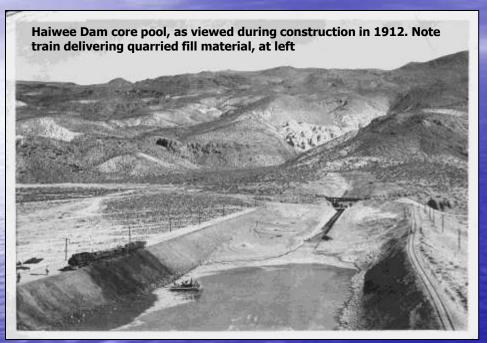
Floods of 1914 and 1916 resulted in the Dam Safety Act of 1917 and creation of the Los Angeles County Flood Control District

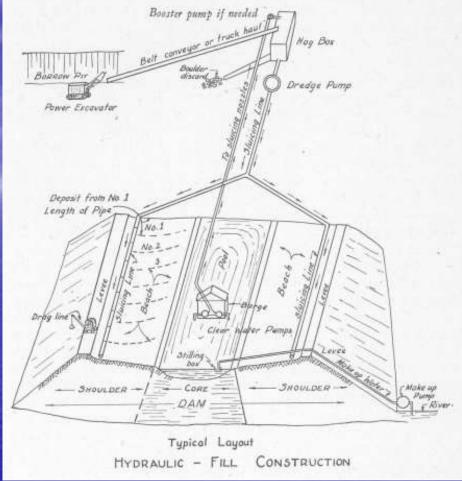




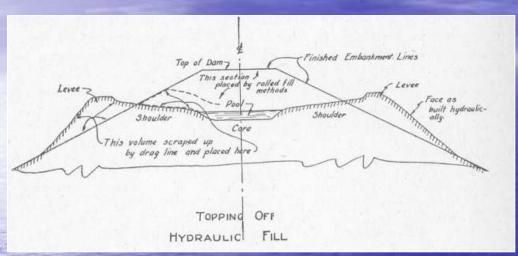
- Public outcry followed failure of the Lower Otay and Sweetwater Dams in January
 1916 in San Diego County
- The State Engineer was granted authority over all dams > 10 feet high or which impound > 9 acre-ft (3 million gallons), with exception of:
 - Dams for mining debris constructed by the California Debris Commission
 - Dams constructed by municipal corporations maintaining their own engineering departments (such as the City of Los Angeles)
 - Dams and reservoirs that are part of water systems regulated by the State's new Public Utilities Act

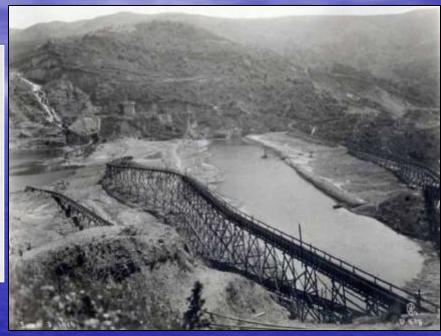
HYDRAULIC FILL TECHNOLOGY





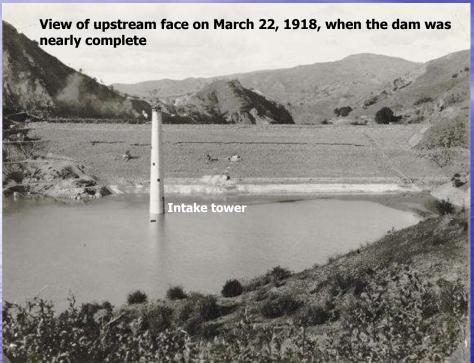
Prior to the Fort Peck Dam upstream shell failure in Sept. 1938, most earthfill dams were constructed using hydraulic monitors to sluice clayey sediments into a slurry that was piped to the dam site and deposited without benefit of mechanical compaction PUDDLED CORES FOR LOW PERMEABILITY

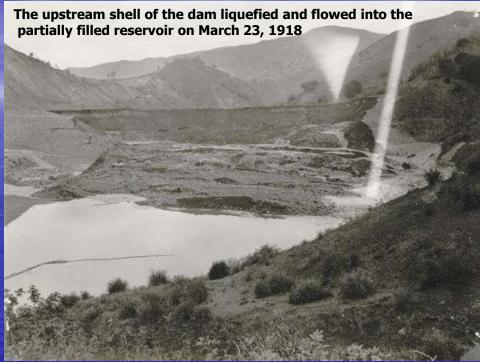




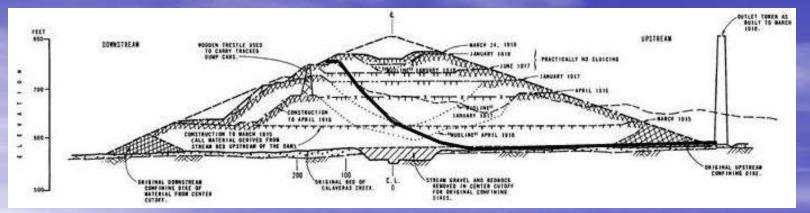
- The embankments of hydraulic fill embankments were raised by constructing temporary levees on either side and allowing the fines to "puddle" in a central "core pool"
- This central zone became the impervious core of the dam (San Pablo Dam is shown at right)

CALAVERAS DAM SLIDE

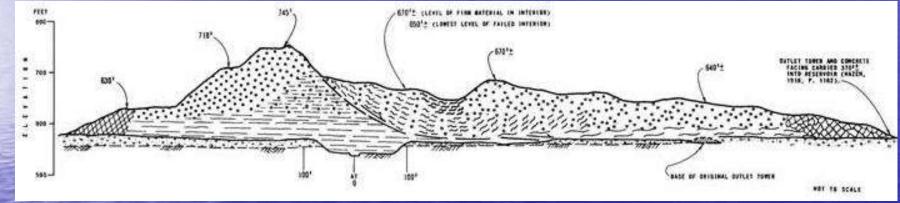




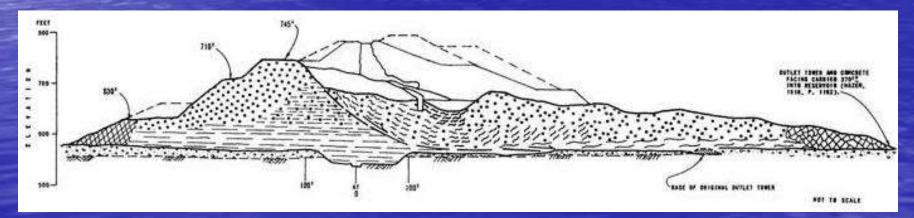
- Calaveras Dam was intended to be 240 ft high with a volume of 3 million yds³ placed by hydraulic filling, making it the *largest earthfill dam in the world in 1918*
- On March 23, 1918, 800,000 yds³ of fill slid upstream into 55 ft of water, destroying the 230 ft high intake tower
- In 1923 construction was resumed on an embankment 25 ft lower, with flattened side slopes. This revised scheme was completed in 1925.



Section through the Calaveras Dam when the upstream shell failure occurred in March 1918



Section through the liquefaction flow slide of the dam's upstream shell in March 1918



Section illustrating how the dam was reconstructed sequentially, between 1923-25



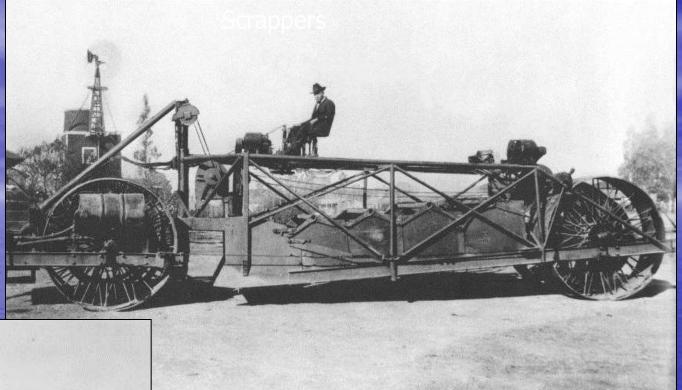
Charles T. Leeds (1879-1960) was a former Corps of Engineers officer who graduated #2 behind Douglas MacArthur in West Point's Class of 1903. He earned a BS degree from MIT in 1906. While working for the Corps' as the Los Angeles District Engineer in 1909-12, he oversaw design and construction of the enormous breakwater that created the Port of Los Angeles in San Pedro. He began private practice with Wilfred K. Barnard in 1912, interrupted by service as the Corps' Los Angeles District Engineer in 1917-19, during the First World War. His firm merged with Quinton, Code and Hill in 1930, becoming Leeds, Hill and Jewett in 1946. Their dams and tunnels group were subsequently absorbed by Woodward-Clyde in 1982.



