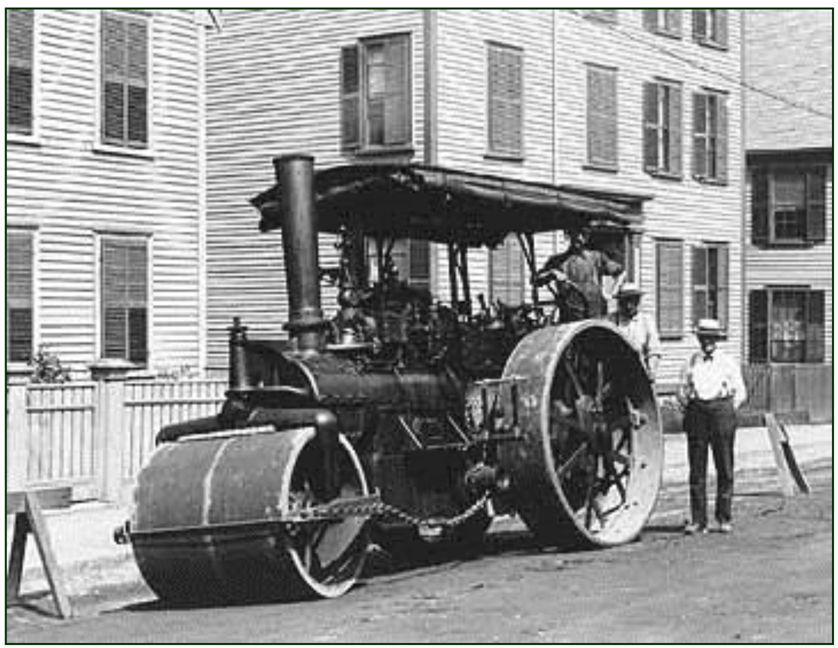
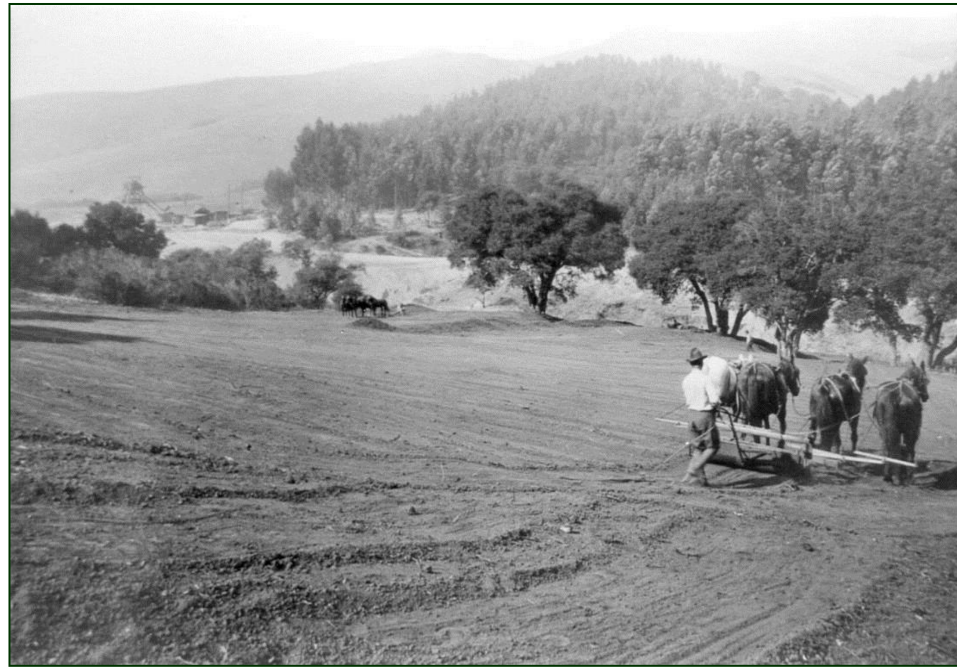
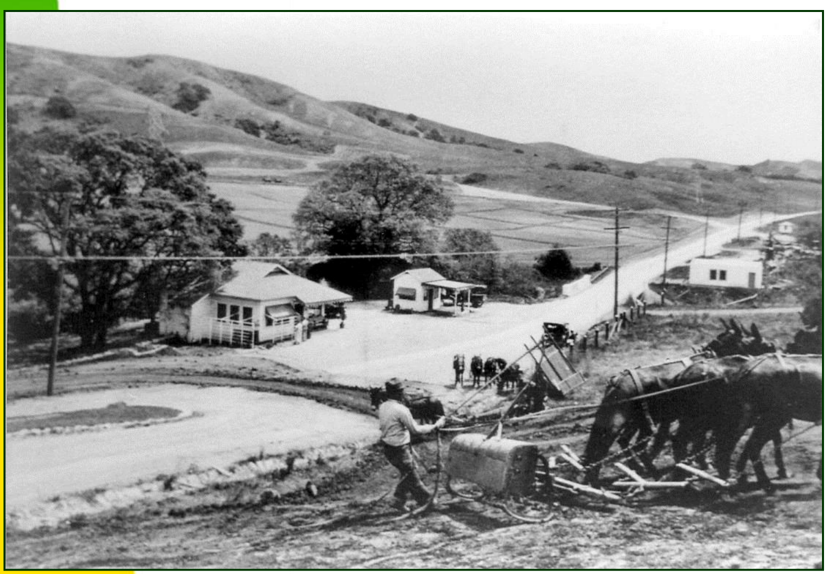
Part 1

ORIGINS OF MECHANICAL COMPACTION



THE FRESNO GRADER





- Abajiah McCall invented the horse-drawn dirt bucket scrapper in Fresno County, California in 1885.
- It became known as the "Fresno Scrapper" and was widely employed as the prime earth moving device until the widespread advent of self-powered scrappers in the 1930s.

