Part 2

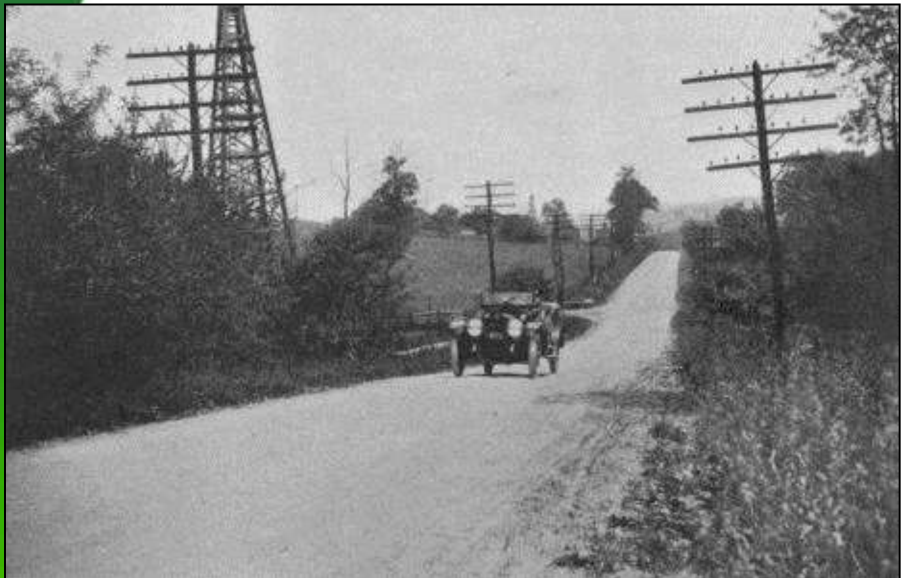
WHY DO WE COMPACT SOIL ?

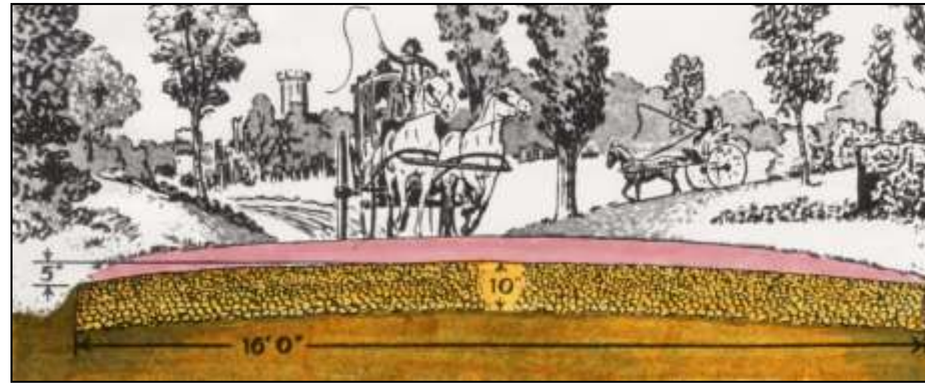
“You don’t always have to do things right, but it sure helps in a pinch” - Jimmy Doolittle

John L. McAdam
(1756-1836)

- In 1816 Scotsman John L. McAdam published a book on road building that promoted a cambered 10-inch thick course of aggregate base rock, 16 feet wide. It employed a top course of < 2 inch rocks that each weighed less than 6 ounces, underlain by increasingly larger stones. These were then packed down by animals and wagon wheels.

McAdam's technique was used to pave the National Pike, which began in 1811





- **The first National Road, or Pike, was constructed westward from Cumberland, Maryland beginning in May 1811. The road corridor was 66 ft wide.**
- **In the 1830s the McAdam paving process was employed to construct a pavement surface 16'-10" wide, 10 inches thick, with a minimum camber of 5 inches. The grades were restricted to less than 5 degrees (8.75%).**

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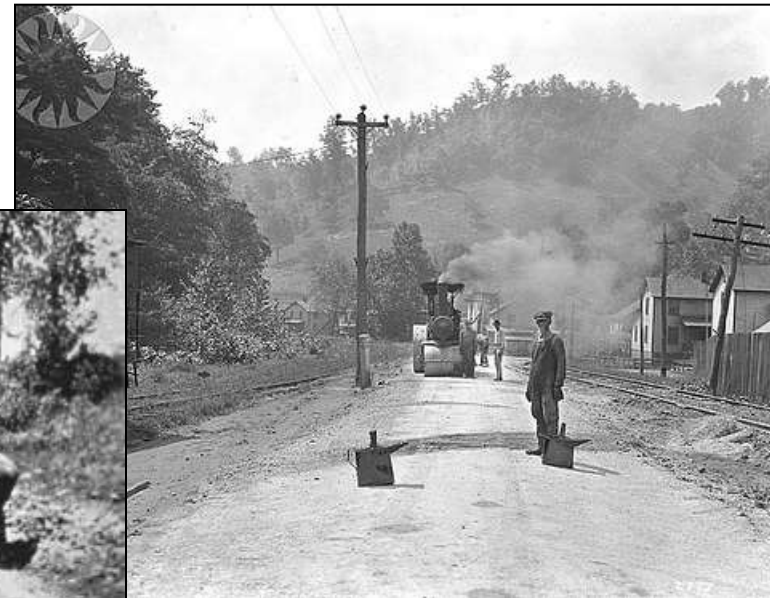
Tarmac

Purnell Hurley
1860-1942



- In 1902 Edgar Purnell Hooley from Nottinghamshire patented the process of heating tar adding slag or macadam to the mix then breaking stones within the mixture to form a smooth road surface. In 1903 he formed TarMacadam Syndicate Ltd and registered Tarmac® as a trade mark.
- The dust problem was thereby solved by spraying tar on the surface to create tar-bound macadam, while creating a much smoother riding surface.
- Tarmac was the forerunner of modern mixed asphalt pavement, often referred to as “blacktop.” This method mixed the aggregates into the hot asphalt with the binding material before being laid on a compacted surface.

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The vehicle that changed everything

- In 1913 the average price of an American car was $2,635. By 1925 this figure dropped to $870 because of mass production techniques funded by defense contracts during the First World War.
- By 1925 Ford's Model T Runabout (shown here) sold for just $260. The sudden affordability of motor vehicles led to the public's demand for a better system of roads and highways, funded by gasoline taxes.

