ENGINEERING CONSULTING SERVICES

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COMPACTION – A CRITICAL COMPONENT IN THE CONSTRUCTION OF EMBANKMENTS, ROADS, AND FOUNDATIONS

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OUTLINE

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- HOW MUCH DO YOU KNOW ABOUT COMPACTION
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- SOIL PROPERTIES AFFECTED BY COMPACTION
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- REASONS FOR FAILED COMPACTION
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DEFINITIONS

“COMPACTION is the process of mechanically densifying a soil. ” (Military Soils Engineering – Department of Army)

“COMPACTION is the process of increasing the bulk density of a soil or aggregate by driving out air.“ (A University Class)

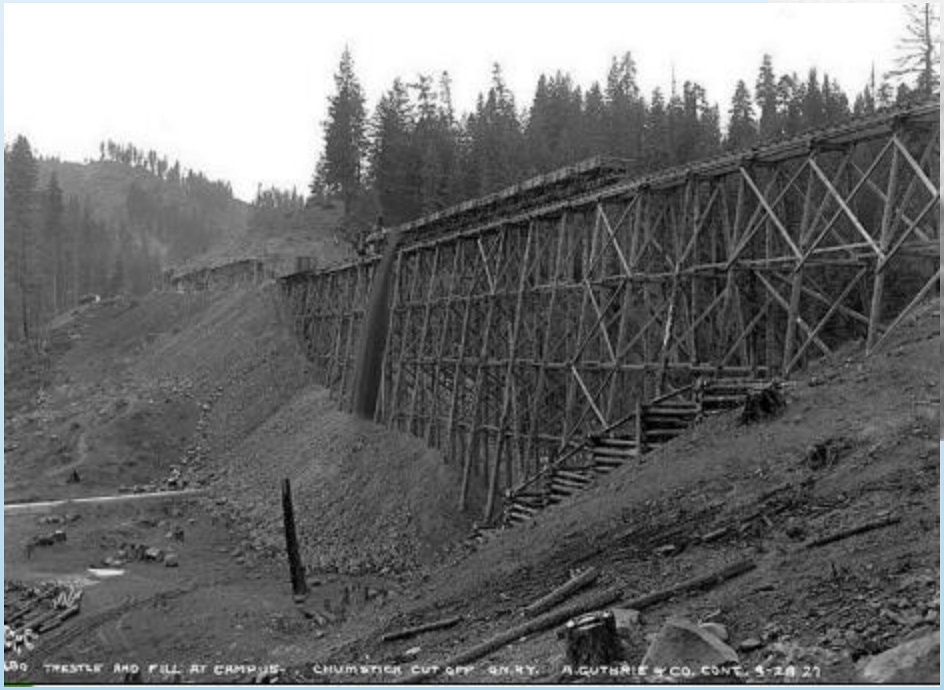
“COMPACTION is the process of increasing the density of soil by mechanical means. It results in the rearrangement of soil particles and the reduction of voids.” (Trenchlesspedia Web Site)

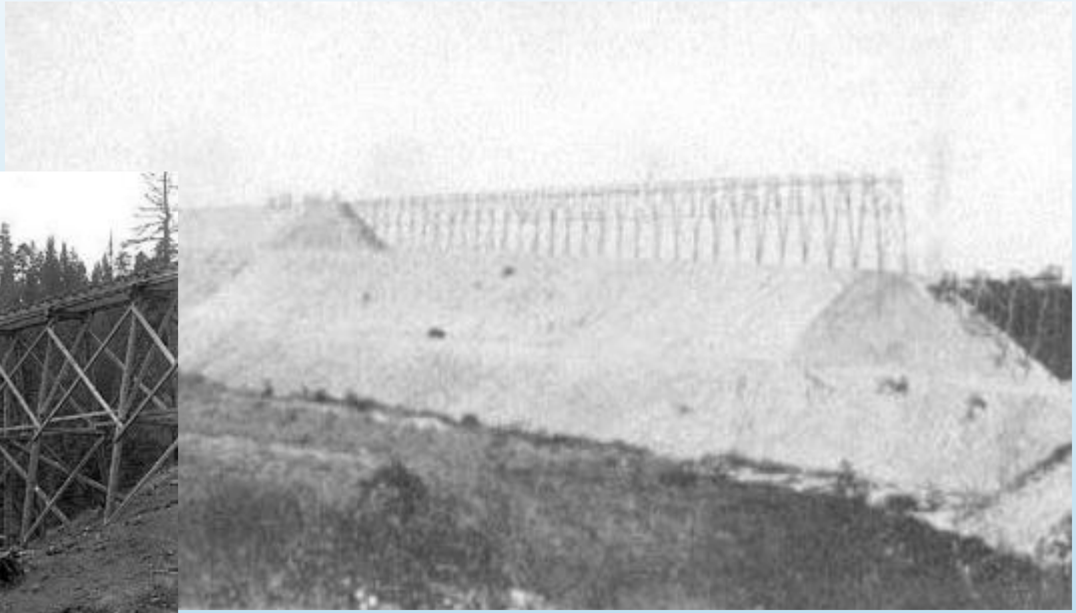
“COMPACTION of soil is defined as the reduction of air voids between particles of soil and is measured by the mechanical compression of a quantity of material into a given volume.“ (FHWA)