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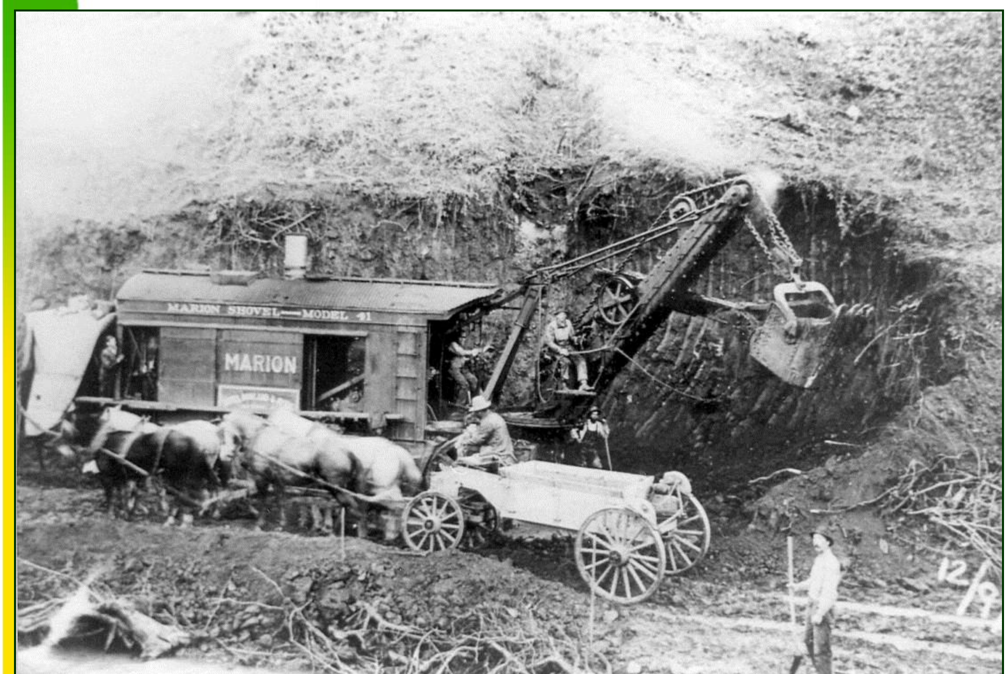
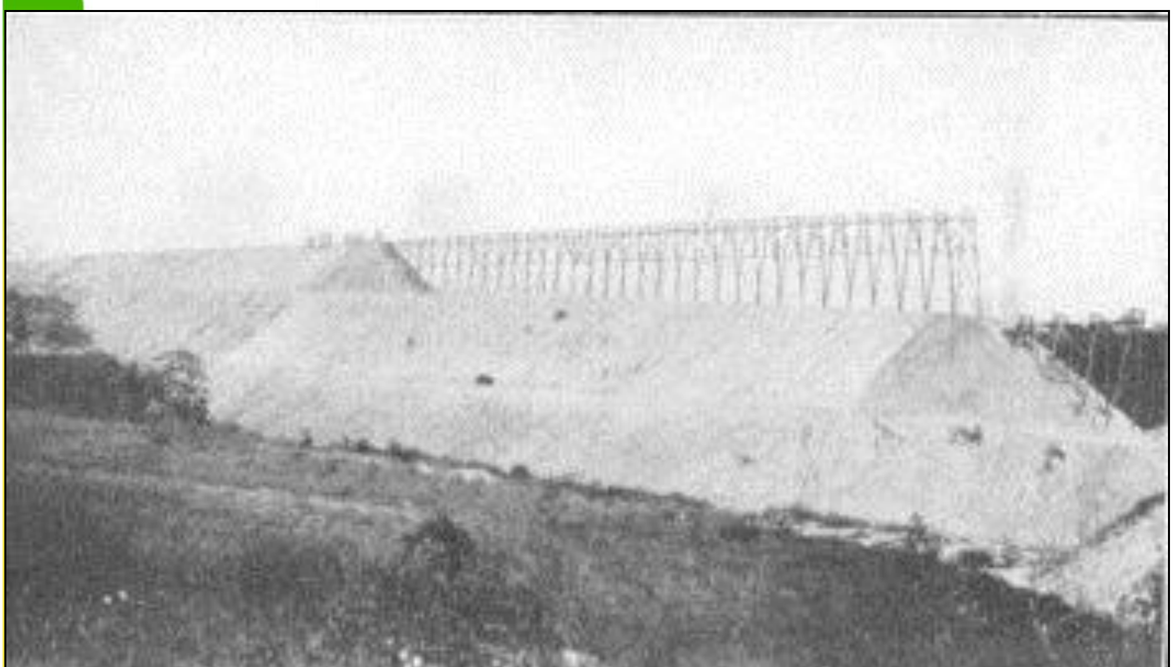
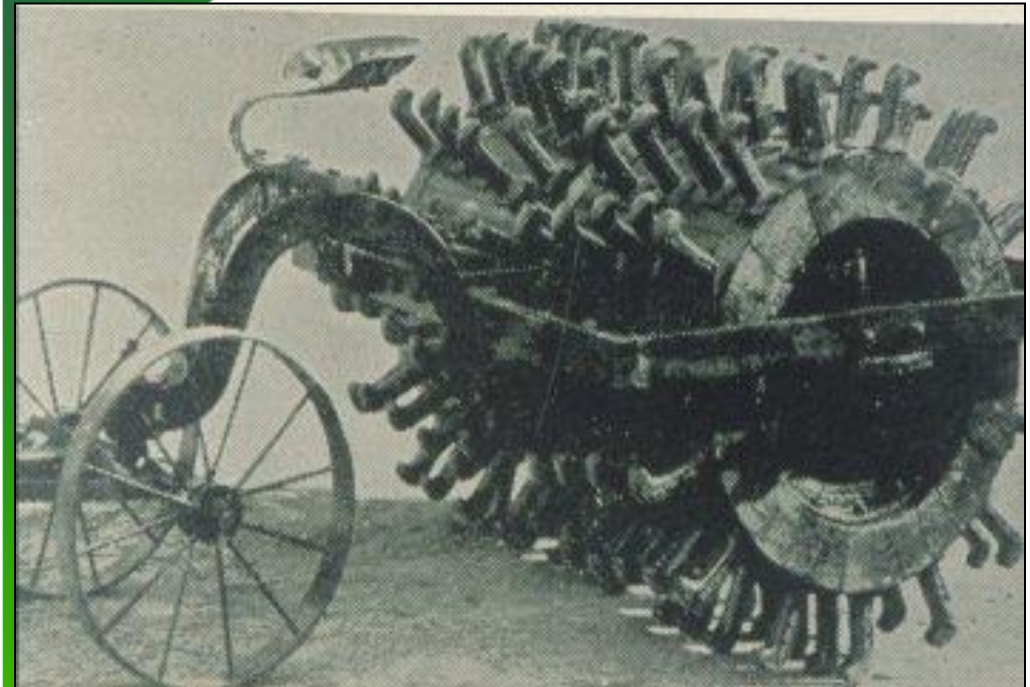


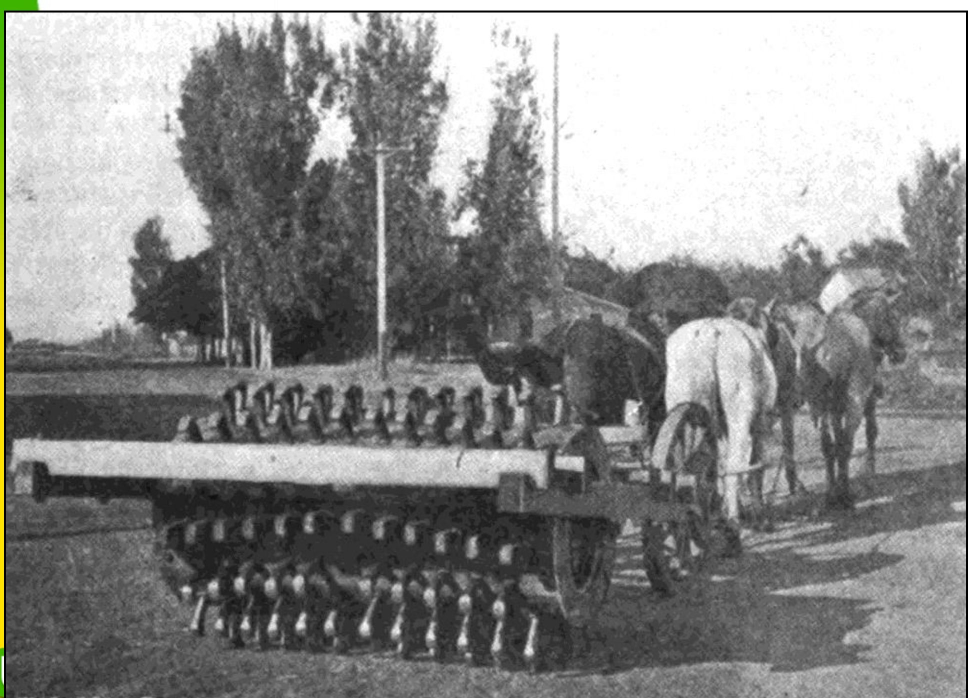
- Above left: 10-horse team pulling an elevating grader to load hopper dumping wagons during construction of the Central Reservoir for the People’s Water Co. in Oakland, California in 1909. Note old Buffalo-Springfield steam roller compacting the dam’s embankment, in left background
- Below Left: Marion shovel loading a hopper dumping wagon at the San Pablo Dam site of the East Bay Water Company in 1920, in Richmond, California. At 220 ft high with a volume of 2.2 million yds^3 it was the highest and largest earth dam in the world when completed in 1922.