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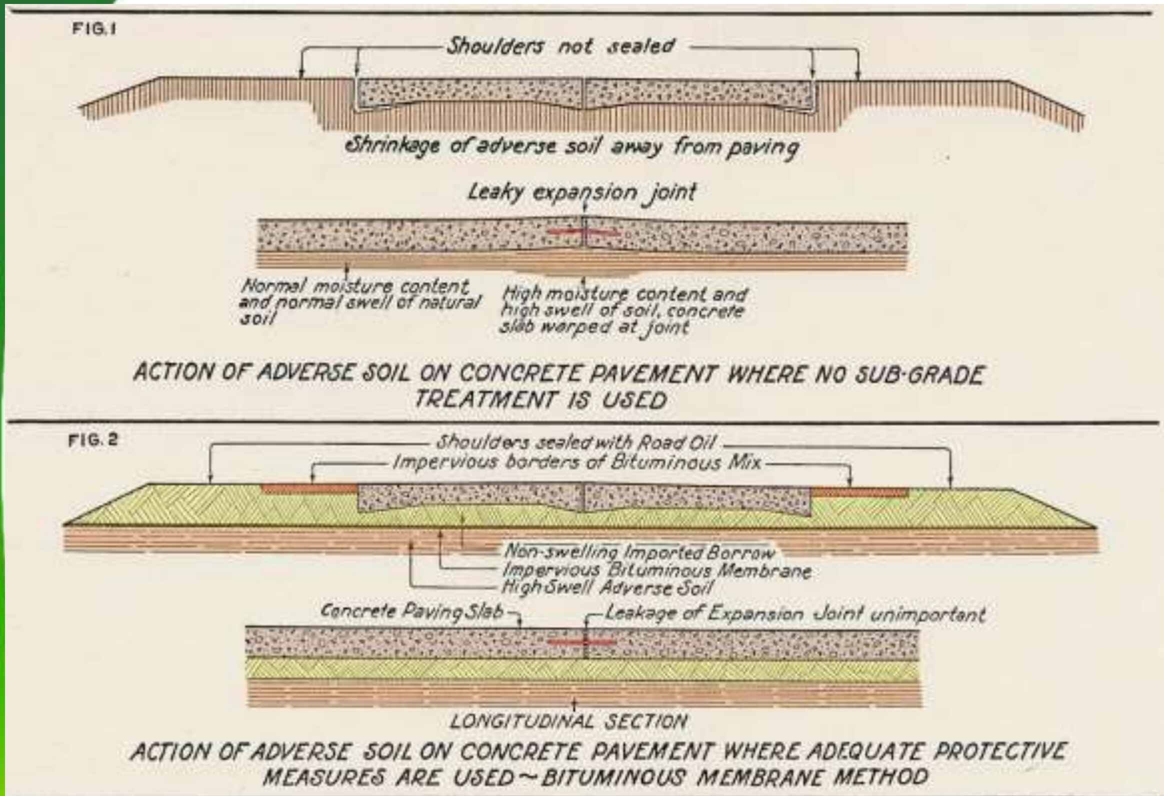

Importance of compaction

- In the 1930s the importance of **subgrade compaction, aggregate subbase,** and **aggregate baserock** became increasingly appreciated, especially on expansive clay soils

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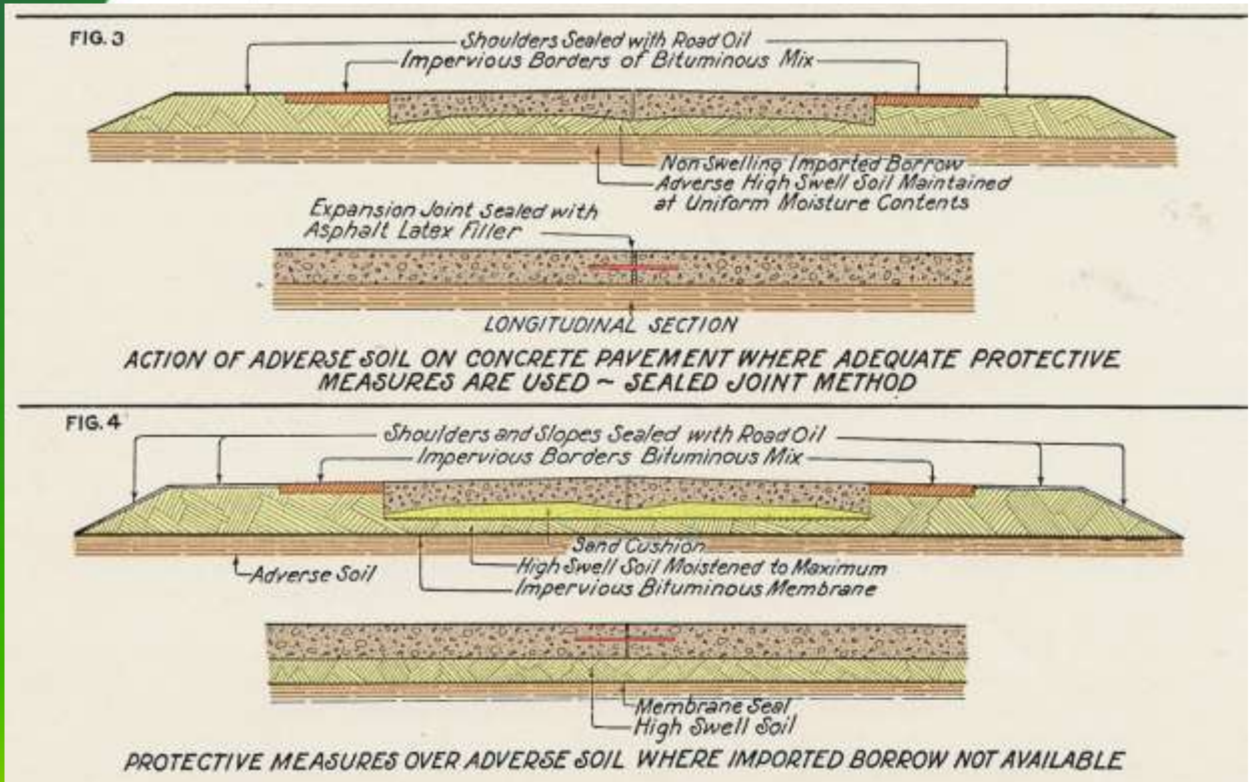
Reducing water penetration



Concrete pavements on ***expansive soils*** presented enormous challenges

- The late 1930s witnessed the introduction of **impervious shoulders, asphaltic membranes,** and **sealed expansion joints**