“COMPACTION or Densification, or a reduction in the void ratio, occurs in a number of ways: reorientation of the particles; fracture of the grains or the bonds between them, followed by reorientation; and bending or distortion of the particles and their absorbed layers.” (Sowers – 1951 - Introduction to Soil Mechanics and Foundations)

HISTORY OF COMPACTION

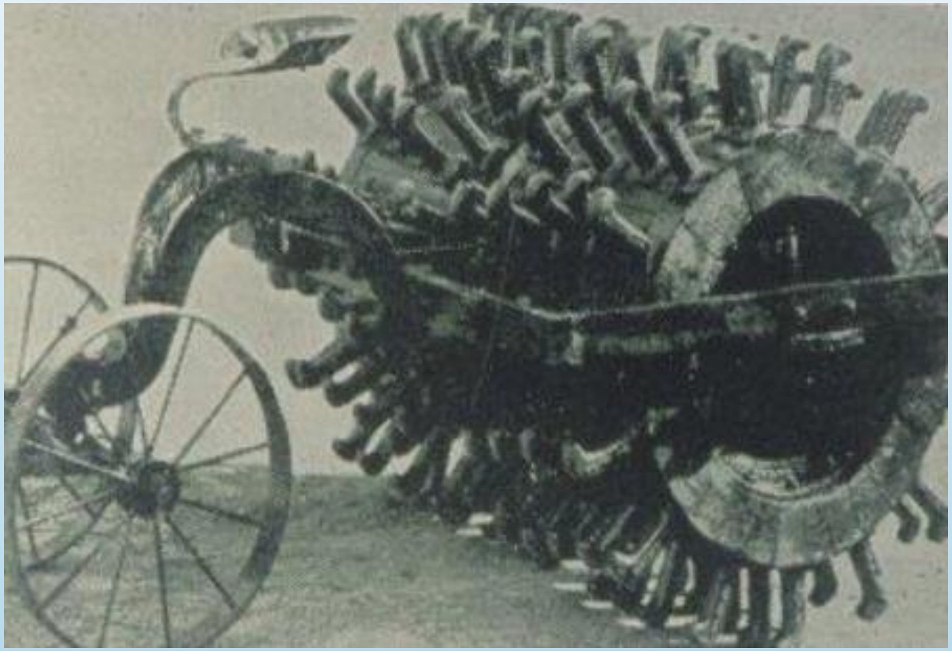
1800's - Large embankments were constructed by side-dumping rail cars or wagons from temporary wooden trestles. Engineers assumed that, after placement and infiltration by rain, the soil would "*compact*" under its own dead load.





HISTORY OF COMPACTION

1900's - 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. The rollers weight could be increased by filling with sand and water. These were pulled with horses or mules.



HISTORY OF COMPACTION

CONT.

1900's - 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.

- Ralph Roscoe Proctor developed the soil compaction test that bears his name in 1933, while working as resident engineer on the Bouquet Canyon Reservoir embankments.