Louis C. Hill (1865-1938) was arguably, the most respected Los Angeles consulting engineer of the 1920s and 30s. A graduate of the University of Michigan in 1886, he earned a second degree in electrical engineering in 1890. He was a professor at the Colorado School of Mines from 1890-1903, at which time he was enticed to join the newly-formed Reclamation Service in Denver. He supervised a string of famous projects in the upper and lower Colorado River basins, including Roosevelt Dam (1903-11), the giant siphon under the Colorado River at Laguna Dam, and design of Elephant Butte Dam on the Rio Grande River. He entered private practice in March 1914, and availed himself as a consultant to the Bureau of Reclamation and Corps of Engineers for the balance of his life. Shortly after the First World War, he became a partner in Quinton, Code, and Hill in Los Angeles, which consulted on a wide range of water supply and flood control projects, nation-wide. In 1930 the Bureau of Reclamation named him to their Board of Consulting Engineers for Hoover Dam. He served as President of the American Society of Civil Engineers in 1937.



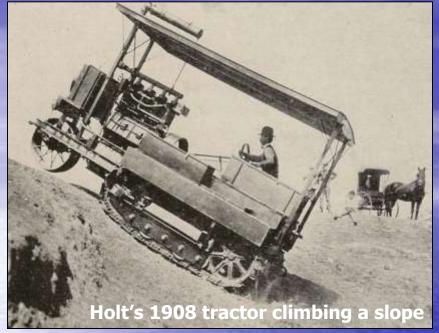
R.G. "Bob" Letourneau (1888-1969) was a legendary figure in the earthmoving business



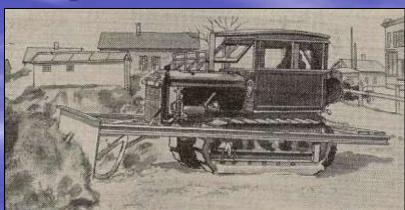


R.G. Letourneau of Stockton, California began leveling farmer's fields in the San Joaquin Valley around 1910, using a Holt Tractor and towed scrapers of his own design, like that shown here, in 1913.

- In 1923 Letourneau invented the first self-propelled scraper, shown above, which employed a series of five telescoping buckets that could carry 12 cubic yards of soil
- The 1923 scraper employed allelectric drive, making it was the first machine that could excavate earth, carry it, and place it, all under its own power.



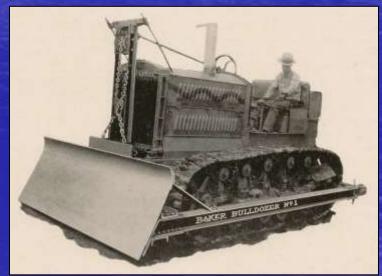
Early Tracked Dozers



The LaPlant Choat tractor bulldozer appeared in 1923, but it lacked meaningful blade elevation and control

Between 1885-1908 Benjamin Holt of Stockton, California gradually developing a gasoline-powered self-laying tractor, like that pictured at upper left. It began simply as a means of motive power, to replace horses and mules.





Baker Manufacturing of Springfield, Illinois' Dozer No 1, which used a chain hoist, appeared in 1927

Letourneau's cable and winch controlled dozer; which changed the earth moving business in 1928.



Caterpillar-Letourneau dozer with power-takeoff cable control at a dam site in Montana in 1937.

Perfecting the tracked dozer

- In 1928 Letourneau began producing dozer blades for Caterpillar tractors, in Stockton, California
- At that time Letourneau also introduced cable and winch control for lifting and tilting the big steel blades, which all their competitors adopted, soon thereafter.
- The power take-off winch (seen at lower left) using cable control became the dominant means of controlling the dozer blades until the adoption of hydraulic actuators, after the Second World War.

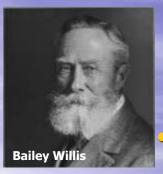
The 1925 Santa Barbara Earthquake and the Los Angeles Insurance Crisis





- The Uniform Building Code came about as a result of the Magnitude 6.3 Santa

 Barbara earthquake of June 25, 1925. This quake caused \$6 million in damage to a city with only 30,000 people. The quake also came on the heels of the Great Kanto Earthquake of 1923 (M 7.9), which killed 143,000 people and burned much of Tokyo to the ground.
- In the wake of the terrible losses suffered in Santa Barbara, the nation's largest insurers asked the Seismological Society of America (SSA) to provide future seismic risk assessments for California.
- The Board of Fire Underwriters of the Pacific funded several research projects aimed at assessing the earthquake hazard risks for various building types, making unreinforced masonry structures virtually uninsurable. When these assessments were released, they were so alarming that most lending institutions refused to invest in any further construction in the Los Angeles area.







Motivation for establishing a worldclass program in geology and seismology

- This led to a crisis involving the California State Chamber of Commerce, the California Development Association, the Los Angeles Chamber of Commerce, and the Seismological Society of America.
- The LA Chamber of Commerce asked Caltech President Robert A.

 Millikan if there was anything he could do to rescue Los Angeles from impending doom. Millikan asked John C. Merriam, President of the Carnegie Institution who the best candidate would be to head up a new geology program at Caltech, and he recommended John Buwalda at Berkeley.
- Millikan then applied a full-court press to convince Bulwada to come to Pasadena and build a geology program that would "be an equal to that in northern California." Buwalda agonized over the decision for almost a year before agreeing to move to Pasadena in January 1926.
- Within a few months he hired Berkeley colleague Chester Stock, and began establishing the Department of Geology as one of four major science divisions at Caltech. His next move was to integrate Carnegie's Seismological Laboratory into Caltech's program, making it one of the first to offer courses in geology, paleontology, economic geology, and geophysics under one roof. By 1946 the geology program had 16 full-time faculty and was the largest in the world.
- Millikan was unsuccessful in getting Buwalda or any other Caltech faculty to publicly disagree with Bailey Willis, so he muzzled them, forbidding them to speak to the media about the "earthquake issue."

Professor Willis was successfully discredited in March 1928 and the insurance crisis thereby abated



SOUTHERN CALIFORNIA GEOLOGY AND LOS ANGELES EARTHQUAKES

With An Introduction to the Physical Geography of the Region

> By ROBERT T. HILL

Late Geologist United States Geological Survey, Fellow and former Vice-President Geological Society of America, etc.

Report Read in Abstract Before the Geological Society of America, Cleveland, Ohio December 30, 1927

> Published by the Southern California Academy of Sciences Los Angeles, California 1928

Nobody seemed to recall R.T. Hill's book in the wake of the 1933 Long Beach earthquake, and Hill died quietly in Dallas, Texas on July 28, 1941, having never set foot back in California after his timely tome had its desired effect in 1928.

PART SEVEN

SUMMARY OF CONCLUSIONS

In concluding this report a brief summary of the premises upon which rests my refutation of earthquake predictions for Los Angeles is in order. The accumulative weight of data substantiates beyond a doubt my deduction that Los Angeles is in no danger of a great earthquake disaster.

Following is a short statement of each step in the progress of this report:

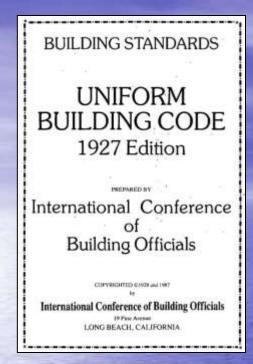
Southern California is not Northern California and the geologic conditions of the two regions are different. Consequently, their seismologic behavior is not the same.

Southern California is a part of a west-American region of mild seismicity and no evidence can be gathered from accurate historic data or from the accounts of the oldest inhabitants that any earthquakes of great intensity have taken place at Los Angeles within historic times.

No proof has been presented of the presence here of the dangerous type of horizontal movements that occurred along the San Andreas Rift at San Francisco or of the transverse stresses that affected the Santa Barbara district.

The City of Los Angeles is remotely situated from the three lines of maximum seismicity in California, San Andreas, Santa Ynez and San Jacinto Rifts. The City of Los Angeles is also at a sufficiently safe distance from the immediate seaboard and the great abysmal escarpment of the continental shelf to give us reasonable assurance against shocks from sea-marginal slipping.

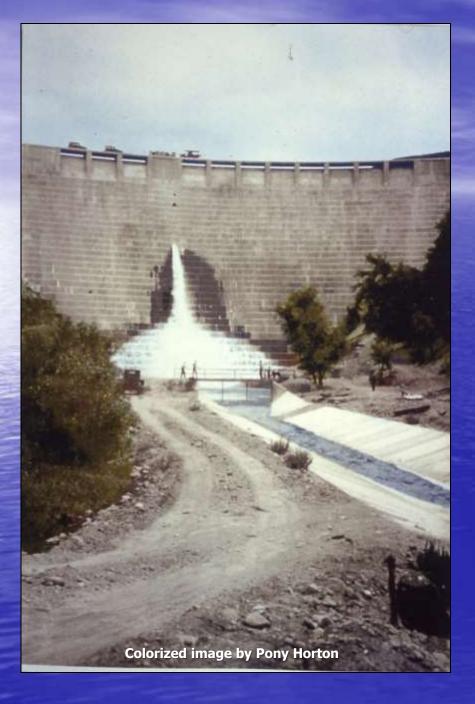
Even though a master shock should take place along the south end of the San Andreas line of seismicity in Southern California there is no reason for asserting that Los Angeles would be seriously affected by it inasmuch as that fault does not come closer than thirty miles of the city. The average distance of Los Angeles from the path of this fault across Southern California is far greater than that amount. In other words, Los Angeles is sufficiently remote from this dangerous line of seismicity and horizontal movement to discredit the belief that the city is apt to suffer serious damage from it.