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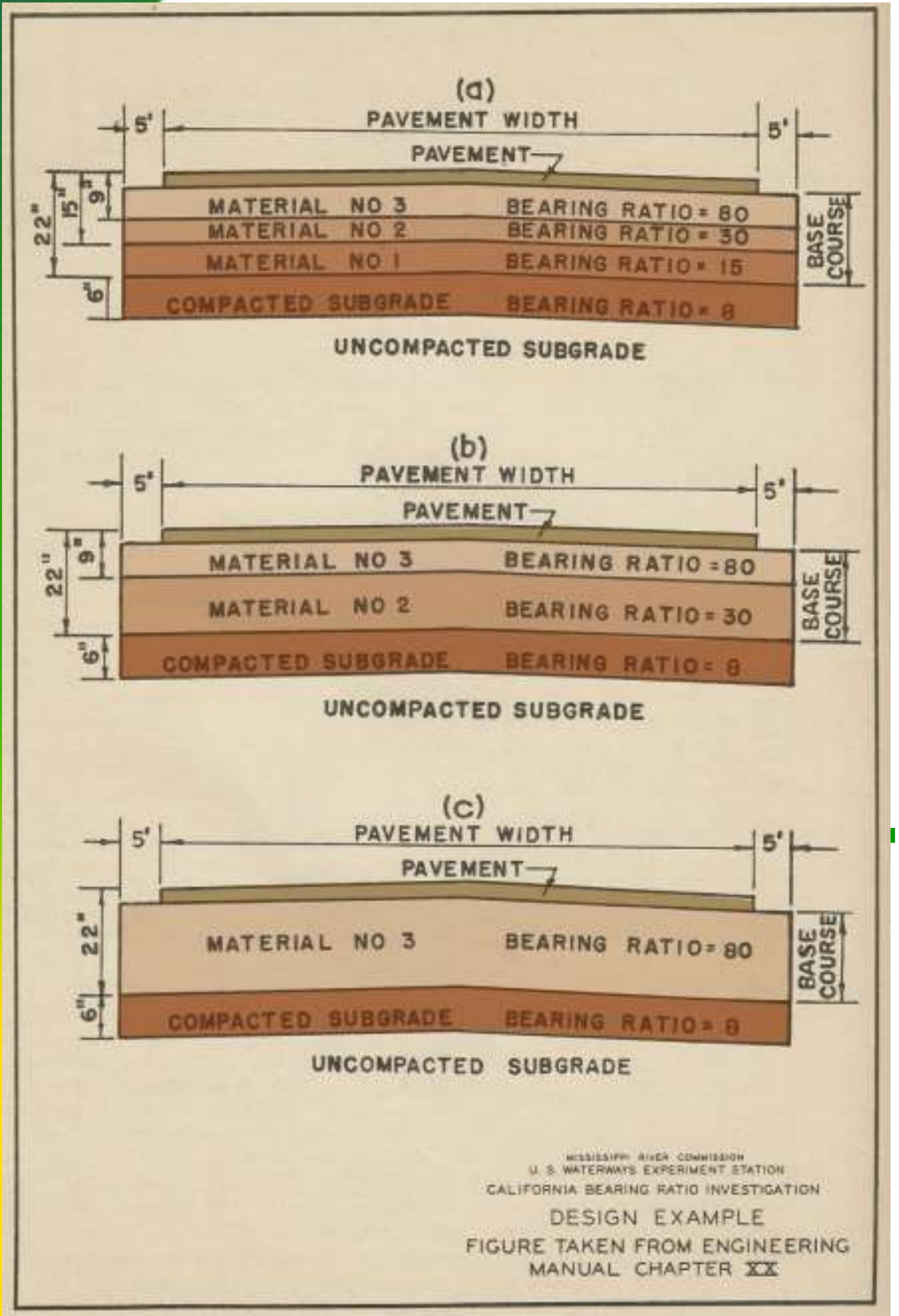
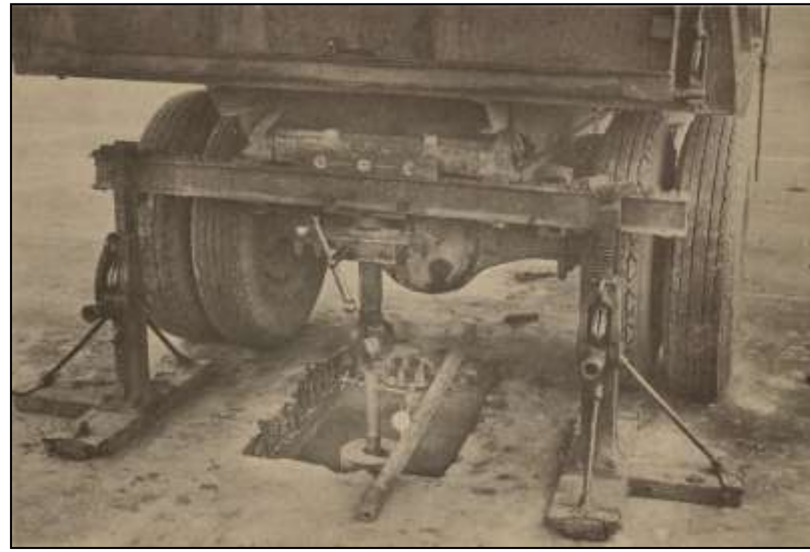
California Bearing Ratio (CBR) Test

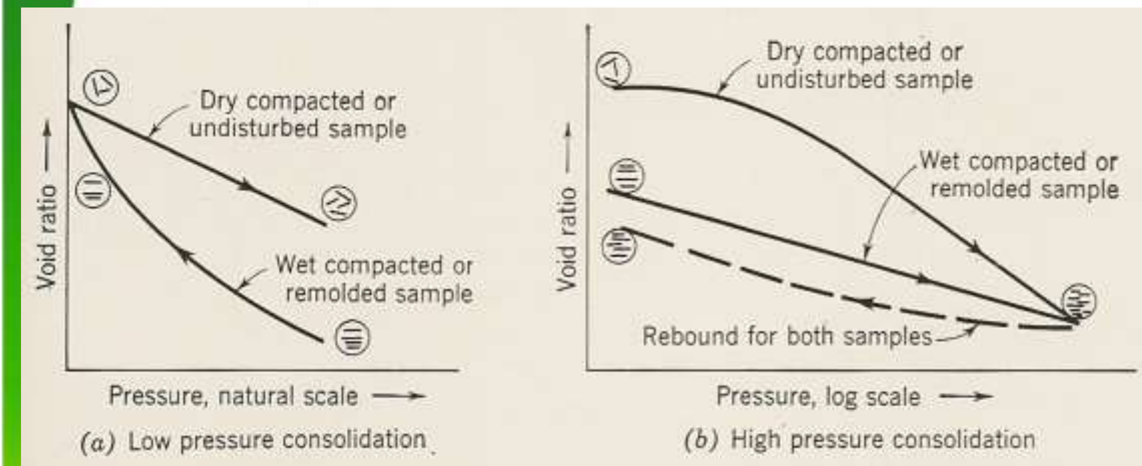


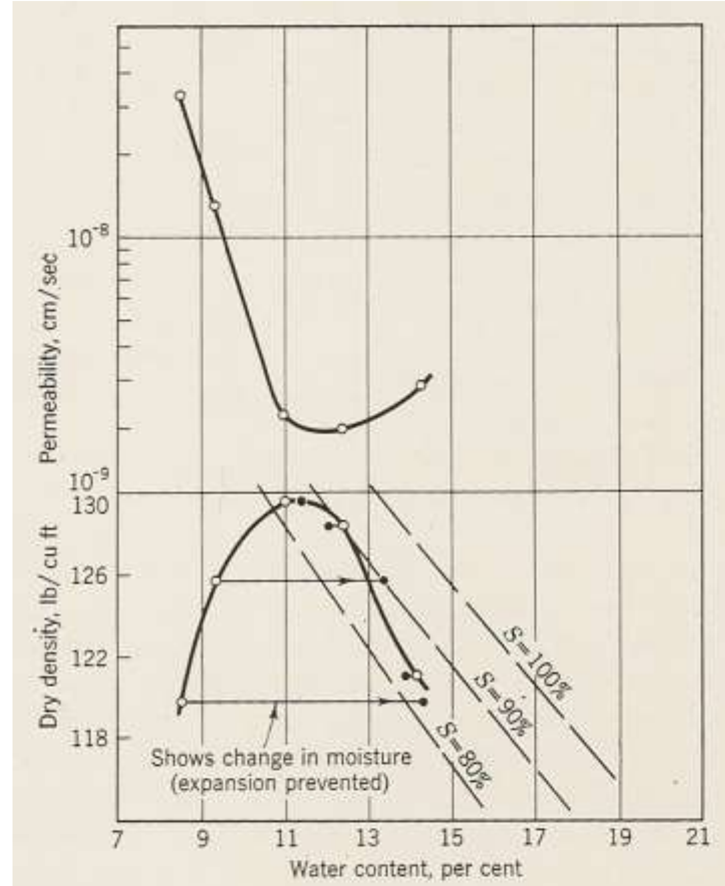


Between 1927-30 O.J. Porter developed the California Bearing Ratio (CBR) and soil swell test, which measured the penetration of compacted soil to evaluate the relative stiffness of pavement subgrades and aggregate base courses, by comparing the penetration resistance of these materials with that of crushed limestone. The stated intent of the CBR test was to evaluate the load bearing capacity of the pavement subgrade.