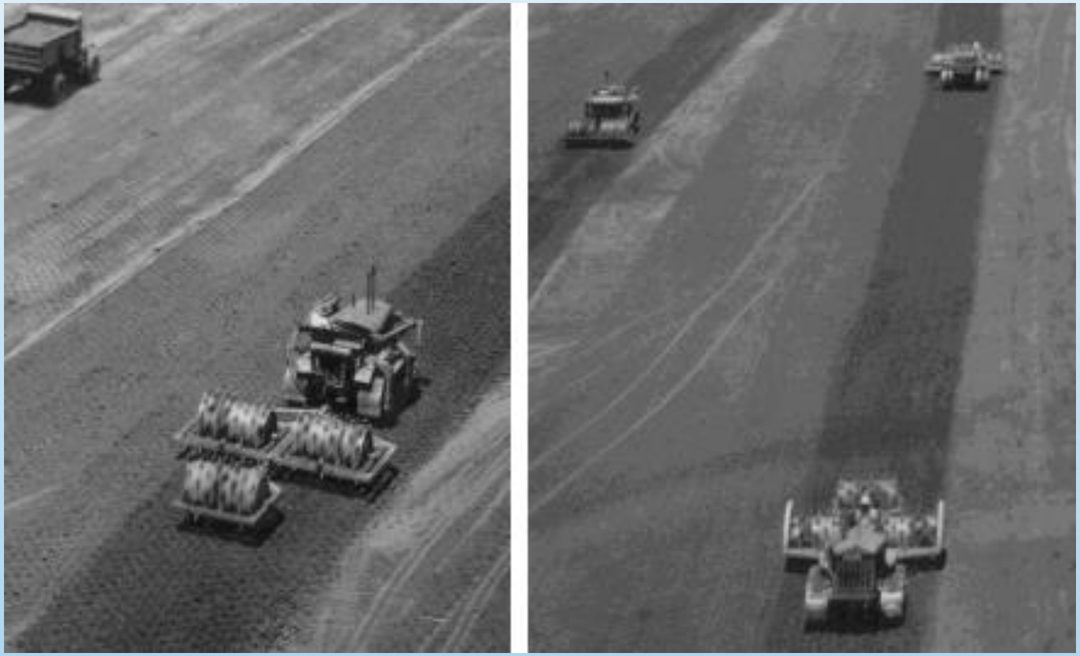
Ralph R. Proctor, PE (1894-1962)

HISTORY OF COMPACTION

CONT.

1900's - 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.

1930's – The engineering approach that soil and rock could be used as construction materials to support buildings and roadways was accepted.



HISTORY OF COMPACTION

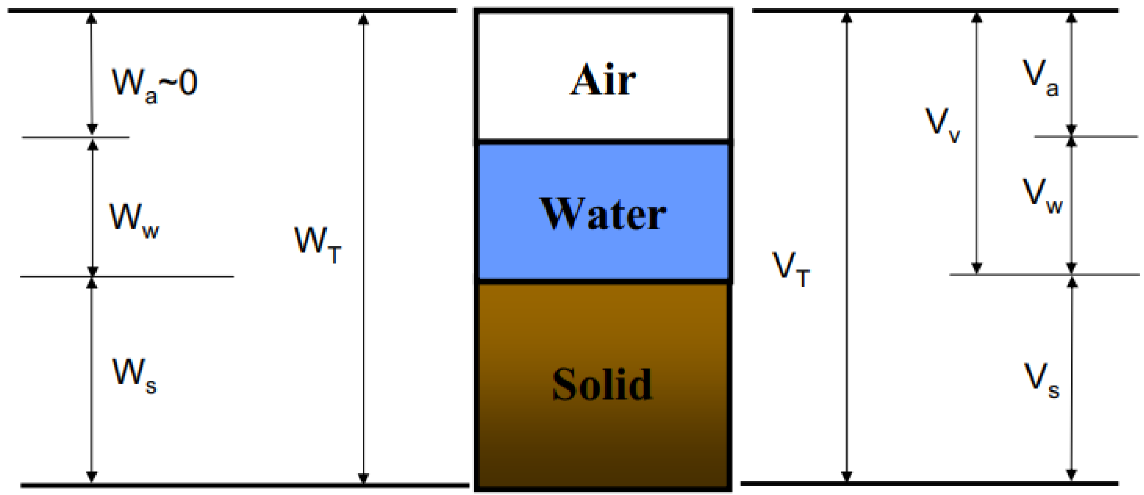
CONT.