"Load Compaction" of Trestle Fills



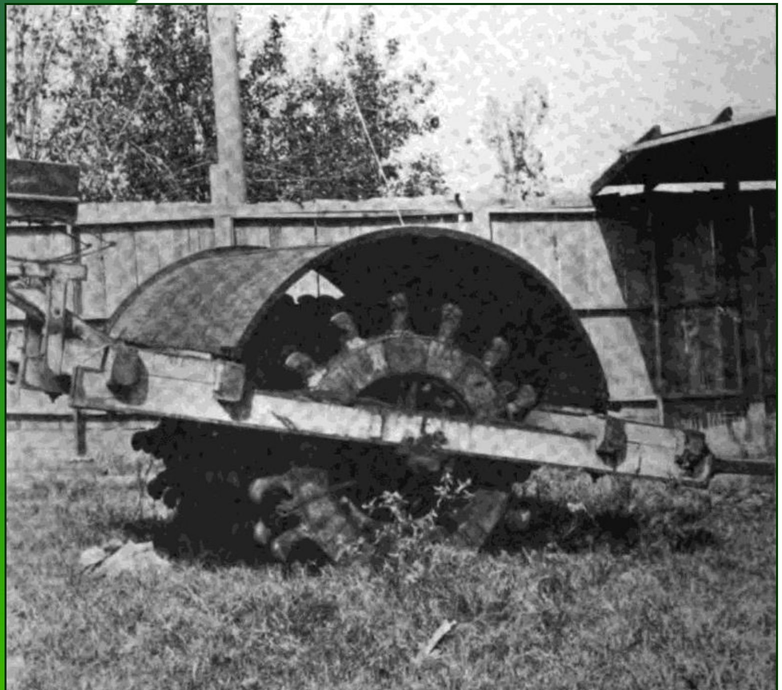
- In the early days large embankments were constructed by side-dumping rail cars or wagons from temporary wooden trestles, as shown at left.
- Engineers assumed that, after placement and infiltration by rain, the soil would ***'compact'*** under its own dead load.

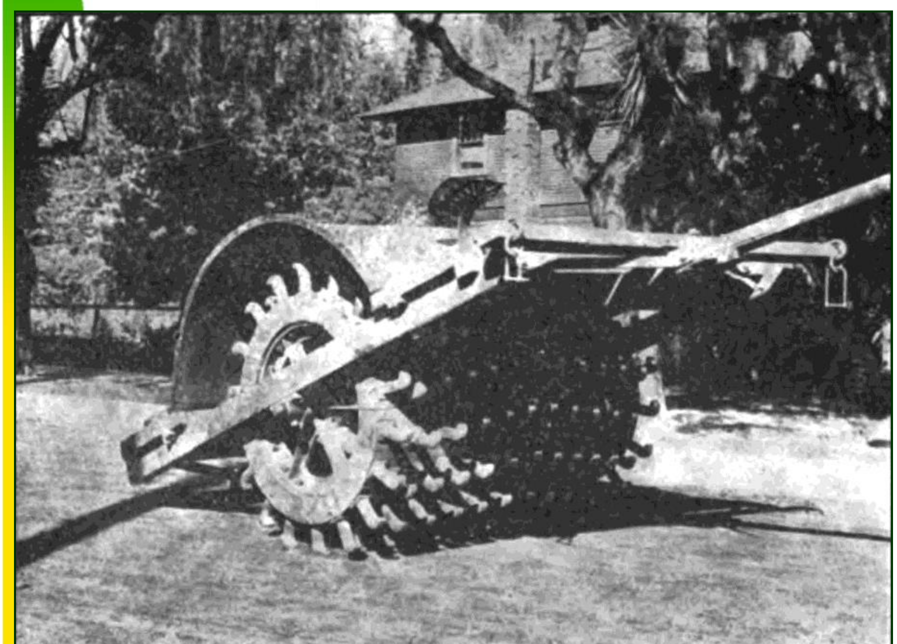




The first sheepsfoot rollers

- **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.**



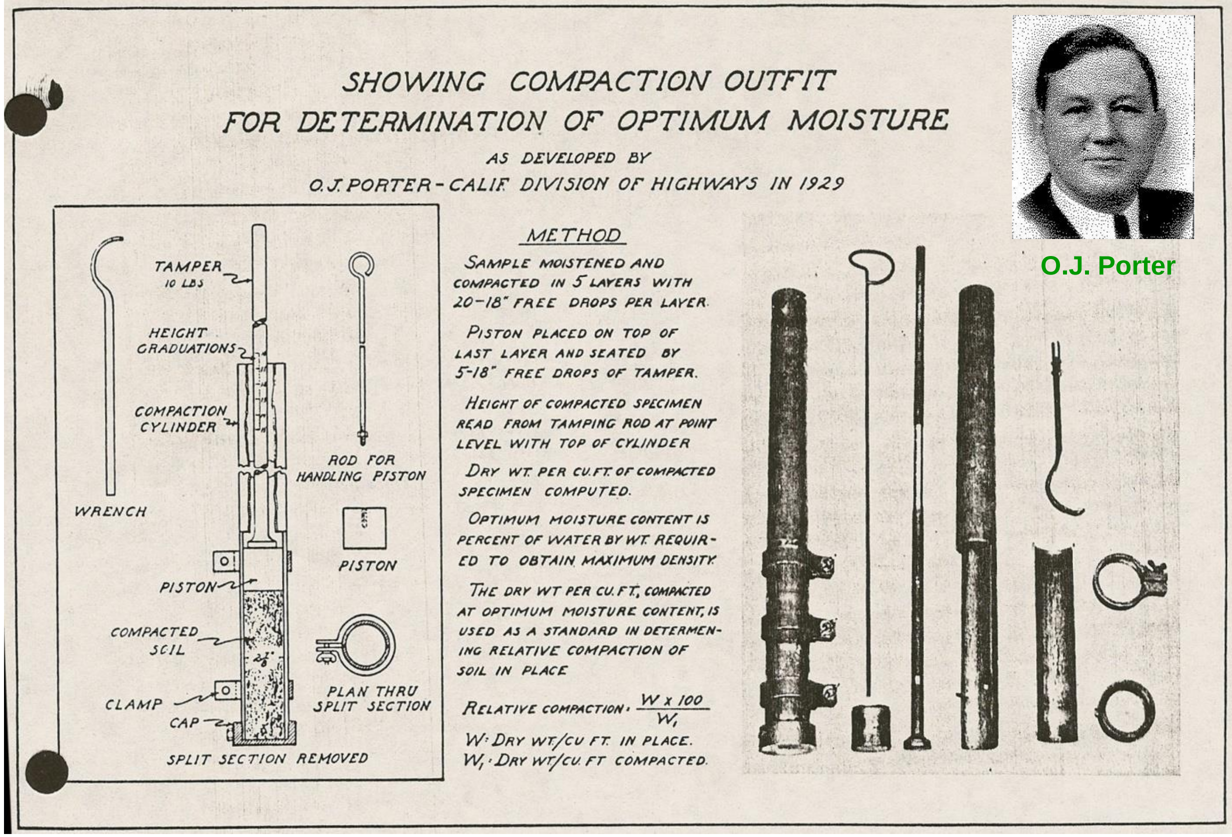


"Fitzgerald Rollers" 1906-23

- 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, is was 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.
- Thoughtful imitations soon appeared, and when the patent expired in 1923, it was not renewed.