Five-ton limestone rollers were used to compact crushed limestone and river gravels in the China-Burma-India Theater during World War II, using the principles first advanced by of John McAdam in 1816, but verifying with CBR test data

Benefits of Compaction





- **Left: Charts showing the benefits of one-dimensional compression on soil structure, changing from a flocculated (open) to more dispersed (layered) structure**
- **Right: Impact of compaction on permeability of Siburua clay, illustrating the dramatic decrease in permeability with increasing density and water content. Both charts from T.W. Lambe, in Leonards' *Foundation Engineering* (1962)**

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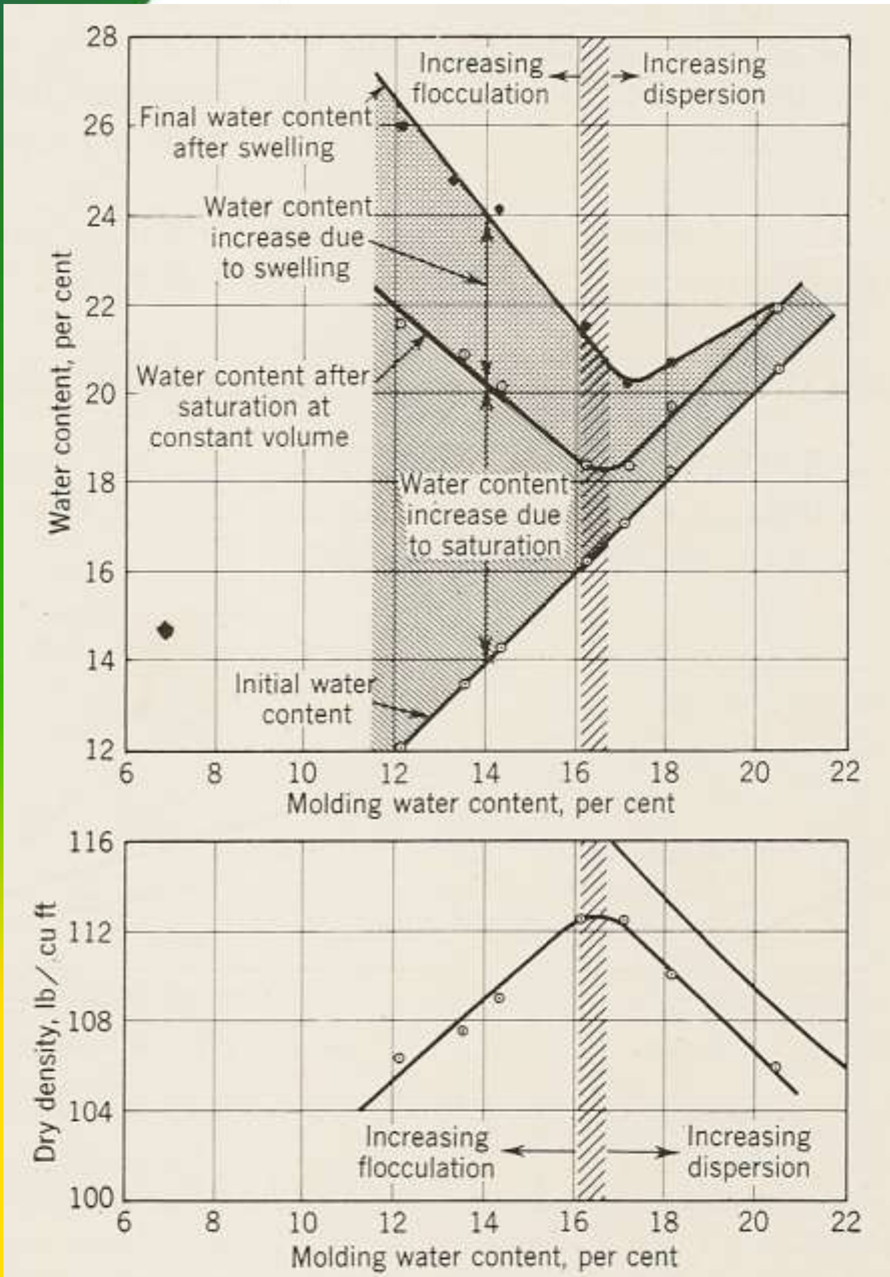
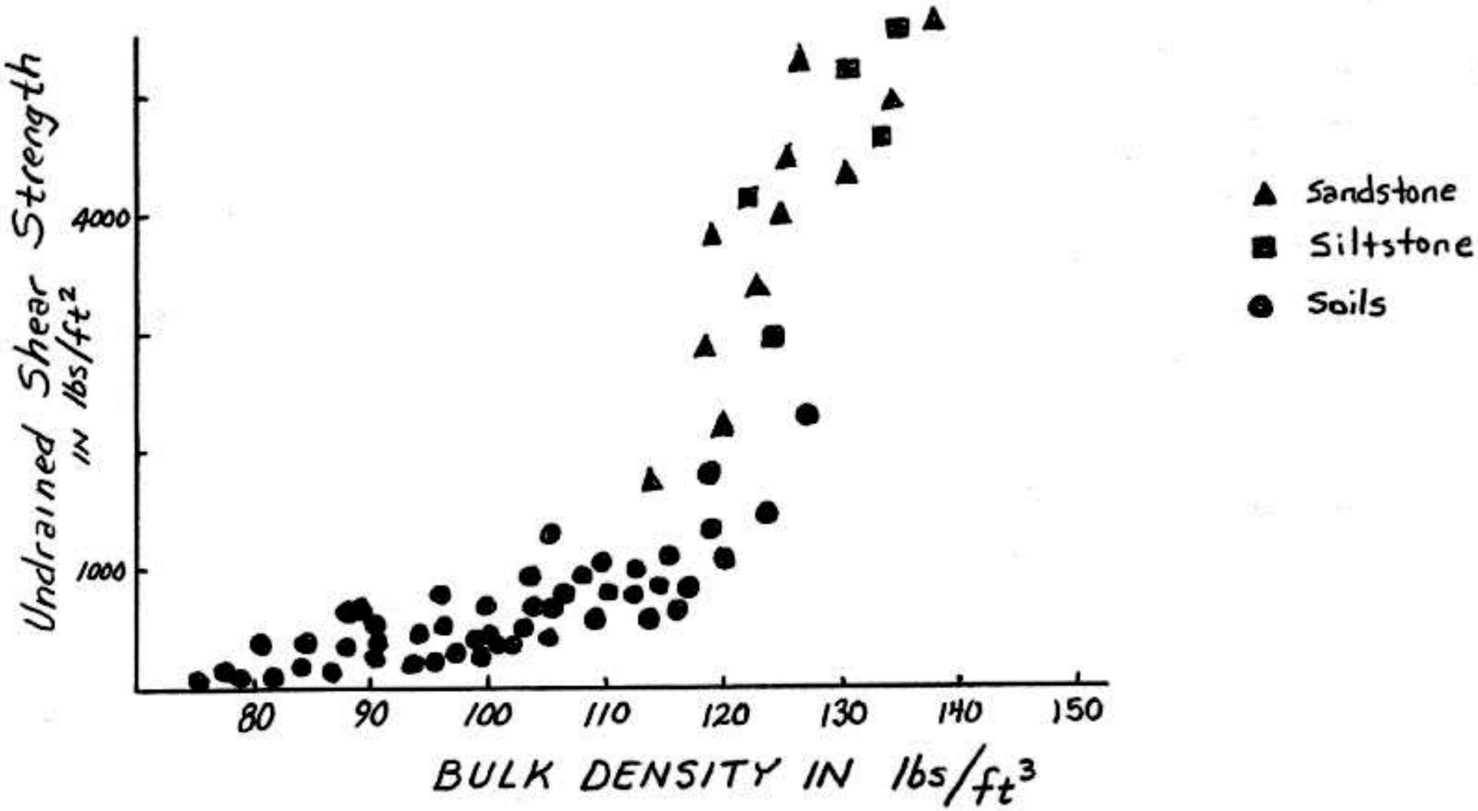