1940’s - During the Second World War (1941-45) square spiked rollers were mass produced because the teeth could be fabricated easily.

1950’s to Current

- Sheepsfoot rollers become more efficient with the development of vibratory sheepsfoot rollers and 4-wheeled sheepsfoot rollers such as the CAT 815.

SOIL MODEL

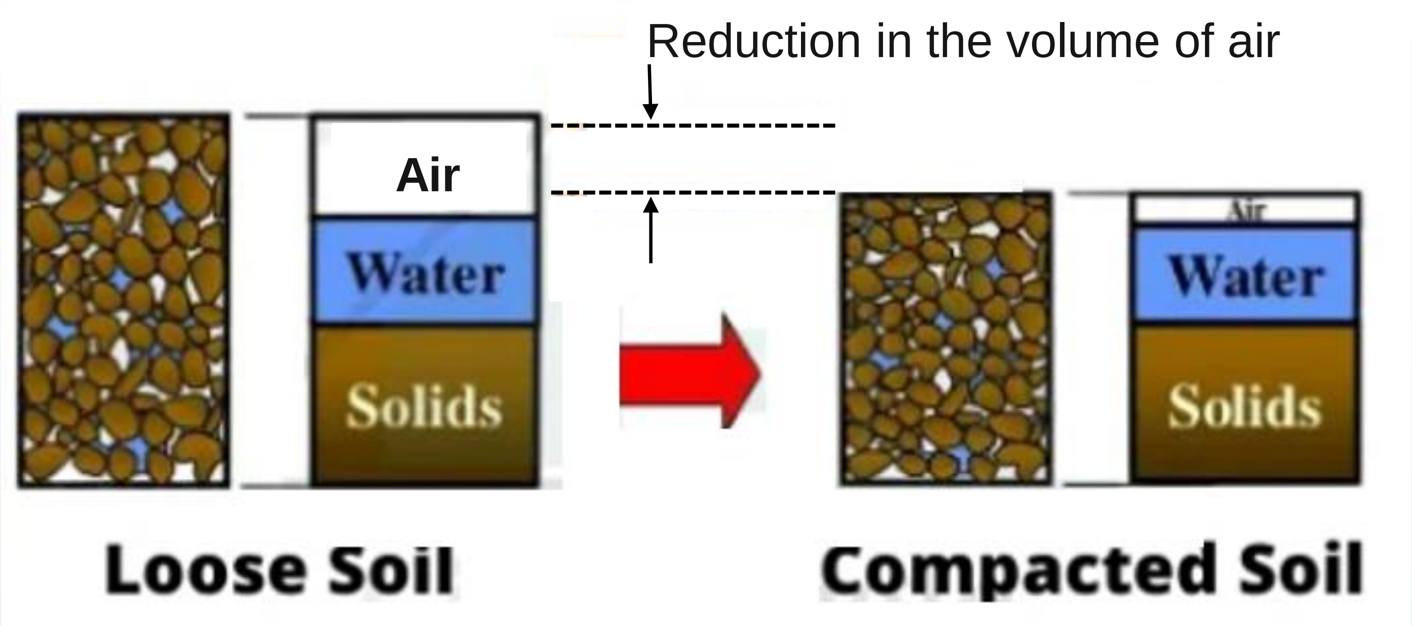


Wt: total weight
Ws: weight of solid
Ww: weight of water
Wa: weight of air = 0

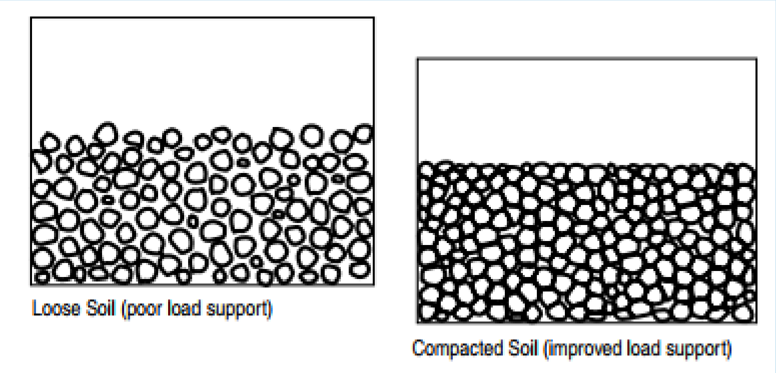
Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void

Soil is composed of different ingredients in all 3 phases of matter – SOLIDS, LIQUID (Water), and GASEOUS (Air).