The Uniform Building Code (1927)

On October 18-21, 1927 the Pacific Coast Building Officials Conference (PCBOC) convened in Los Angeles and hammered out a new Uniform Building Code (UBC), which was published by the PCBOC in Long Beach. The primary purpose of the PCBOC was to establish regulations and minimum standards for life safety of building occupants.

- In March 1956 the PCBOC was conjoined with several other building code conferences to form the much larger International Conference of Building Officials, known as ICBO. While ICBO had no legal authority to create laws, most cities in the western United States adopted ICBO standards after 1956. Revised editions of this code were published approximately every 3 years, up through 1997.
- From 1927-56 PCBOC/ICBO was headquartered in Los Angeles, and from 1956, in Whittier. During the late 1950s and throughout the 1960s ASCE, CCCE, AEG, and ICBO formed numerous joint committees to explore the establishment of suitable standards for foundation engineering, grading and excavation. These consultations resulted in the establishment of Expansion Index Test (UBC Test 29-2/18-2), adopted in 1967; and the UBC [compaction] Test Standard 70-1, adopted in 1967 (and discarded in 1985).



- St. Francis Dam was completed in May 1926
- The dam was 205 feet high, and contained 130,000 cubic yards of concrete
- 11 spillway panels were fitted across the dam's crest, each 18" high and 20 ft wide
- Five 30"-diameter outlet pipes had a maximum capacity of 1184 cfs, with a full reservoir pool
- If all 5 outlets had been opened at noon on Monday March 12th, the reservoir would have dropped only 1.67 feet by midnight

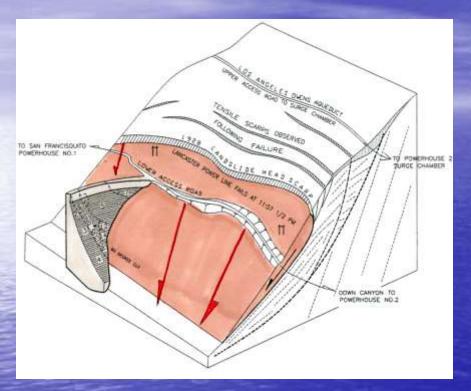
Before and After





- Comparative views taken of the dam's upstream face looking at the right abutment 12 hours before the failure (at left) and the day after (right)
- Note exposed keyway beneath right abutment dike

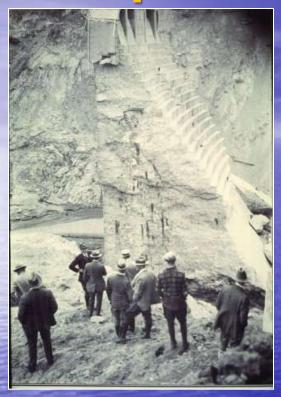
LEFT ABUTMENT LANDSLIDE





- Around midnight March 12/13, 1928 a massive landslide occurred along the dam's left abutment
- The landslide involved 1.52 million tons of schist moving against the dam's 271 thousand tons of concrete, so the schist won

Inquiries and a demands for justice





- A flood wave 140 ft deep swept down the canyon, killing at least 430; 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

BENEFITS THAT CAME FROM THE ST. FRANCIS DAM FAILURE

- Engineering geologic input on dams became commonplace in the 1930s (it had been all but absent in the 1920s).
- Independent review of all federal dams
- Increased dam safety legislation in California; which became model legislation for other agencies
- Professional engineering registration for California
- State-mandated arbitration hearings for victims of natural disasters
- Creation of the independent Colorado River Board by Congress to review the design of Hoover Dam
- AIME and ASCE conferences on foundations for high dams
- Increased awareness of uplift theory and the role of effective stress in the stability of hydraulic structures
- State review of San Gabriel Dam at The Forks
- Retrofit of Mulholland Dam and many other dams
- External Peer Review of dams and the Proctor Compaction Test



Professional engineering registration

- The Civil Engineers Registration bill sailed through the state legislature in early July 1929 and became law on August 14th, even though it was opposed by a number of professional organizations, such as the American Institute of Mining Engineers and the American Society of Mechanical Engineers.
- The act defined civil engineering and mandated that any person who practices or offers to practice civil engineering in any of its branches must be registered, and created The Board of Registration for Civil Engineers.
- The act also directed that civil engineers in state service must be duly registered if they served in a capacity of "Assistant Engineer" or higher.
- The California Supreme Court quickly issued rulings that a contract for engineering services was invalid if the party undertaking to furnish engineering services was not registered.

One P.E. for every 1,000 people!

- 5,700 individuals applied for civil engineering registration during the first year applications were accepted, more than double what the state board had expected. Grandfathering was allowed for 10 months, until June 30, 1930
- After June 30, 1930 new applicants were required to take a written examination.
- Many of those who applied for grandfathering were asked to appear before the three man board (appointed by the governor) for oral interviews, to ascertain if they had entered the profession through the labor ranks of construction
- Of those who applied the first year, slightly more than 5,000 were accepted, providing the State of California with about one registered engineer for every 1,000 people then living in the state!
- It would take the next 25 years to register the second 5,000 civil engineers!



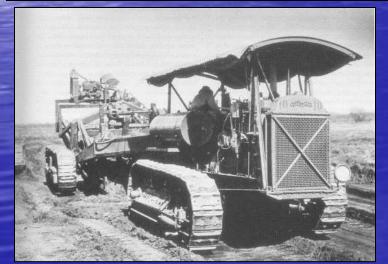


First dams compacted with sheepsfoot rollers

- The first earth embankments compacted with sheepsfoot rollers were the Lake Henshaw Dam in southern California in 1920-23 for the Vista Irrigation District in San Diego County, shown at left. This was followed in 1926 by Philbrook Dam for PG&E by R.G. Letourneau, and the Puddingstone Dam for the LACoFCD in 1925-27, using a new roller patented by contractor H.W. Rohl that employed ball-shaped heads.
- The first earth dam compacted by sheepsfoot roller for a federal agency was Echo Dam in Utah for the Bureau of Reclamation in 1928.
- The sheepsfoot roller's narrow spikes induced *kneeding* compaction, critical for densifying clayey soils.





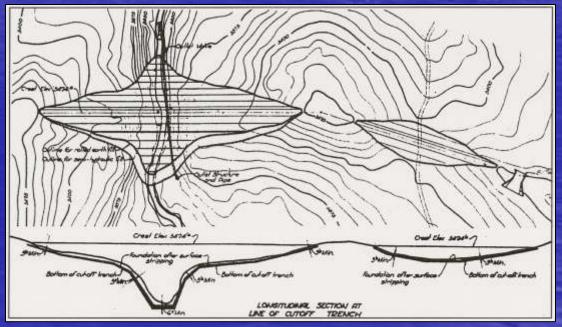


FIRST DAM BUILT WITH SCRAPERS

Philbrook Dam was an 85 ft high earth fill and wing embankment built by Kaiser Construction for PG&E as a power supply reservoir in 1926, off the West Branch of the Feather River.

Kaiser retained R.G. Letourneau Construction Co of Stockton to move the earth with his patented telescoping scrapers, shown at left. The total volume of fill was 142,000 yds³

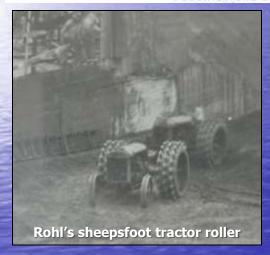
It was the first rolled fill dam in the world constructed with mechanical scrapers



Puddingstone Dam & Reservoir







The project was comprised of three rolled fill embankments up to 177 ft high, capable of storing 17,398 ac-ft. The soils were compacted with a sheepsfoot roller that employed ball-shaped heads, patented by contractor H.W. Rohl.



Puddingstone Dam and Reservoir was built by Los Angeles City & County in 1925-28 along Walnut Creek, but also stores water diverted from San Dimas Creek. Work began in early 1925 with excavation of a 5 x 7 ft outlet tunnel 700 ft long, about 35 ft above the streambed, while a 40 ft deep core wall was excavated into the creek channel and a temporary storage dam 53 ft high was to be constructed as a cofferdam (shown above). The cofferdam was only 45 ft high and storing about 500 ac-ft of water when storms dropped 8 inches of rain on the area in April 1926, producing an inflow of 500 cfs. This overwhelmed the outlet tunnel and the cofferdam began overtopping. 1 hr and 15 min later the cofferdam collapsed, resulting in a flood of 10,000 cfs lasting about 15 minutes, which eroded 18,000 yds³ of fill.