Benefits of compaction

- Influence of molding water content and soil structure on swelling characteristics of sandy clay, from Seed and Chan (1959).
- Note significant increase in water content on the “dry” side of the compaction curve
- This is why it is so important to moisture condition expensive soils “wet” of optimum moisture content



- **We also compact soil and rock mixtures to *increase* their effective shear strength, making them more able to resist gross deformations**

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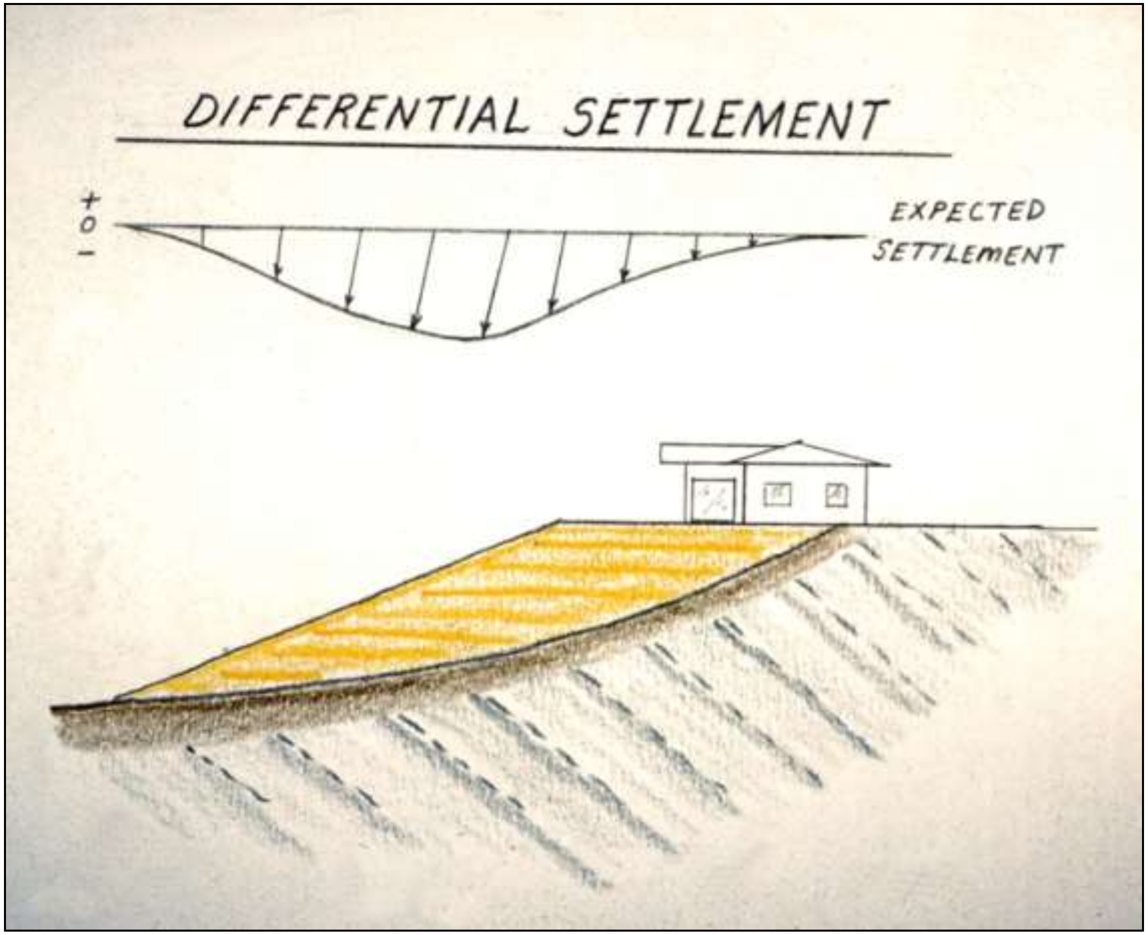
FILL PRISMS

- **We compact soils to reduce the long-term settlement. Fill prisms reach their greatest dimensions over old watercourses, like the one shown here. Excessive settlement may eventually lead to complete slope failure (note scarp)**

DIFFERENTIAL FILL THICKNESS

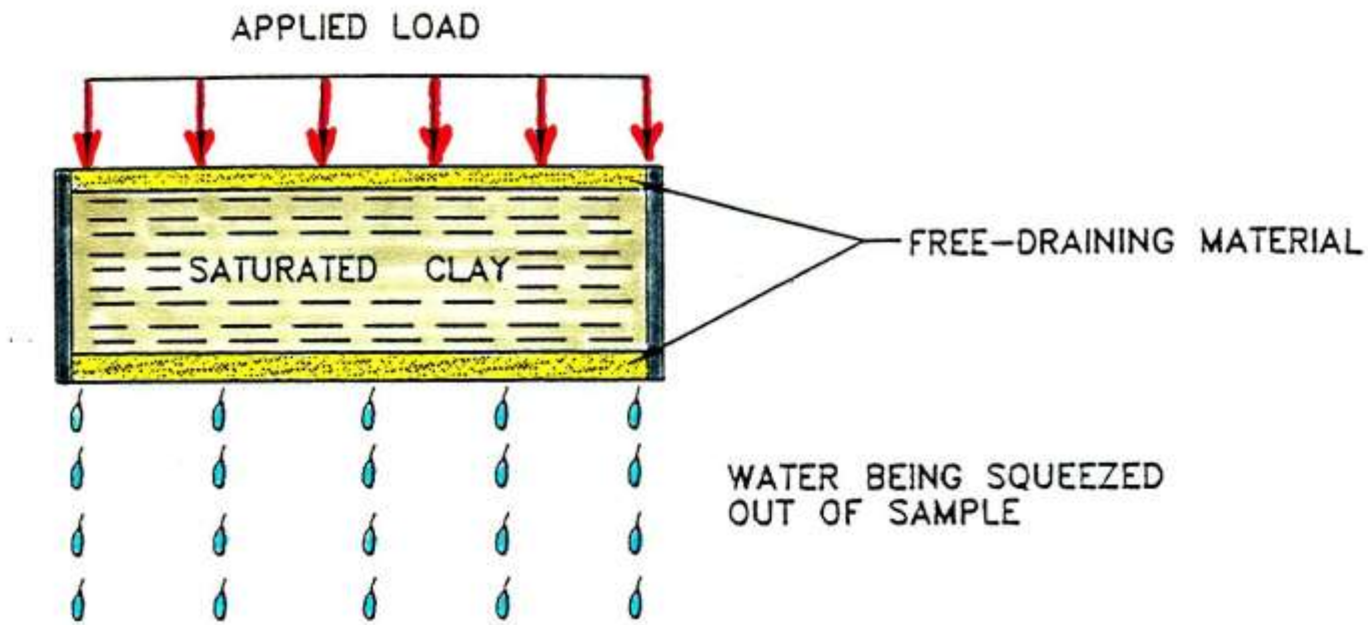


- **We compact soil to reduce differential settlement. Sidehill embankments are of differing thickness, which promotes differential settlement and differential heave**