SOIL MODEL



As soil is compacted, the water is squeezed out into the air and the voids or air are reduced.



SOIL PROPERTIES AFFECTED BY COMPACTION

- Increased Density
- Increased Strength Characteristics (Shear Strength)
- Increased Load-Bearing Capacity
- Reduces Settlement
- Increases Stability of Embankment Slopes
- Decreases Permeability
- Reduces Swelling & Shrinkage – Volume Change
- Corrosion Rates
- Reduces Erosion Through Increased Density

SOIL PROPERTIES AFFECTED BY COMPACTION

Settlement - A principal advantage resulting from the compaction of soils used in embankments is that it reduces settlement that might be caused by consolidation of the soil within the body of the embankment. This is true because compaction and consolidation both bring about a closer arrangement of soil particles. Densification by compaction reduces later consolidation and settlement within a fill embankment.

SOIL PROPERTIES AFFECTED BY COMPACTION

Shear Strength - Increasing density by compaction generally increases shearing resistance.

SOIL PROPERTIES AFFECTED BY COMPACTION

Permeability – As illustrated in the Soil Model, when soil particles are forced together by compaction, both the number of voids contained in the soil mass and the size of the individual void spaces are reduced.

SOIL PROPERTIES AFFECTED BY COMPACTION

Volume Change - Change in volume (shrinkage and swelling) is an important soil property, which is critical when soils are used as subgrades for roads and airfield pavements.

SOIL PROPERTIES AFFECTED BY COMPACTION

Corrosion - When soil compaction occurs evenly, soil resistivity is consistent and corrosivity is generally decreased. Soil permeability is reduced with compaction and provided drainage is adequate and the soil is non-aggressive (neutral or alkaline), corrosion should be decreased. However, the effect of compaction is related to soil cohesiveness. In clay soils, the corrosion rate shortly after burial increases with compaction and in well-drained, granular soils it is mostly non-aggressive.

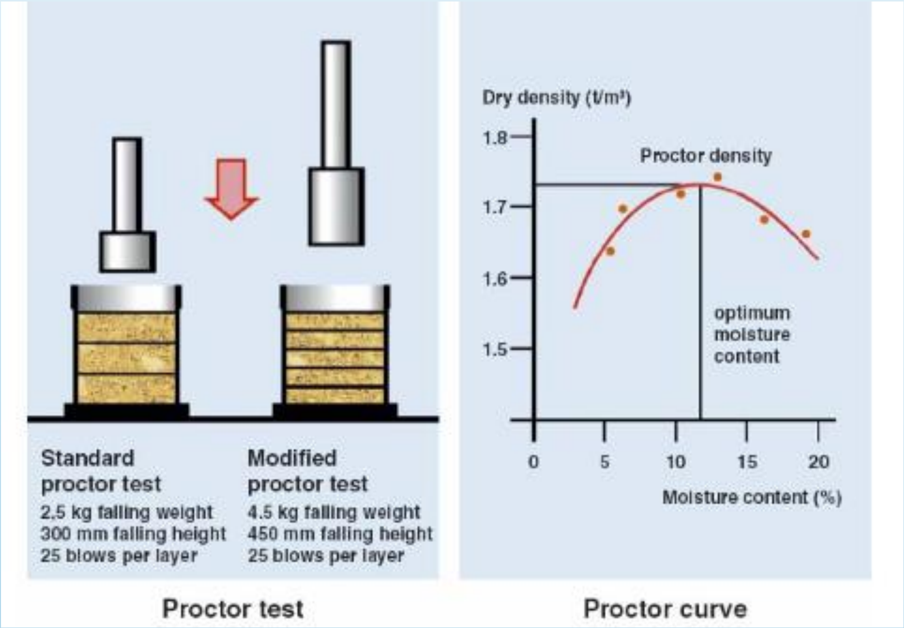
LABORATORY TESTING AS AN AID FOR DEVELOPING COMPACTION SPECIFICATIONS

"From early times, earth that was merely dumped in place without compaction frequently failed under load and continued to settle for decades. It remained for R. R. Proctor to point the way to low-cost, effective densification." (G. F. Sowers)

Proctor Tests - Nearly all soils exhibit a similar relationship between moisture content and dry density when subjected to a given compactive effort.