Pneumatic tires introduced in 1932











 These tires worked so well the entire industry shifted over to pneumatic tires over the next few years. In 1932 R.G.
Letourneau fitted
pneumatic tires to some
scrapers he built for a
client that was grading
a new state highway in
the loose blow sands of
the Salton Sink, in the
Colorado Desert of
southeastern California



CHARLES H. LEE

M. AM. SOC. C.E.

ONSULTING ENGINEER

58 SUTTER STREET

SAN FRANCISCO

4





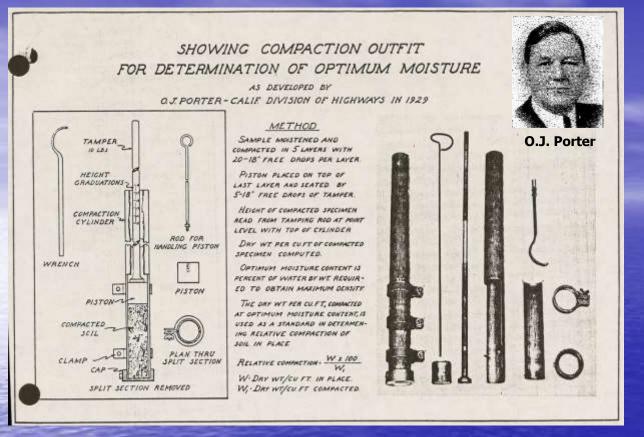
Charles Hamilton Lee (1883-1967) graduated from U.C. Berkeley in 1905 and went to work for the U.S. Geological Survey as a hydrologist He made the first credible studies of groundwater resources of San Diego County. In 1906 he was hired by the City of Los Angeles to assess the water resources of the Owens River watershed, preparing a comprehensive report published as U.S.G.S. Water Supply Paper 294, which was included an appendix to the final report on the Los Angeles Aqueduct in 1916.

While working on the aqueduct in 1912 he began a life-long association with Karl Terzaghi (1883-1963), an Austrian engineer who visited the aqueduct to view its construction. Lee left the City's employment after completing construction of the earthen dams associated with the aqueduct in 1916. In 1919 he opened up a branch office in Los Angeles to compliment the office he maintained in San Francisco, focused on hydrology and water resources. He was regularly engaged by the City of Los Angeles as an expert witness in many of the lawsuits involving matters of hydrology in the Owens Valley and the St. Francis Dam failure.

Lee was also one of the first engineers in California to make consultations in the emerging field of soil mechanics, building on the increasing notoriety of Terzaghi, who taught at MIT in 1925-29, and then, at Harvard between 1938-56. In 1926 he established the Pacific Hydrologic Laboratory, the first soils engineering laboratory on the West Coast.

Lee's pioneering work on predicting long term settlement of the hydraulic fill supporting Treasure Island in San Francisco Bay proved remarkably accurate and prophetic. He continued working for the City of Los Angeles and the Metropolitan Water District into the 1950s.

Increasingly cantankerous with age (he refused to pay employees for vacation or sick time), he died in his Berkeley home at the age of 84 on May 4, 1967.



First compaction test procedure (1929)



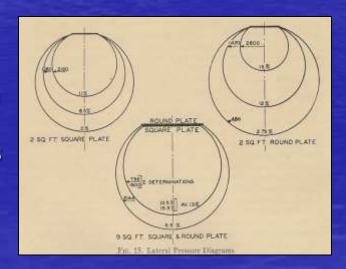
- The first published standard for testing the mechanical compaction of earth was the California State Impact Method, or "California Impact Test." It was developed in 1929 by
 James Porter, PE (1901-67) of the California Division of Highways in Sacramento.
- It presented a procedure for ascertaining the in-place wet density of aggregate baserock or compacted soil, and the preparation of a wet density versus soil moisture content curve (similar to what Ralph Proctor developed a few years later).
- The 216 test uses wet density as the measurement standard and has been modified six times since its original adoption in 1929. The current version of the test is referred to as California Test 216 "Method of Test for Relative Compaction of Untreated and Treated Soils and Aggregates." It employs energy input of 37,000 to 44,000 ft-lbs/ft³ of soil.

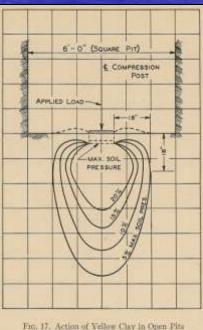
Early days of soil mechanics



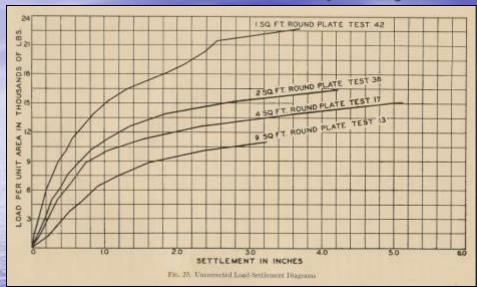


In the late 1920s foundation engineering basically revolved around the application of plate load tests in hand excavated test pits. The sizes and shapes of the plates were varied according to the need, as was the depth of the pit

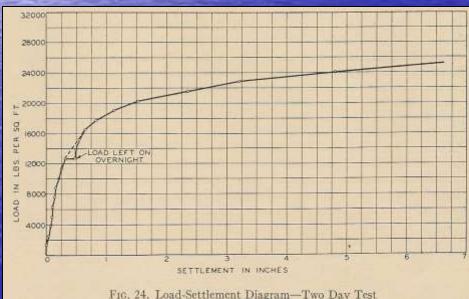




Figures from "A Practical Method for the Selection of Foundations Based on Fundamental Research in Soil Mechanics," by W.S. Housel (1929)



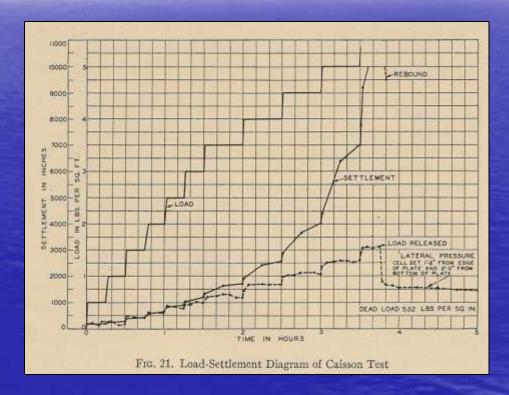






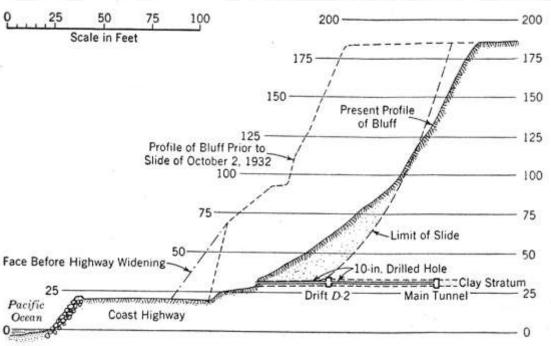
2-15-1-420" RALANCE BEAM HOPPER BOX BOTTOM OF TEST PIT Fig. 3. Soil-Testing Apparatus Fig. 4. Soil-Testing Apparatus

Caisson Load-Settlement Test



These are figures from Bill Housel's 1929 text, which Fred Converse used in the first soil mechanics courses he taught at Caltech in the spring of 1934. His students in that first class included Trent Dames and Bill Moore.

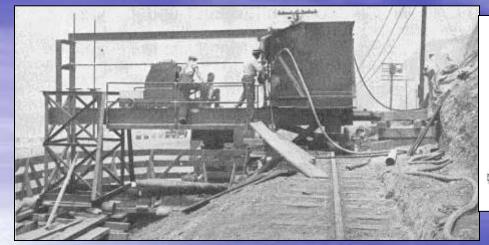


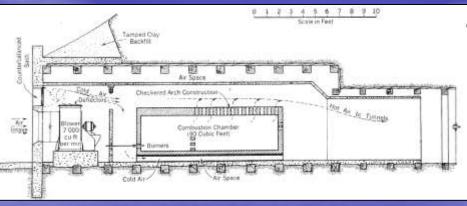


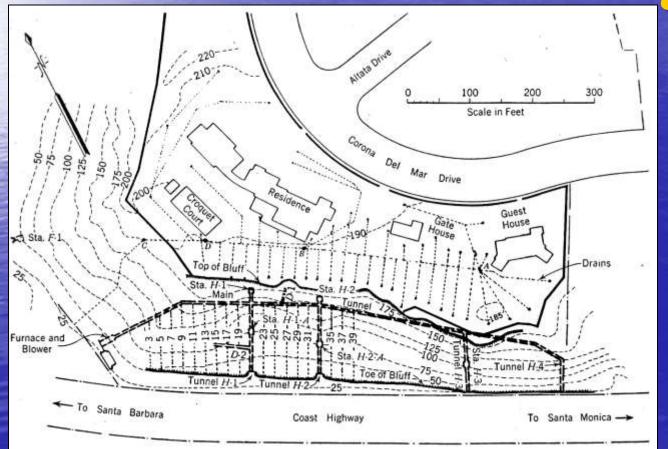
1932 Quelinda Estate Landslide



- The Quelinda Estate slide shut down Pacific Coast Highway in 1932.
- Los Angeles engineer Robert A. Hill attacked the clay seam at the base of the cliffs using hot air to desiccate the clay







An ingenious system of tunnels were excavated and hot air was circulated through these to hasten desiccation of the low strength clay layer.