SLOPE CREEP AND DILATION

- **We compact (densify) fine grained soils so they absorb less free moisture. Soil tends to absorb moisture with time and softens, promoting bearing capacity failures, settlement, loss of strength and slope creep, evidenced here by linear tension cracks in the pavement.**

PRIMARY CONSOLIDATION



PRIMARY CONSOLIDATION OCCURS WHEN INTERSTITIAL PORE WATER IS SQUEEZED OUT OF SATURATED CLAY

- **Primary consolidation occurs when water is expelled from the pore spaces of a saturated soil. It is not usually a problem in compacted clayey embankments less than 15 to 20 feet deep.**

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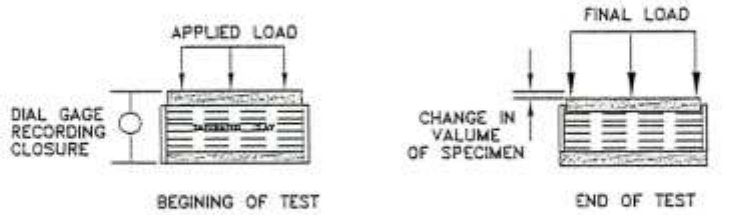
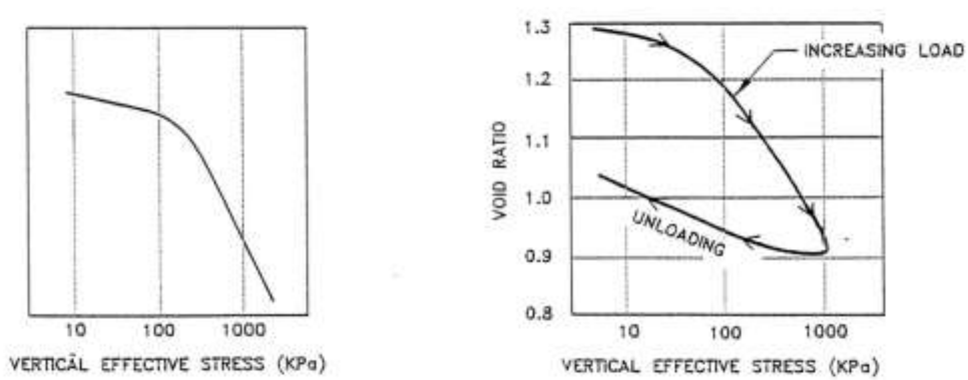
1-D CONSOLIDATION