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.

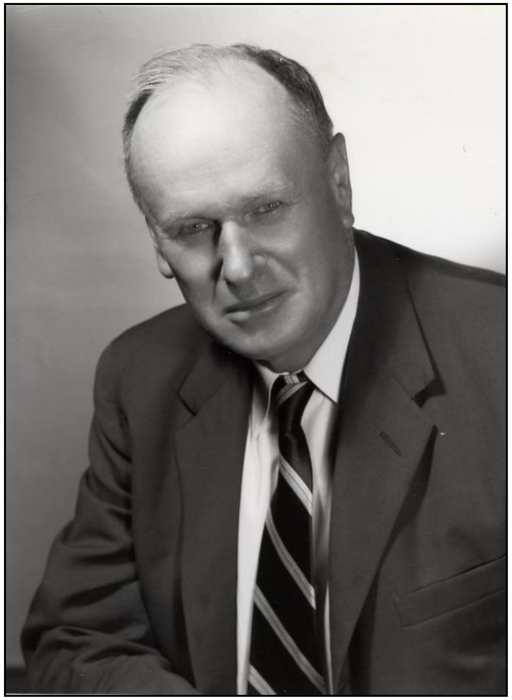


O.J. Porter

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 O. 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/ft^3 of soil.

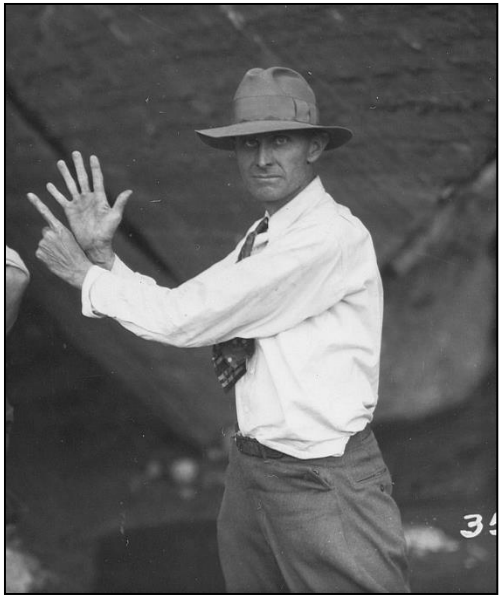
Ralph Proctor of the Proctor Compaction Test



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 never completed his college degree).
- 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 as a field engineer. He was the resident engineer for the ill-fated St. Francis Dam during its construction and the post-failure surveys in 1928.
- He gained world renown for his work in developing the soil compaction test that bears his name in 1933, while working as resident engineer on the **Bouquet Canyon Reservoir** embankments, the replacement structure for St. Francis.
- 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 dear to the hearts of LADWP engineers who lived through the humiliation of the St. Francis Dam disaster.
- His last project for LADWP was as the resident engineer for the construction of the Baldwin Hills Reservoir in 1953-54, which failed 14 months after his death, in December 1963. He joined ASCE in 1927, becoming a Fellow and Life Member.

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.

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Engineering News-Record

Vol. 111 New York, August 31, 1933 No. 9

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

Fundamental Principles of Soil Compaction

PROCTOR'S FOUR ARTICLES in 1933

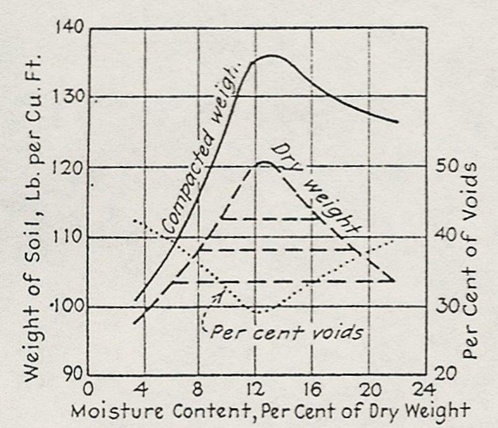
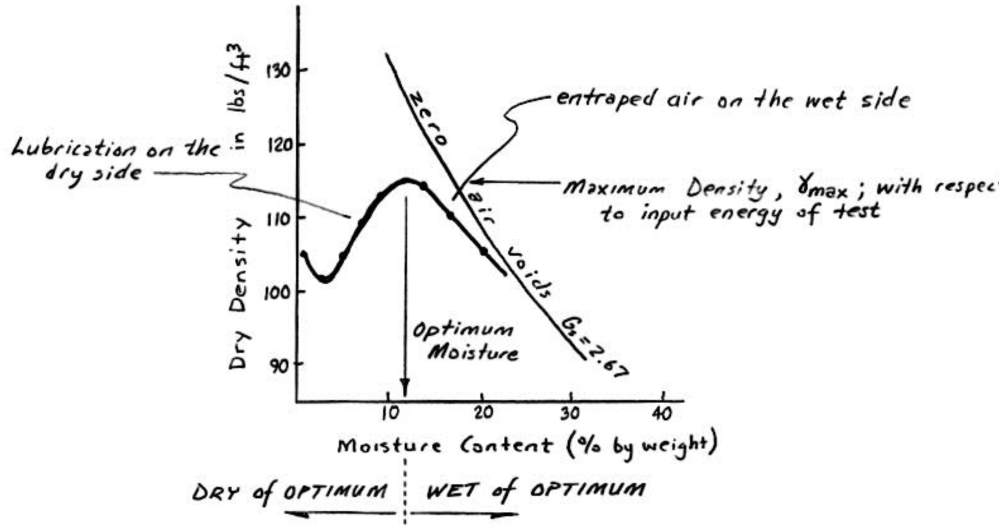


Fig. 2—Graph showing the effect of moisture content on the compacted weight, dry weight and voids of a soil when compacted by a particular method.



- 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.**

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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).

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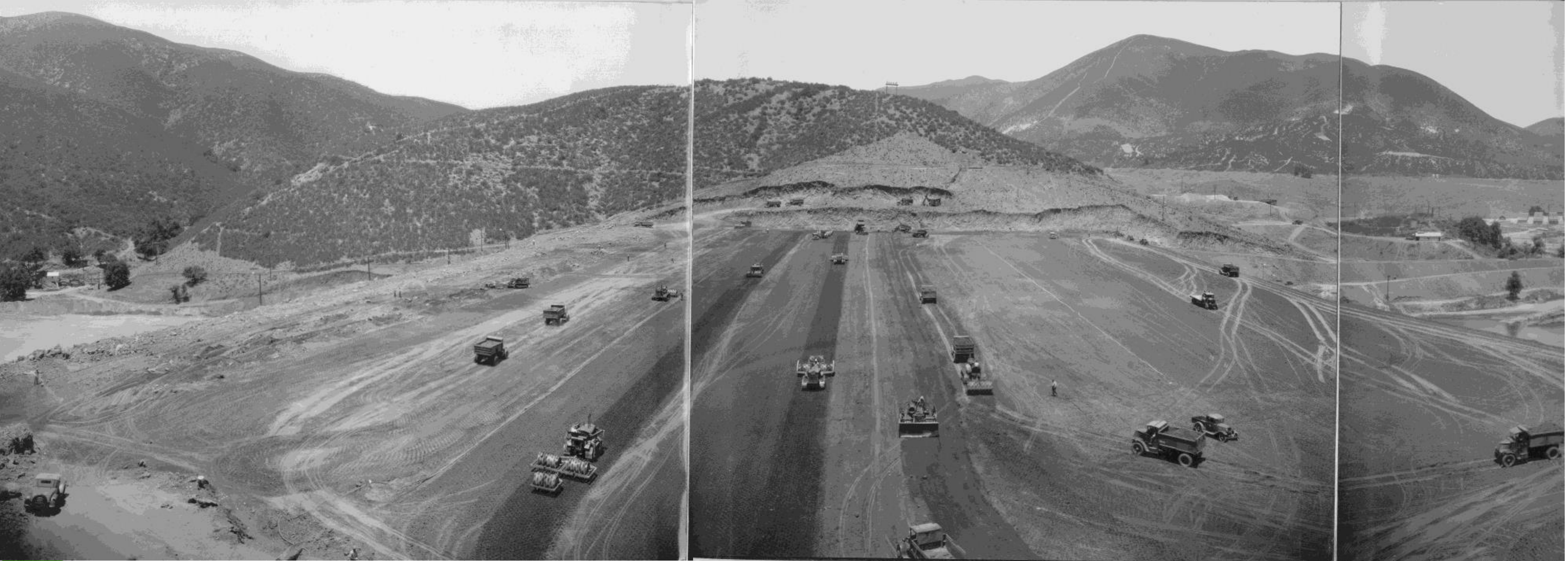