How many years does it take to forget about past problems?

The Quelinda Slide repair soldiered on successfully for about 15 years. At that juncture, the problem seemed solved because the site hadn't experienced any additional sliding, so the decision was made to shut down the furnace and the blowers, to save money.



Consulting geologist Harry R. Johnson used aerial photo overlays to illustrate the geologic conditions along 1-3/4 miles of coastline, shown here.

March 1933 Long Beach Earthquake

*Carson City



Terror-Stricken City Emerging From Frightful Experience LONG BEACH SUN

53 DIE, 1000 HURT AS EARTHQUAKE SPREADS DESTRUCTION IN LONG BEACH

Transformed By Earth Shock

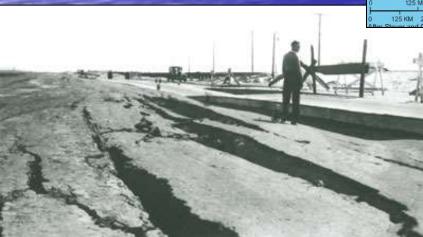
Phoenix *

Southland Communities As Buildings Crumble



250 Miles

125 KM 250 KM





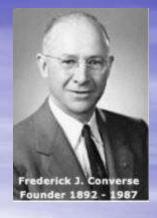


R. V. Labarre Consulting Engineer and Lebarre & Converse



- Robert Volant Labarre, PE, SE was born in Gretna, Louisiana (across the Mississippi River from New Orleans) in October 1873. He began his career as a draftsman, then worked as a civil engineer across the South, from Houston to Miami.
- By 1914 he was running his own construction firm in Birmingham, Alabama, doing work for the Southern Railway, among other clients. In 1917 the Foundation Company of New York secured a contract with the French government to build steel-hulled merchant ships of 4,200 tons in New Orleans. Lebarre was hired to oversee construction of the sheetpile cofferdam drydocks and slipways along the new Inner Harbor Navigation Canal.
- During the First World War he accepted a captain's commission in the Army Corps of Engineers, teaching civil engineering for the Corps' Engineer Reserve Officers' Training Camp. After the war he referred to himself as "Cap Labarre," and used "Captain R.V. Labarre" as his byline in the BSSA articles he published in 1936 and '37.

- Lebarre's role in the construction of the Inner Harbor Navigation Canal in New Orleans gave him experience dealing with dredge spoils, soil consolidation, dewatering, and port facilities, which were to sustain him through the balance of his professional career.
- After the war Lebarre rejoined the Foundation Company, and spent most of the 1920s working in the Detroit area on construction projects for the automotive industry, which expanded dramatically during that decade. When the Great Depression struck, he retired and moved to Glendale.
- Finding retirement dull and Los Angeles teeming with development, he began consulting as a foundation engineer, and was registered as Civil Engineer #298 in 1929.
- Lebarre designed and built equipment for testing the bearing capacity of soils for building foundations. In early 1930 Lebarre enticed Caltech Professor Fred Converse to work with him as a consultant. Converse accepted because Lebarre was in active correspondence with Austrian Professor Karl Terzaghi (1883-1963). Terzaghi's articles had recently appeared in Engineering News Record, while working on differential settlement problems at the Massachusetts Institute of Technology (MIT).



Lebarre & Converse, Consulting Foundation Engineers (1933-36)

In January 1933 Fred Converse agreed to form a partnership with Lebarre, making them the first soils engineers working out of the Los Angeles area. Converse continued teaching at Caltech.

- The Long Beach Earthquake of March 10th 1933 changed everything. Following the quake, Lebarre served as one of two ASCE representatives on the prestigious Joint Technical Committee on Earthquake Protection chaired by Caltech President Robert A. Milliken.
- Cap Labarre also capitalized on the passage of the Field Act in 1933, because it required retrofitting or replacement of more than 230 school buildings in southern California which had been constructed of unreinforced masonry. Lebarre became one of the founding members of the Structural Engineers Association of Southern California (SEAOC) that same year, along with Professors R.R. Martel, F.J. Converse, and T. VonKarman at Caltech.
- Lebarre also developed several plate and pile load tests to ascertain the insitu bearing capacity of foundations (in the July 1933 issue of *Popular Science*) and later, "*Test Pit Exploration Kit in Foundation Study,"* which appeared in *Engineering News Record* in 1936. Labarre and Converse also penned an article in the April 1933 issue of *Civil Engineering*. Lebarre was the only engineer who marketed himself to prepare foundation engineering reports, which structural engineers desperately needed to carry out this work, during the height of the Great Depression.

R.V. Lebarre, Karl Terzaghi, Trent Dames, and Bill Moore

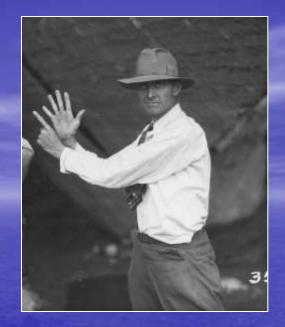
- In 1935 Lebarre hired Caltech grads **Bill Moore** and **Trent Dames** to perform plate load tests using 12" x 12" steel plates on exposed ground to back out the allowable bearing capacity of the various school sites.
- They would load these plates until they started sinking into the ground, assuming this to be the ultimate bearing capacity by dividing the figure by 2, 3, or 4, depending on the type of foundation (2 for an isolated footing beneath a building interior, 3 for an exterior footing, and by 4 for continuous strip footings).



- Labarre hosted Karl Terzaghi on his tour of California in 1936, following the *First International Conference on Soil Mechanics and Foundation Engineering* at Harvard. Labarre sent a chauffeured car to pick up Terzaghi in San Francisco and took him on a scenic tour of California, through Yosemite, over Tioga Pass, and down the Owens Valley, along the Los Angeles Aqueduct.
- * Karl Terzaghi was well received in southern California, including a dinner at Caltech hosted by Prof. Theodore von Karman (1881-1963), who directed the Aeronautical Laboratory. They were joined by Richard von Mises (1883-1953), then teaching at Harvard. The three men had served in the same Austro-Hungarian aviation engineering unit during the First World War! What storied academic careers they all went on to have in the United States!

Dry Density Compaction Tests





Ralph Proctor was the resident engineer for the ill-fated St. Francis Dam during its construction in 1924-26. This led to his role in developing a method for evaluating soils compaction as the resident engineer for the Bouquet Canyon Dams.

- Ralph Proctor was a field engineer on the Bouquet Canyon Dams in 1932-34. The Construction Superintendent was H.L. Jacques.
- Jacques asked Proctor to devise a method of testing the compacted fill so the Los Angeles Dept of Water & Power could demonstrate to the world that they were constructing the safest dam possible.
- Note use of horses as well as a dump truck (in background) to pull the sheepsfoot rollers.

Engineering News-Record

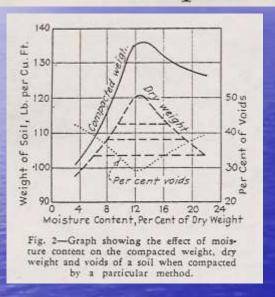
Vol. 111 New York, August 31, 1933

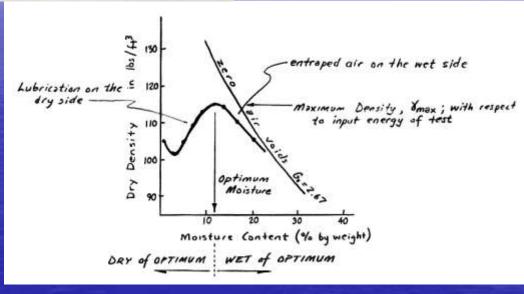
PROCTOR'S FOUR ARTICLES in 1933

First of Four Articles on the Design and Construction of Rolled-Earth Dams

Fundamental Principles of Soil Compaction

No. 9





- Ralph Proctor devised an alternative method to California Test 216 introduced by the California Division of Highways in 1929, which measures the *maximum wet density* ('compacted weight,' shown above left), and controls the compactive effort based on the total weight, not the volume, of the test sample (Caltrans still uses this alternative test procedure).
- The primary advantage of Proctor's procedure is that the test results could be computed onsite, as evaporation of the compacted sample is not necessary. This allowed immediate adjustment of the soil water content, which was the critical variable the contractor needed to know.

The Standard Proctor Compaction Test (1933)



Standard Proctor Compaction
Mold with collar extension
and drop hammer in
cylindrical sleeve

- The original Proctor Compaction Test of 1933
 used cylindrical mold 4 inches in diameter and
 4.6 inches high, with a removable mold collar 2.5
 inches high. The mold volume is 1/30th cubic
 foot
- A 5.5 pound hammer, 2 inches in diameter, was pulled upward and allowed to free-fall 12 inches, onto the soil (5.5 ft-lbs per blow)
- The soil was compacted in three lifts, with an average thickness of 1.33 inches/lift.
- 25 blows were exerted per lift, which equals 25 x 5.5 = 137.5 ft-lbs. The total input energy for the three lifts was 3 x 137.5 = 412.50 ft-lbs on a soil sample with a volume of 1/30th cubic foot. This equals 12,400 ft-lbs of compactive energy per cubic foot of soil
- Designated ASTM Test D698 (adopted July 1950), AASHTO T99 (adopted 1950), and BurRec E11 (adopted 1947).