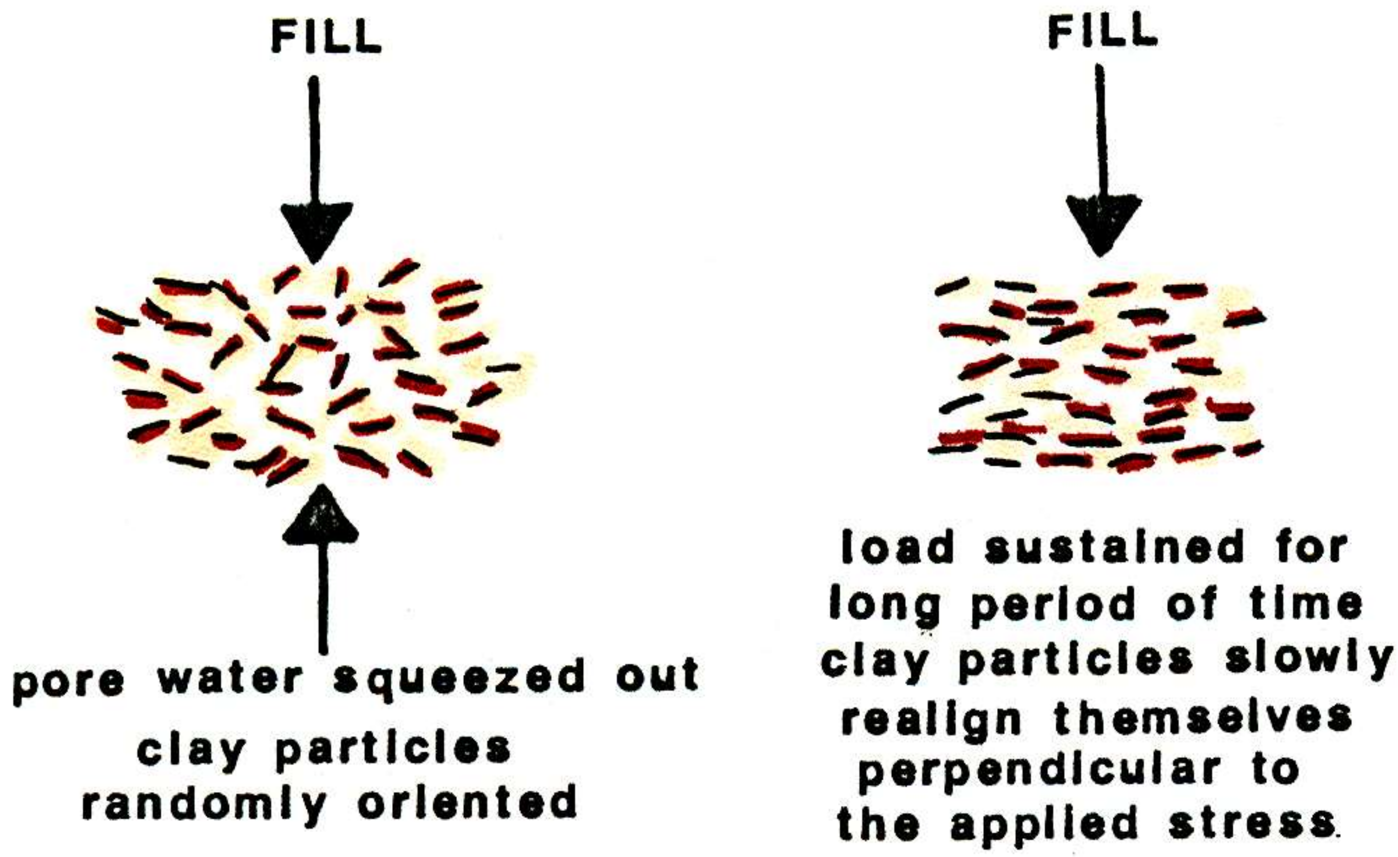
CHANGE IN SOIL VOLUME MEASURED IN ONE DIMENISONAL CONSOLIDATION TESTS



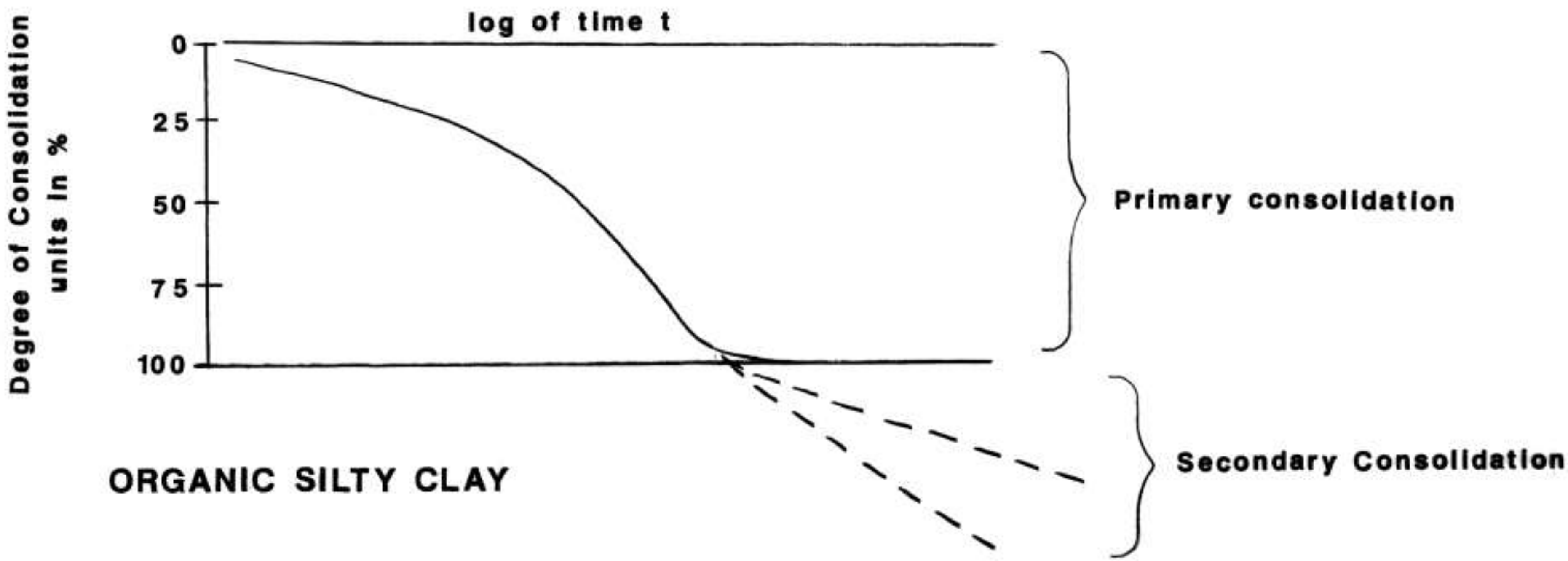
TRADITIONAL REPRESENTATIONS OF PRIMARY CONSOLIDATION TESTING.

- **Estimates of consolidation-induced settlement rely upon data derived from one dimensional odometer tests, like that sketched here.**

SECONDARY CONSOLIDATION



- **Secondary consolidation occurs indefinitely as clay platelets re-align themselves under sustained loading and pore water is expelled. Usually occurs in underconsolidated estuarine and lacustrine clays.**



- The time required for consolidation to occur depends on the imposed load (surcharge), the thickness of the compressible strata, and the length of the pore water drainage path(s).
- Primary consolidation ceases after a predictable period, but secondary consolidation may continue at a near-constant rate, for a much longer period of time.

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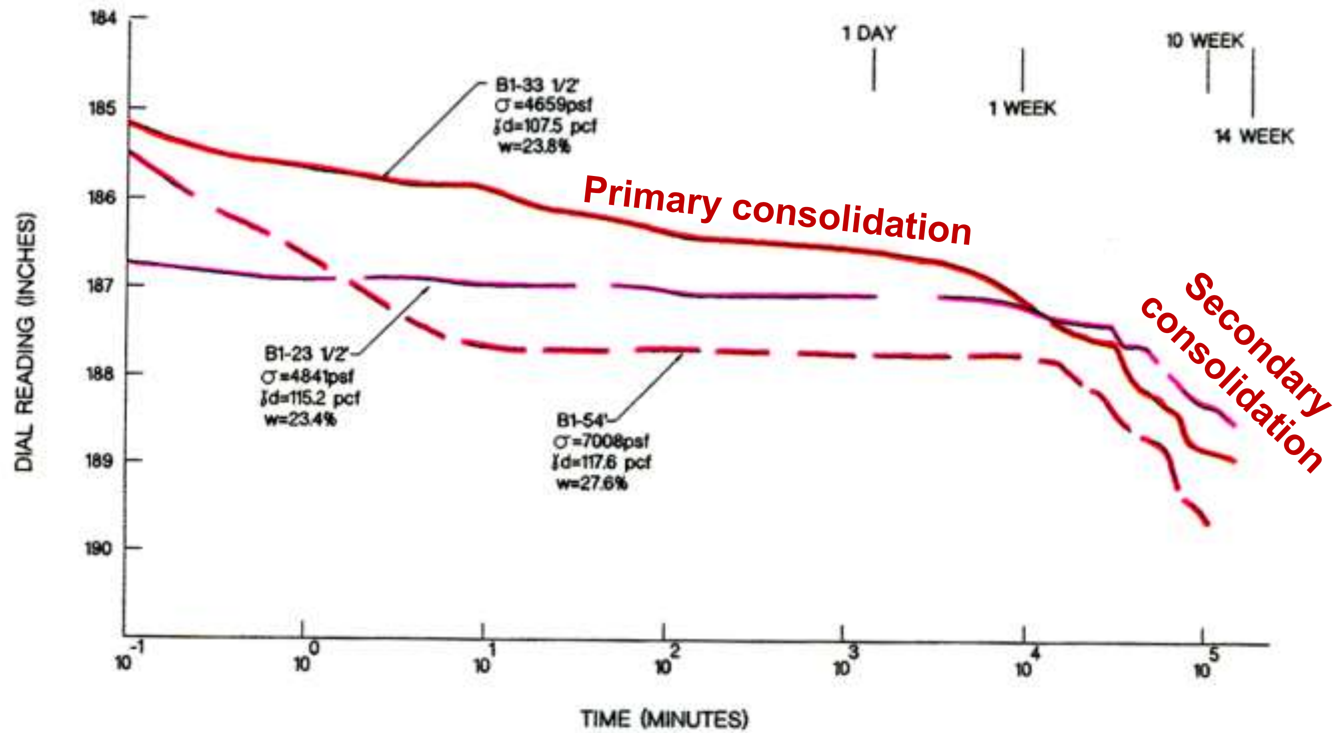
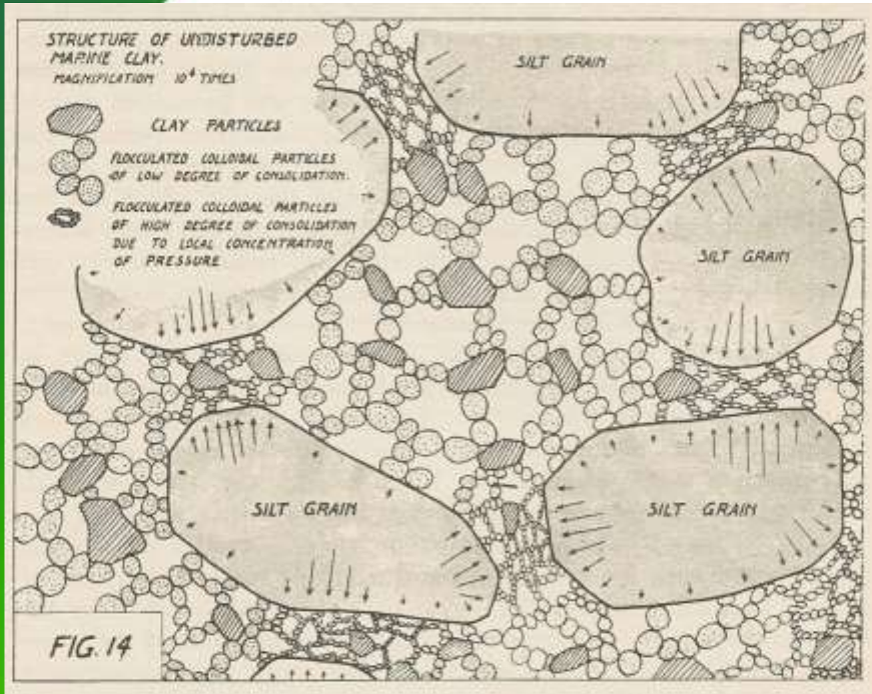