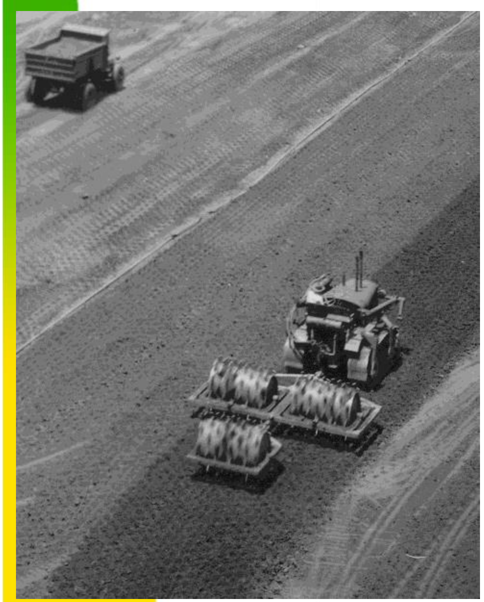

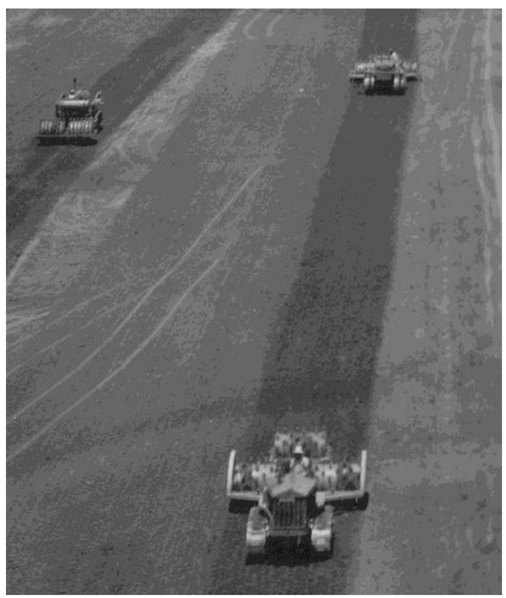

- The two Bouquet Canyon zoned fill embankments were constructed by the Los Angeles Department of Water & Power between 1932-34 to replace the St. Francis concrete dam, which failed in 1928.
- These were the first embankments constructed using the standard Proctor Compaction Test

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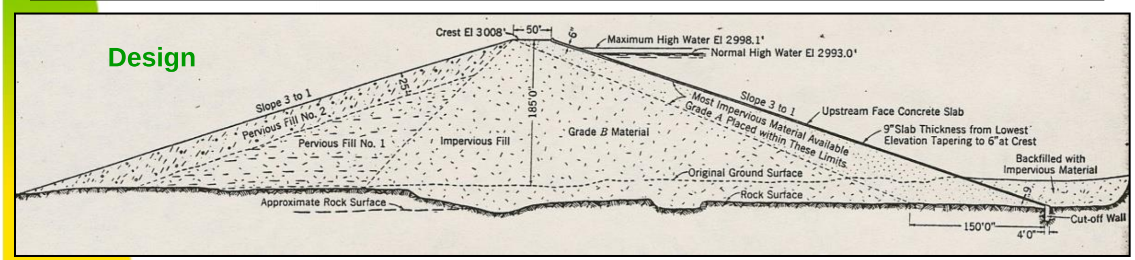
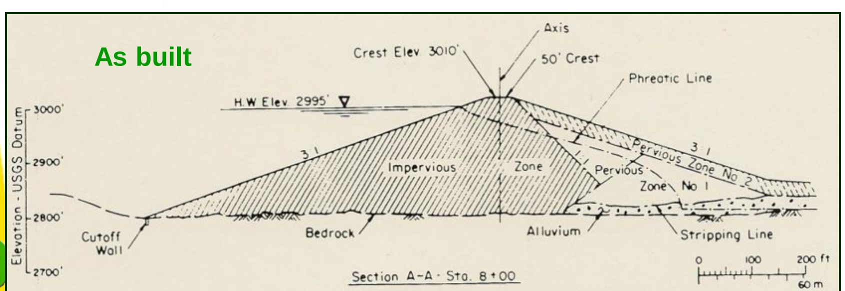
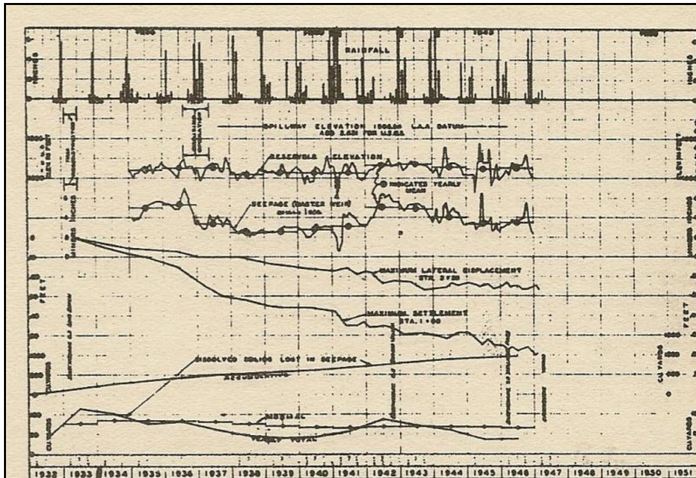
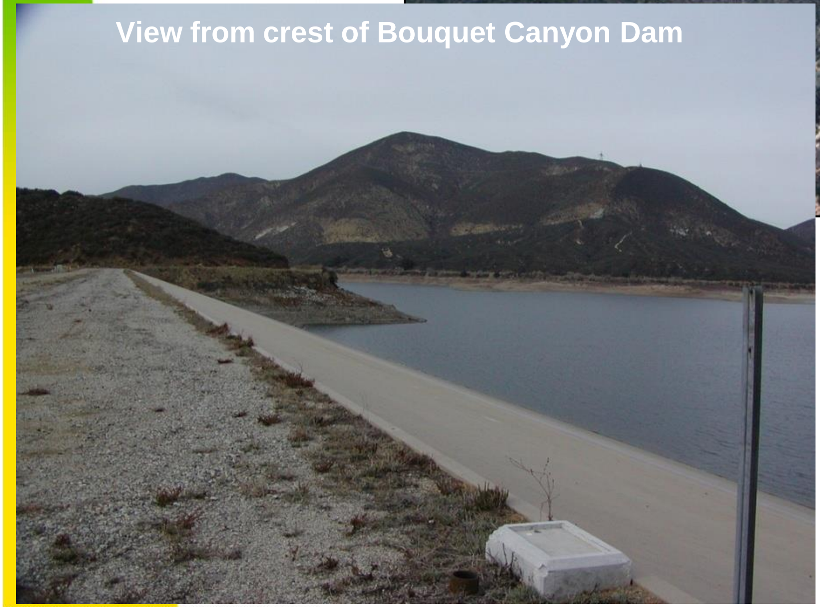
- Upper - The main embankment of Bouquet Canyon Dam was completed in March 1934, with concrete paving of the upstream face.
- Middle - Original design for main embankment
- As-built section thru main embankment – but in opposite direction
- Below right – Long-term monitoring of embankment