Ralph Proctor of the Proctor Compaction Test



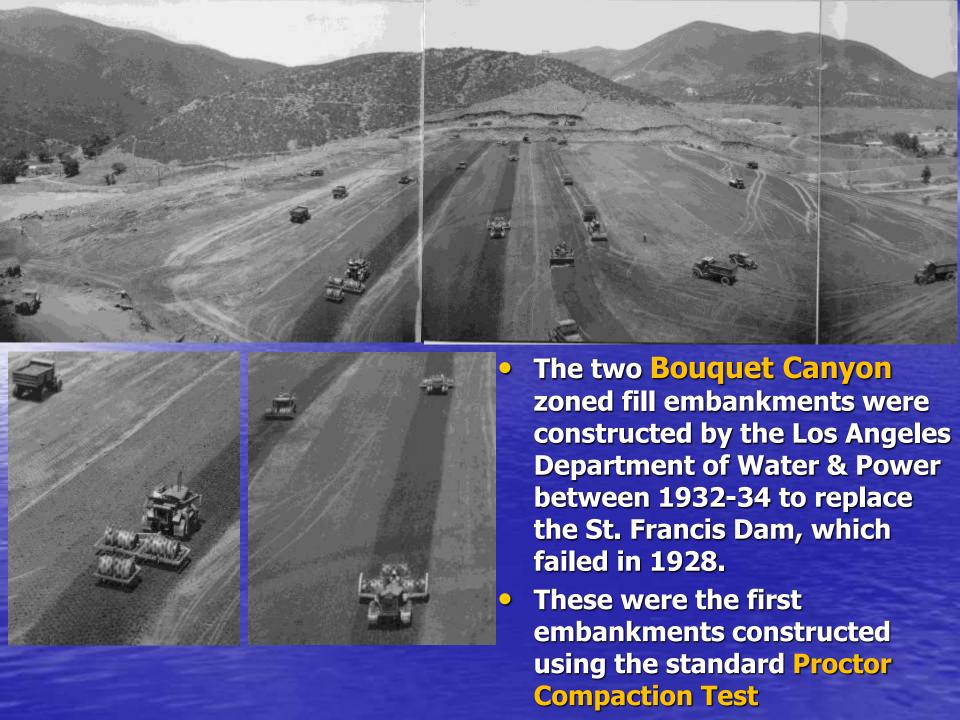
Ralph R. Proctor, PE (1894-1962)

- Ralph Roscoe Proctor joined the Los Angeles Bureau of Waterworks & Supply in 1916 (which was absorbed into the Department of Water & Power in 1931), after studying engineering at USC for two years.
- He served in Co. E. Of the 23rd Engineers in Europe during the First World War, constructing railroads.
- Proctor returned to Los Angeles and rejoined the Department of Water & Power. He was the resident engineer for the illfated St. Francis Dam during its construction in 1924-26 and the post-failure surveys in 1928.
- He gained considerable notoriety for his work in developing the Proctor compaction test in 1933, while working on the Bouquet Canyon Reservoir embankments.

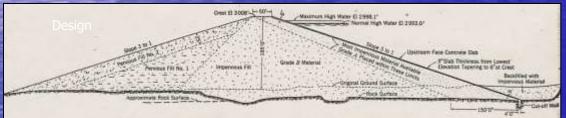
From 1933 until his retirement in 1959 he was in charge of design, construction, and maintenance of all dams in the LADWP system.

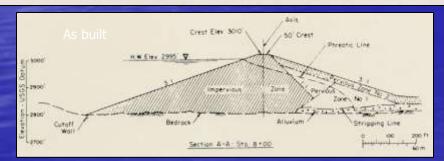
In 1948 Proctor authored four papers for the Second International Conference on Soil Mechanics in Rotterdam, including one titled *The Elimination of Hydrostatic Uplift Pressures in New Earthfill Dams*, considered one of the pioneering papers on a subject, triggered by the humiliation of the St. Francis Dam disaster.

His last project for LADWP was as the resident engineer for construction of the Baldwin Hills Reservoir in 1953-54, which failed 14 months after his death, in December 1963.

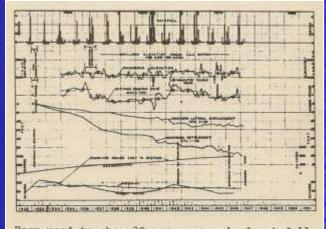








- Upper The main embankment of Bouquet Canyon Dam was completed in March 1934, with concrete paving of the upstream face.
- Middle Original design for main embankment
- As-built section thru main embankment – but in opposite direction
- Below right Long-term monitoring of embankment



Form used to show 20 years record of rainfall, reservoir stages, seepage, lateral displacement and settlement of crest of dam, and dissolved solids in seepage water, together with earthquake, repair, grouting and related data.





- In 1937 Letourneau introduced the revolutionary Tournapull Scraper, shown here. It employed a clever cantilever design with an articulated U-joint, which allowed it to turn a very tight radius, with straight-away speeds of up to 25 mph
- During the Second World War Letourneau turned out 70% of the earth moving equipment used by Allied forces, from five manufacturing plants, including one in Australia.

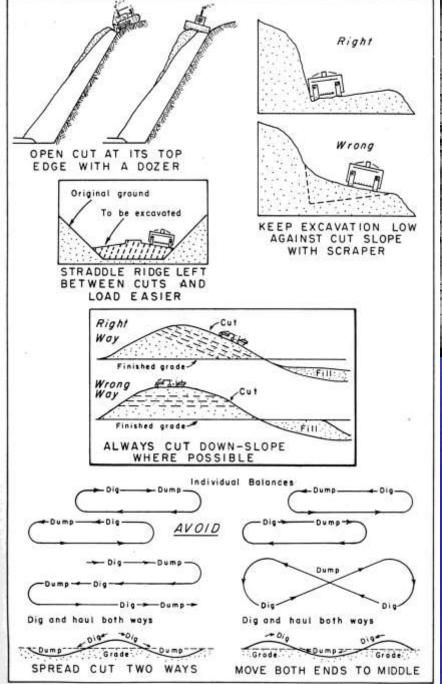


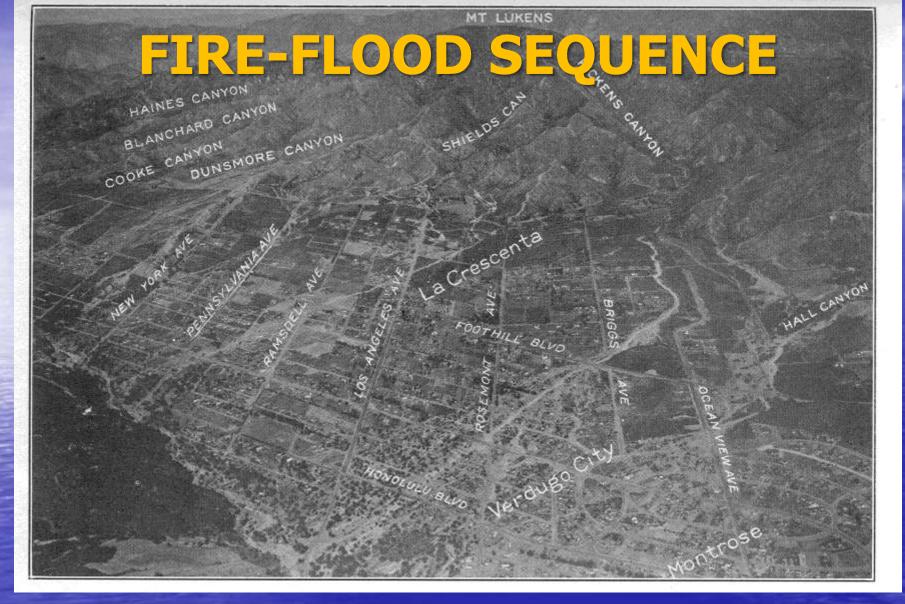
Figure 7. Some principles of excavation using a dozer and scraper.

(After Park, 1942.)