- **Lab compression data from an urban fill placed in 1963 and sampled in 1985, from depths between 24 and 54 feet. Secondary consolidation was not evidenced in the consolidation apparatus until after a week. These one-dimensional consolidation tests were continued for 14 weeks (from Rogers, 1992).**

HYDROCOMPRESSION



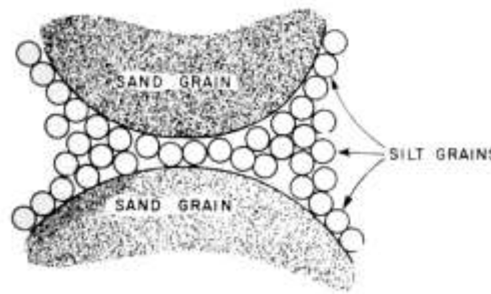


FIG. 6.—SCHEMATIC ARRANGEMENT OF SAND AND SILT GRAINS

FIG. 7.—SCHEMATIC ARRANGEMENT WITH AGGREGATED CLAY GRAINS

Honeycomb structure of a clay-silt sediment

Honeycomb structure of a silty sand

- **Hydrocompression occurs water is added to mixtures of silt, silty sand or aeolian silts and sands, which have not previously been saturated under sustained load. The figure at upper left is taken from an article by Arthur Casagrande in the *Journal of the Boston Society of Civil Engineers* in April 1932.**

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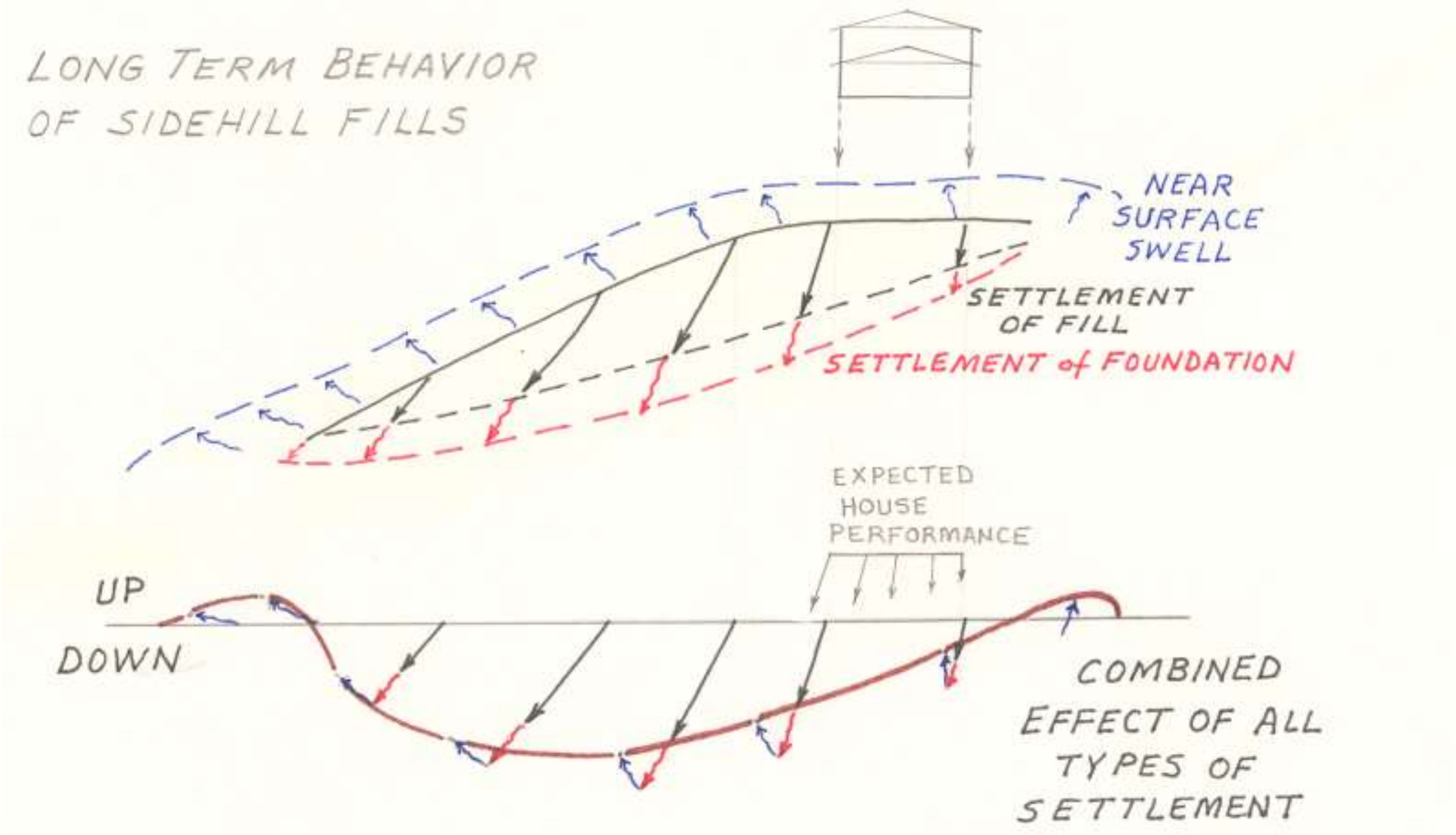
Hydrocompaction of low density sands and silts

Dr. Jack W. Hilf (1912-92)

Jack W. Hilf, Ph.D., PE led a group of engineers at the US Bureau of Reclamation that performed pioneering research on low relative density and susceptibility to hydrocompression, while working on Trenton Dam project in Nebraska.

- **The Bureau of Reclamation constructed a series of distribution canals like the Meeker-Driftwood Canal in the Republican River Valley of Nebraska, shown above left. These were founded on low density loess and blow sands that were susceptible to densification by seepage from the canals.**
- **Engineering geologists with the California Department of Water Resources made similar discoveries a few years later in the Kern and Tulare Basins (lower left), while working on the State Water Project canal.**

LONG TERM BEHAVIOR



- **Long term behavior is usually influenced by the aggregate sum of settlement, heave and creep of fill and underlying foundation materials**

- Another form of hydrocompression is loosley termed **"clod consolidation."** This is actually a mechanism of ***soil collapse*** frequently caused by percolation of free water (in this case, through a gunite pool shell) into low density fill of low water content.
- This view shows typical settlement of concrete flatwork placed near the crest of a modest embankment. The loose-dumped muck from the pool excavation has settled about 6.5 inches (seen at far right).

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