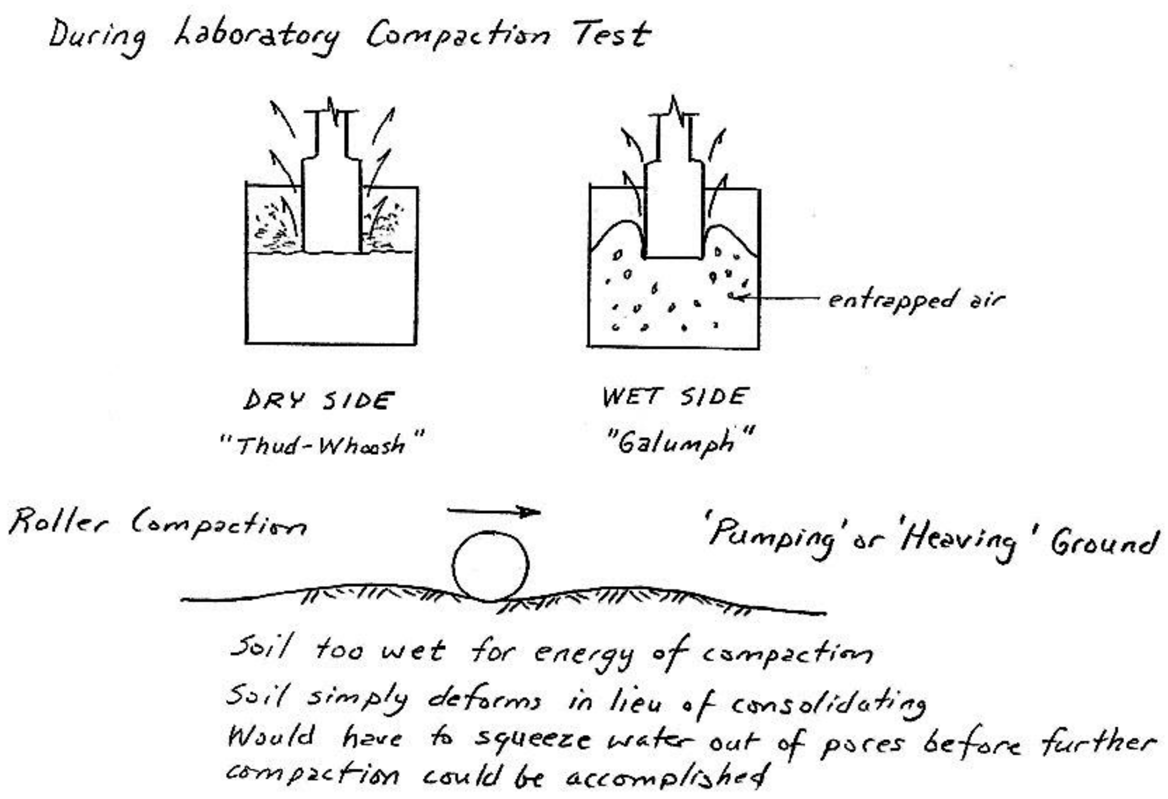


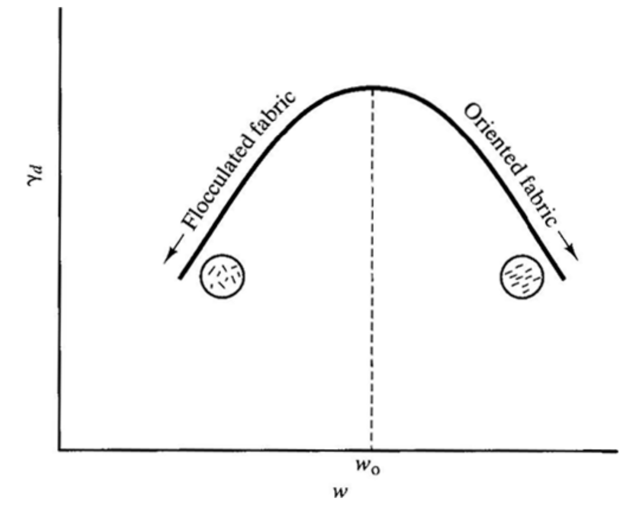


Form used to show 20 years record of rainfall, reservoir stages, seepage, lateral displacement and settlement of crest of dam, and dissolved solids in seepage water, together with earthquake, repair, grouting and related data.



- The Bouquet Canyon embankments were carefully constructed and monitored over the next 20 years. They ushered in a new era of mechanically compacted embankments. Their 3:1 upstream faces were re-lined with concrete slabs in 1981.





Soils "dry" of optimum moisture tend to be more flocculated, with a "cardhouse" fabric. Soils compacted "wet" of optimum moisture tend to be more compact, with lower void ratio

- **Sufficient moisture *must be added* to the soil to encourage lubrication of particles for better densification; but it is difficult to expel trapped air from wet cohesive soils, leading to "ground pumping" when vehicles pass over, as sketched above.**

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Standard Proctor "compaction curves"