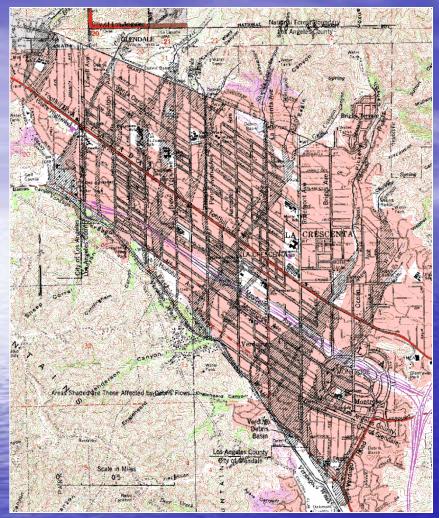


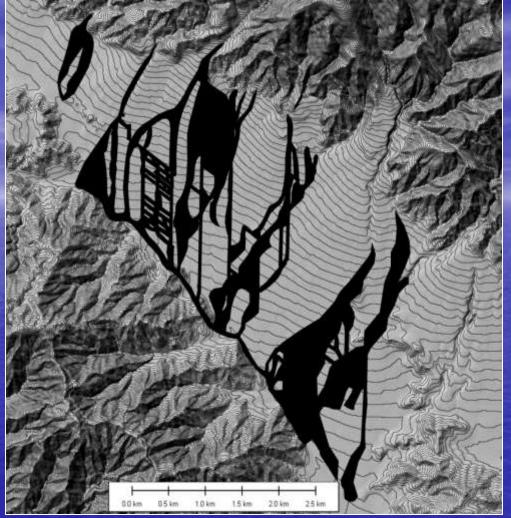
Excavation and Grading Protocols

 The plethora of grading and excavation work carried out in the 1930s and 40s resulted in well-established protocols for how grading jobs could best be accomplished, employing gravity whenever possible, to reduce energy expenditures.



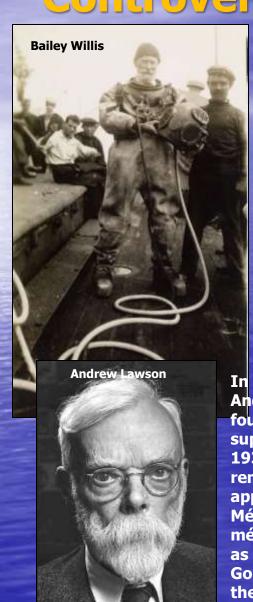
The Dec 31, 1933-Jan 1, 1934 Montrose-LaCresenta debris flows damaged or destroyed 600 homes and killed 44. At least 600,000 cubic yards of material was deposited on the fan that evening (the actual volume appears to have been considerably higher).

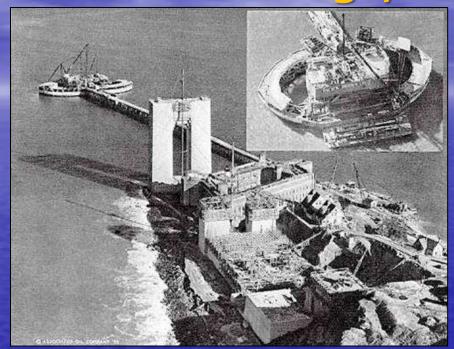




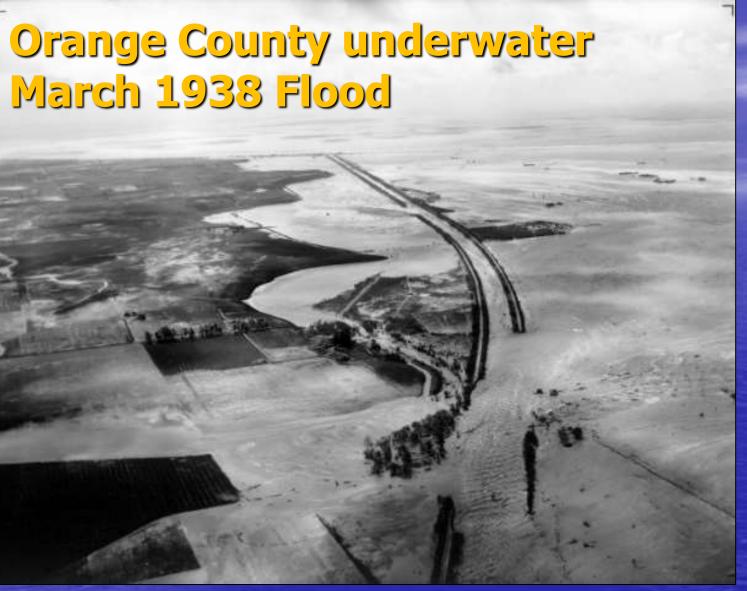
- Left: DRG overlay of 1934 Montrose-LaCresenta debris flows, which occurred several weeks after a series of brush fires in the watersheds at upper right. This is known as a fire-flood sequence.
- Right: DEM overlay of same map. Note flow paths along streets.
 Los Angeles County constructed nine debris basins to catch debris
 from these watersheds. These basins were severely tested in the
 spring of 2010.

South Tower Serpentine Foundation Controversy Golden Gate Bridge, 1934





In 1934 Stanford Geology Professor Bailey Willis and Berkeley geology Professor Andrew Lawson got into a heated debate about the stability of the serpentine foundation supporting the South Tower of the Golden Gate Bridge. Lawson had supervised the initial exploration of the anchor and tower sites in 1929-30. In early 1934 excavations for the south Tower began, and over 60,000 yds³ of rock was removed with aid of explosives. The excavations were carried down to a depth of approximately -100 feet below sea level, to create a suitable socket in the Fransiscan Mélange. After the caisson was de-watered Willis made a personal inspection of the mélange exposed in the excavation. He felt that the seams of serpentine could serve as planes of weakness that could cause a catastrophic failure of the South Tower. The Golden Gate Bridge Board of Consultants decided to agree with Professor Lawson, and the two professors demonstrated that two geologists seldom agree on everything, all of the time.



 Heavy storms in early March 1938 slammed into Southern California, dropping as much as 36 inches of precipitation on the San Bernardino Mountains, triggering flooding of lowland areas, like that shown here, along the Santa Ana River in Orange County.

FEDERAL FLOOD CONTROL ACTS





Damage like that shown above along the channelized Los Angeles River in the March 1938 flood spurred the Federal Flood Control Acts of 1936, 1941 and 1944, which placed the U.S. Corps of Engineers into a prominent role to help provide flood control nationwide, on a 65/35 shared cost basis with local agencies.

Constructing Flood Control

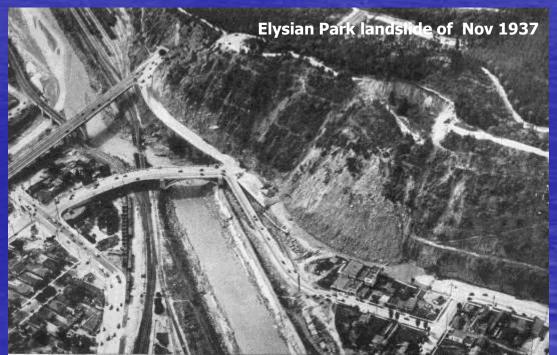
Infrastructure



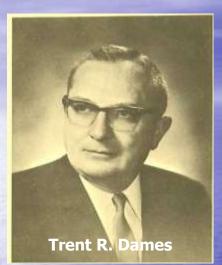


a large number of federal-match projects for flood control infrastructure were built, employing a cost share of 65% federal and 35% local funds





Dames & Moore established in Aug 1938



Trent R. Dames was born in Brooklyn, New York, in 1911 and at age seven moved with his family to southern California, where he attended San Diego High School and developed an interest in civil engineering. William W. Moore was a native of Pasadena, born three months after his future business partner. The two men met one another at the California Institute of Technology (Caltech), where both earned Bachelor of Science degrees in civil engineering in 1933 and master's degrees in 1934.



They became intrigued by the study of soil mechanics and foundation engineering, which was then in its infancy. Caltech didn't offer any courses in soil mechanics, so they lobbied their professors to include it as part of the school's post-graduate courses. In the spring of 1934 Fred Converse taught the first soil mechanics course in California, using Bill Housel's University of Michigan Research Bulletin (profiled earlier).

When Dams and Moore left Caltech in mid 1934, each possessed expertise in a field few others had ever heard of. The civil engineering world was about to be changed...

DAMES & MOORE, Civil Engineers

Foundation Investigations • Soil Mechanics Engineering

LOS ANGELES . SAN FRANCISCO . PORTLAND . SEATTLE . NEW YORK

August 28, 1950

VERNON A. SMOOTS

WILLIAM ENKEBOLL





Leroy Crandall

It took several years before Dames and Moore realized that their best chance to put their academic training to work was to form their own firm. After graduation Moore took a position with the U.S. Coast and Geodetic Survey, while Dames joined the Bureau of Reclamation. The two remained in touch with one another, subsequently taking jobs with Labarre & Converse, between 1935-37.

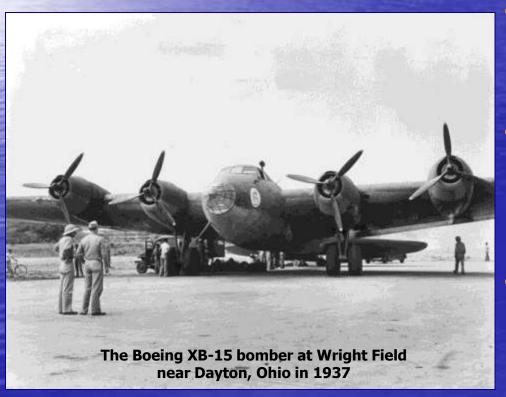
In August 1938 they decided to form a partnership, but Moore kept his job with the Corps of Engineers LA District office, working on weekends and during the evenings, while Dames worked out of his home in Pasadena. When their book of business was sufficient to keep Moore busy full-time, he quit his job with the Corps.