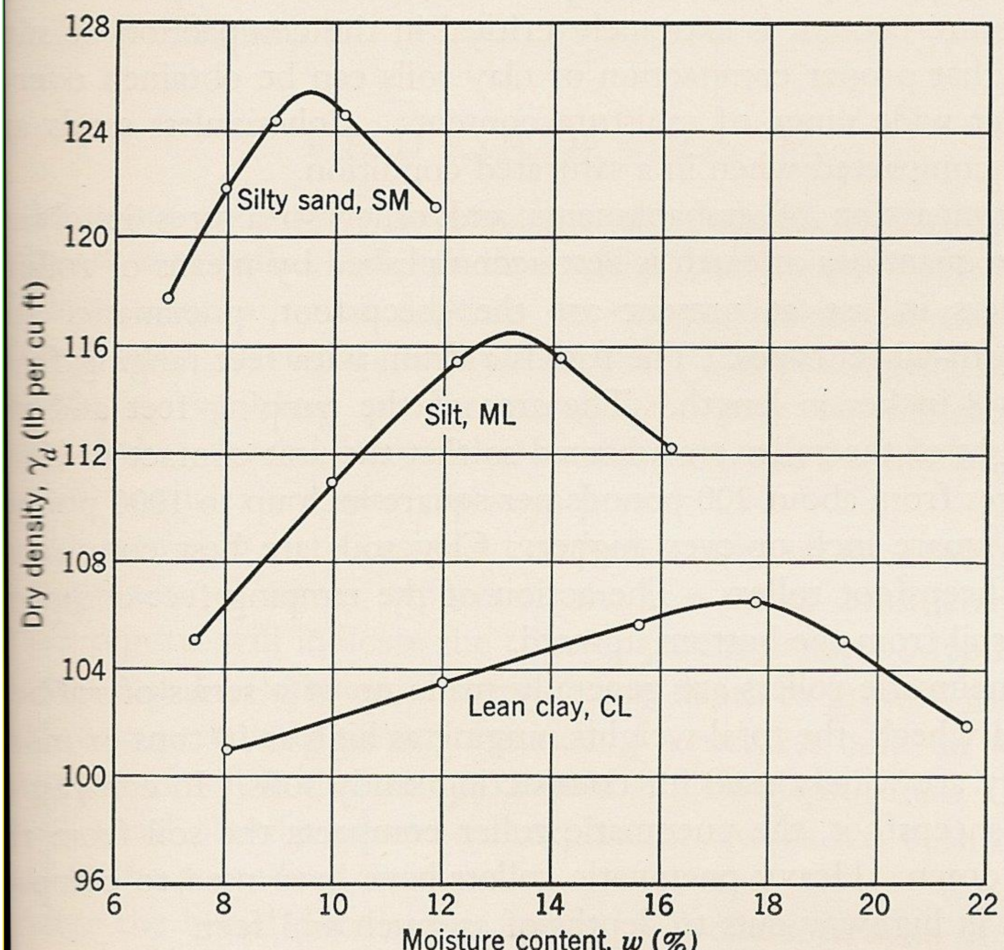
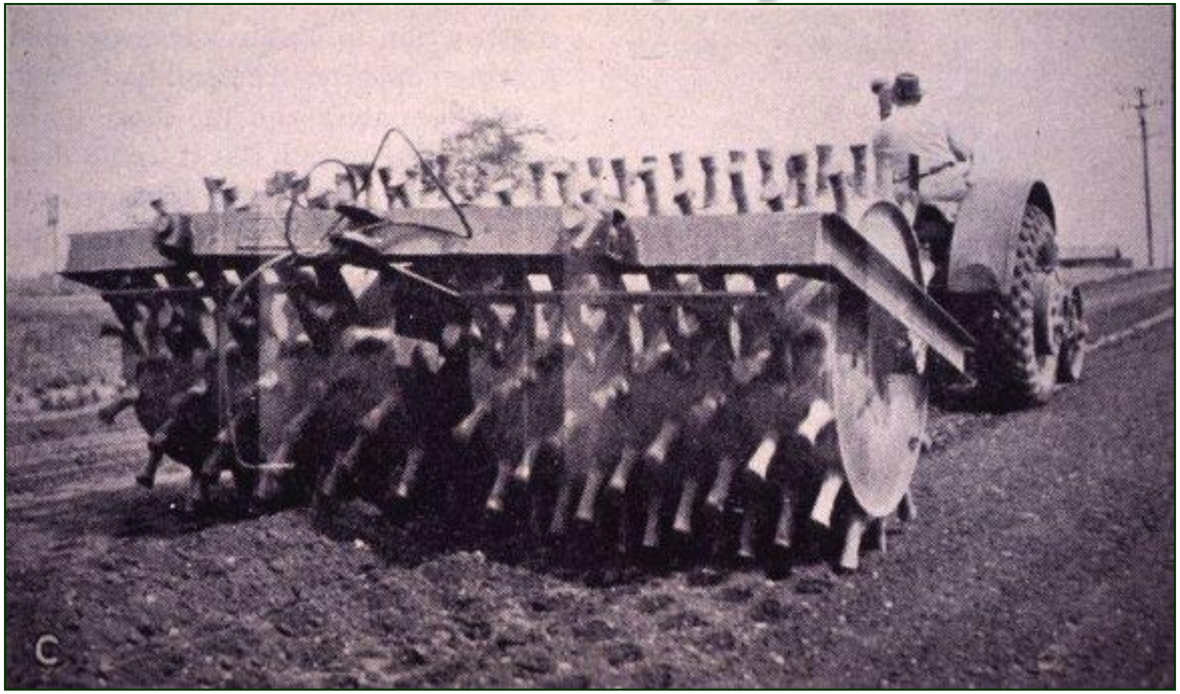


Fig. 171. Standard Proctor compaction curves.

- **Sandy materials typically require the least amount of water (<10%) to achieve good compaction**
- **Silt requires more water than sand; and**
- **Clayey soils generally require the most moisture**
- **These materials are often blended together on actual grading jobs**

Kneeding compaction advantageous for clayey soils



- Between 1904-14 more than 10,000 miles of asphalt highways were constructed in the United States; followed by more than 30,000 miles of concrete paved highways between 1909-25.
- Contractors began building their own variants of spiked sheepsfoot roller to keep up with the expanding industry. Tractors began supplant horse and mule power in the mid-1920s.

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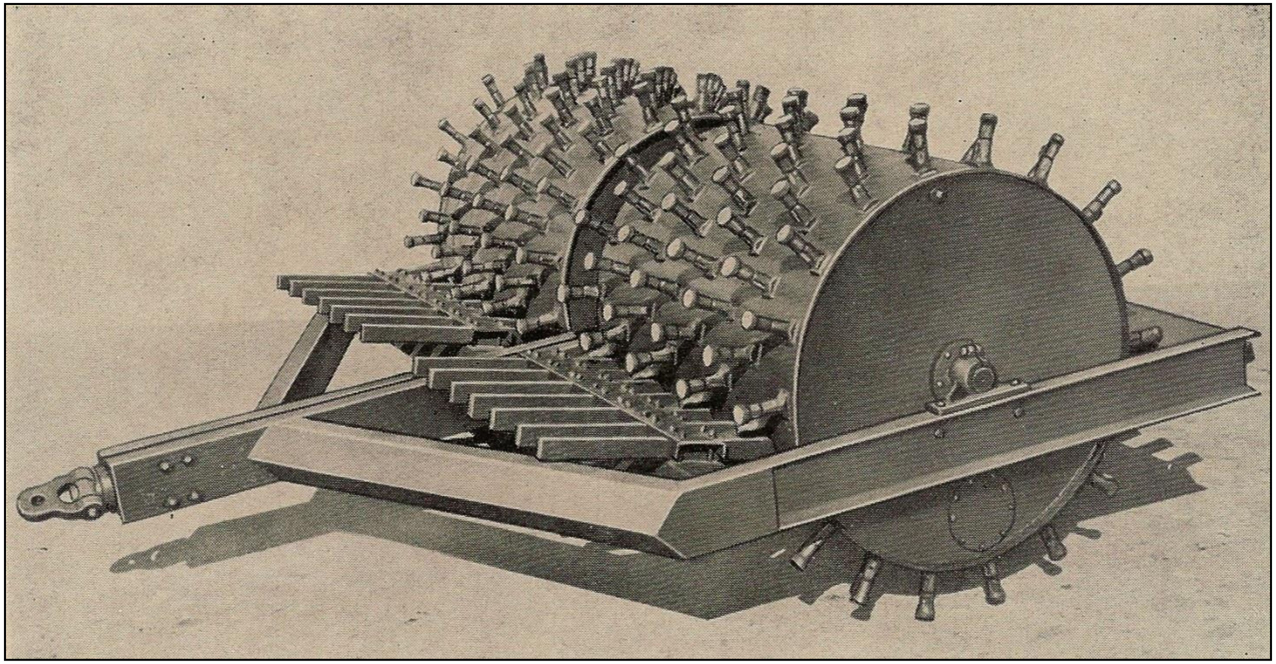
First Roller with cleaning teeth



- In 1931 Euclid Crane & Hoist Co. of Cleveland, Ohio introduced a 12-ton articulated twin-drum tamping rollers, similar to that shown here. By this time manufacturers were pouring about 4000 lbs of molten lead into each drum to increase weight. The drums were 42 inches diameter and 5 ft long.
- This was followed a few years later by the Grace Tamping Roller manufactured in Dallas, Texas (shown above), which was the first sheepsfoot roller equipped with a set of cleaning teeth, designed to remove moist soil that adhered to the spikes.
- Both rollers employed Timkin roller bearings and could be broken down into smaller components for easy transport between job sites (image from the W. E. Grace Co. archives).