Their work load took off in 1940 when defense related suddenly soared, as war materials and facilities were expanded and constructed along the Pacific. In 1941 they established branch offices in Seattle and San Francisco. Leroy Crandall became the firm's 3rd partner, in 1946.

The Modified Proctor Compaction test also evolved in California, during World War II to support bomber loads on runways







Need to increase bearing capacity

- Up through the mid-1930s military aircraft were relatively light, and could be supported on natural fields with grass runways, like that shown at upper left
- In 1937 the Army Air Corps began flight testing new long range bombers, like the Boeing XB-15, at lower left.
- This aircraft had a gross takeoff weight of 71,000 lbs, spread on tandem main gear tires and a single tail wheel. It could only use select concrete runways.
- Prior to this time, 12,500 lbs were the heaviest wheel loads any runway had been designed to handle

The airfield runway crisis of 1941





- The massive Douglas B-19 bomber had a wingspan of 212 feet with a maximum gross weight of 162,000 lbs, spread onto just three tires. Its extreme weight engendered bearing failure of the concrete ramp at the Douglas factory in Santa Monica, forcing delays until a thicker concrete runway could be constructed.
- On June 27, 1941 the B-19 departed Clover Field in Santa Monica and landed at March Field near Riverside, California. Upon touchdown and taxi its massive 8-foot diameter tires inflicted noticeable damage to the taxiways and parking aprons. This damage hastened an investigation by the Army Corps of Engineers, eventually leading to development of new design procedures to enhance compaction of pavement subgrades, which became the Modified Proctor Compaction Test.



Most bearing capacity failures occurred on taxiways in the European Theater







During World War II, the Corps of Engineers noted an increasing problem with pavement distress near the edges of heavily traveled taxiways. The weak link appeared to be subgrade preparation (images from 401st Bomb Group at Deenethorpe, UK)

The Corps of
Engineers
Airfield Pavement
Design Advisory
Council
at the Stockton Test
Track in California in
1944

Army Corps of Engineers Airfield Pavement
Design Advisory Council, standing on a B19 bomber tire at the Stockton Test Track

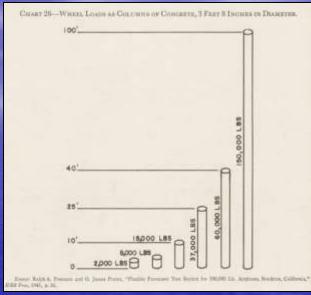


Front row (left to right): Colonel Henry C. Wolfe (who had worked on the Fort Peck Dam soil mechanics problems), Prof. H.M. Westergaard of Harvard, and Dr. Philip C. Rutledge of Moran, Proctor, Freeman & Meuser. Back row, left to right: Prof. Arthur Casagrande of Harvard, Thomas A. Middlebrooks (the Corps senior expert in soil mechanics, who had also worked on the Fort Peck Dam landslide), James L. Land of the Alabama State Highway Department, and O. James Porter of the California Division of Highways, who originated the CBR test procedure in 1928.

Stockton Airfield Test Track



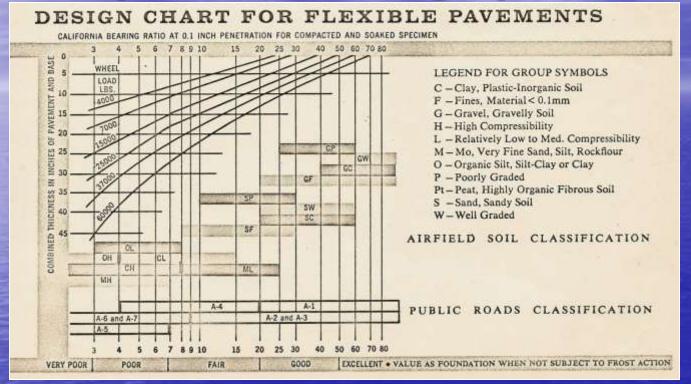
240,000 lb pneumatic roller used in the runway pavement tests at the Stockton Airfield test track



Aircraft wheel loads depicted as equivalent columns of concrete, three feet in diameter (from Freeman and Porter, 1945)

Stockton Airfield was the Corps' principal test site for evaluating Pappy Porter's California Bearing Ratio (CBR) test to compare subgrade modulus with various wheel loads and repetitions, working with the California Division of Highways and the Sacramento District of the Corps of Engineers, under Porter's supervision, between 1942-45.

The Corps of Engineers developed flexible pavement design procedures



During the Second World War (1941-45) the Army Corps of Engineers developed specialized design procedures for flexible asphalt runways that incorporated the properties of the pavement subgrade, because the aircraft wheel loads are transmitted directly to the subgrade in flexible pavements. This focused attention on the importance of subgrade compaction, leading to the Modified Proctor compaction test in 1946.

These same design procedures were subsequently incorporated into post-war design of flexible asphalt highway pavements (as shown in the above chart), used in the Interstate & Defense Highway Program, beginning in 1956.









Simplified flexible pavement design methods had an enormous impact on highway and airfield construction during the **Second World War, leading** to a post-war explosion in highway construction, beginning with the first **Federal Aid to Secondary** (FAS) highways program in 1944.





The Big Bomber

With a maximum takeoff weight of 133,500 lbs, the B-29 Superfortress bomber required new pavement design methods and construction techniques at western Pacific bases



In the fall of 1944 'Pappy' Porter was dispatched to the Mariana Islands to troubleshoot the pavement problems





The landing gear of the B-29 spread 133,500 lbs on six tires

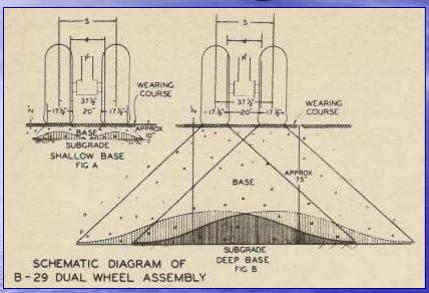
Bearing failures of B-29s in the Pacific Theater

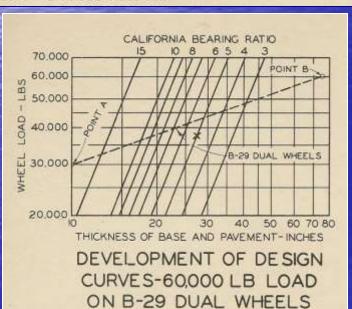
These images show B-29 bombers on taxiways in the Mariana Islands and Iwo Jima, where an unusually high degree of pavement distress occurred because of inadequate subgrade compaction. The volcanic cinders at Iwo Jima proved particularly problematic, as shown below.



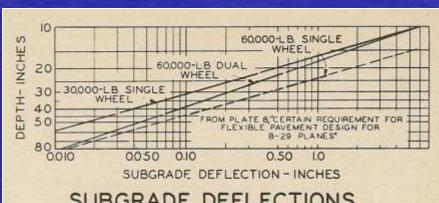


Solving the B-29 pavement design problem — focusing on subgrade compaction









SUBGRADE DEFLECTIONS
SINGLE VS DUAL WHEELS

The Modified Proctor Compaction Test (1946)



The Modifed Proctor Test uses a 10-lb hammer in an 18-inch drop sleeve. Both the original and Modified Proctor test components are shown here

- The "modified Proctor basis" of 1946 was developed by the US Army Corps of Engineers Waterways Experiment Station in Vicksburg.
- It uses the same cylindrical mold as the Standard Proctor (4 in. diameter and 4.6 in. high, with a removable mold collar 2.5 in. high). The mold volume is 1/30th cubic foot
- A 10 pound hammer, 2 inches in diameter, was pulled upward and allowed to free-fall 18 inches, onto the soil (15 ft-lbs per blow)
- The soil was compacted in five lifts, with an average thickness of 0.80 inches/lift.
- 25 blows were exerted per lift, which equals 25 x 15 = 375 ft-lbs. The total input energy for the five lifts is 5 x 375 = 1875 ft-lbs on a soil sample with a volume of $1/30^{th}$ cubic foot. This equals 56,250 ft-lbs of compactive energy per cubic foot of soil
- It was designated ASTM Test D1557 or Modified AASHTO T180, initially adopted in 1958

Post-War Expansion

During World War II more defense infrastructure was constructed in California than any other state

260,000 people were employed in aircraft manufacturing in southern California

California was the second leading state in aviation training; and #1 in training for the Marine Corps

California sported more logistics supply centers than any other state

197,000 people were employed in shipbuilding

Mexican braseros were brought in as a seasonal wartime contingency to gather crops until American labor returned from the war

Commercial expansion included major investments, such as the \$100 million Kaiser Steel plant in Fontana