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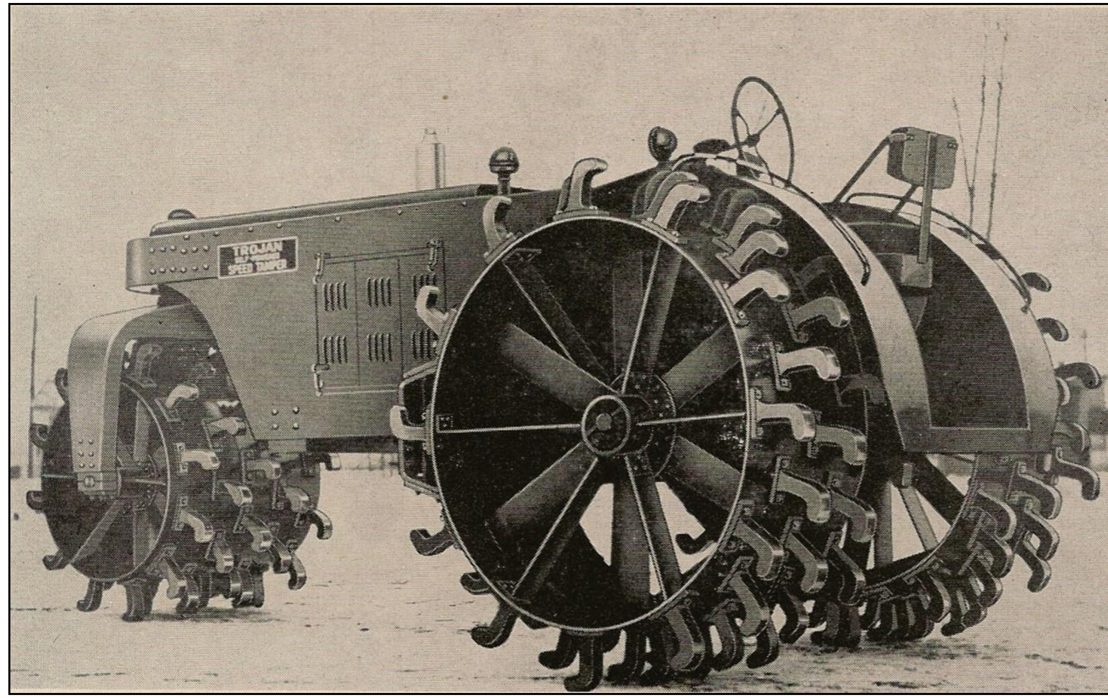
Early self-propelled tamping rollers



- Right - Ragland’s power driven Trojan Self Propelled Speed Tamper roller, produced by Contractor’s Machinery Co. of Batavia, NY in the 1930s. It weighed 8,740 lbs and the club headed teeth exerted a 250 psi contact pressure.
- Left – In 1925 H.W. Rohl Construction Co. patented a tamping sheepsfoot roller that employed ball shaped heads to heavy wheels mounted on conventional lightweight tractors to use for compacting soils for dams in southern California.

Rollers designed to break down rock and soil particles

Mike Scullin standing next to a Hyster Grid Roller

- Upper left: The grid roller was developed by Gardner Byrne Construction Co of Los Angeles in 1947 to compact soils with a high volume of cobbles or rocky soil mixtures.
- The design was acquired by Hyster, who began manufacturing grid rollers in 1949. Note concrete ballast blocks.
- Lower Left: The hammerhead Sheepsfoot roller was also developed around 1940 for the same purpose. These remain in production (see below)

Tandem hammerhead Sheepsfoot rollers (above right) being used to compact runway gravel subgrade on Iwo Jima in June 1945

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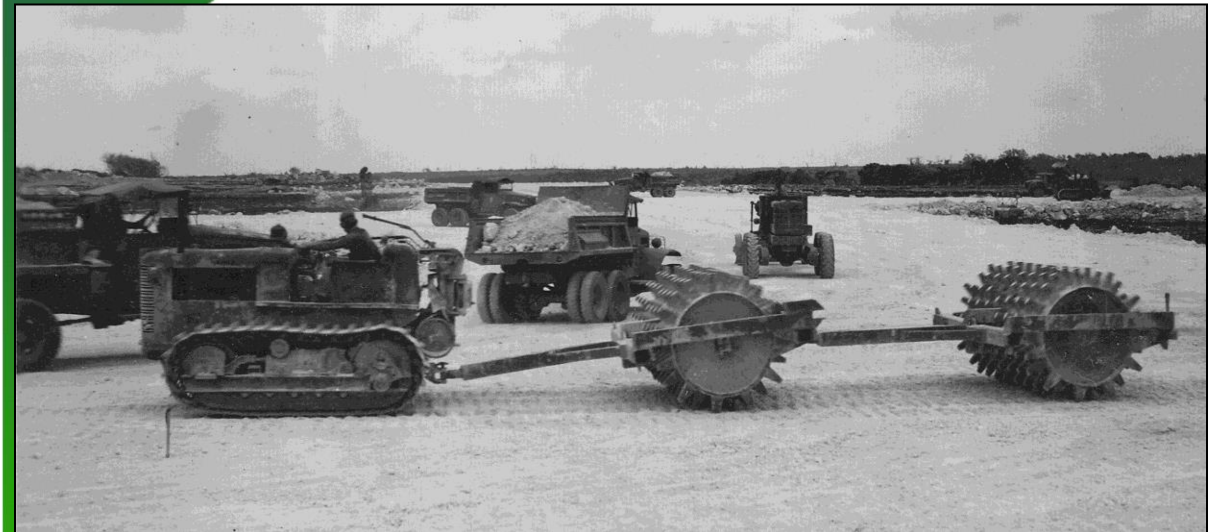
Rapid development of mechanized compaction

- The 1930s and 40s witnessed the rapid development of mechanical compaction of soils, using increasingly larger equipment, often fashioned by contractors. This view shows quadruple 3-ft diameter 5,000 lb rollers, typical of highways work by 1940, just before the Second World War.

Rectangular spiked sheepsfoot compactors



- During the Second World War (1941-45) square spiked rollers were mass produced because the teeth could be fabricated easily.
- Left above: The tapered tamping spike rollers worked better breaking down brittle coral for Pacific airstrips, and were usually towed in trail, as shown.
- Lower left: After the war many of these smaller 5500 lb dual box spike rollers were sold off as surplus.

Kneading compaction

- Postwar tests demonstrated the benefit of kneading compaction engendered by spiked sheepsfoot rollers on cohesive soils was verified through lab and field tests.
- This shows sheepsfoot rollers of the Los Angeles Department of Water & Power compacting fill on Eagle Rock Reservoir in 1952.

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Big Post-War Rollers

- Upper left: A 5-ft diameter 17.5 ton Letourneau roller is being used on an earth dam embankment in Australia in 1946
- Lower left: A pair of 5-ft diameter sheepsfoot rollers weighed 35 tons, fully loaded. These began to be employed on earth dams in the 1940s, engendering spike pressures of 275 to 375 psi.