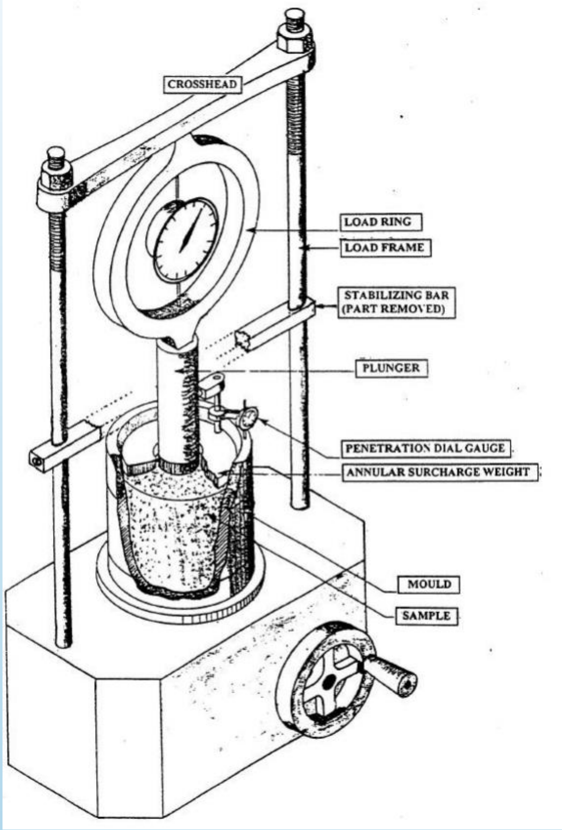
LABORATORY TESTING AS AN AID FOR DEVELOPING COMPACTION SPECIFICATIONS

Specifications for soil compaction are established during the design phase of the project and depend on both total loads anticipated and whether those loads will be static or dynamic. The 2 methods of Proctor testing includes – Standard Proctor (ASTM D698) and Modified Proctor (ASTM D1557).



LABORATORY TESTING AS AN AID FOR DEVELOPING COMPACTION SPECIFICATIONS

California Bearing Ratio (CBR) –
A CBR test allows the geotechnical engineer to use a laboratory CBR value representative of the site or borrow soils for the design of pavements verses estimating a conservative number based on experience and soil type.



LABORATORY TESTING AS AN AID FOR DEVELOPING COMPACTION SPECIFICATIONS

Atterberg Limits Test – Atterberg limits tests (ASTM D4318) are performed to aid in classification of the site soils. The Atterberg limits test determine the Plastic Limit (PL), the Liquid Limit (LL), and the Plasticity Index (PI). The test values and derived indexes have direct applications in predicting the behavior of soil embankments and pavements.

CONSTRUCTION PROCEDURES AND IDENTIFYING THE APPROPRIATE COMPACTION EQUIPMENT

The general construction process of a rolled-earth embankment requires that the fill be built in relatively thin layers or “lifts,” each of which is rolled until a satisfactory degree of compaction is obtained.

CONT.

The type of equipment used for soil/rock fill compaction depends exclusively on the selection of embankment materials. Fine grained, clay and cohesive silt, soils will require kneading to achieve compaction from a sheepsfoot compactor. Coarse grained soils, sand and non-cohesive silts, require vibratory smooth drum rollers for compaction.

MATERIALS	Lift Thickness	Vibrating Sheepsfoot Rammer	Static Sheepsfoot Grid Roller Scraper	Vibrating Plate Compactor Vibrating Roller Vibrating Sheepsfoot	Scraper Rubber-tired Roller Loader Grid Roller
		IMPACT	PRESSURE with kneading	VIBRATION	KNEADING with pressure
GRAVEL	12+	Poor	No	Good	Very Good
SAND	10+/-	Poor	No	Excellent	Good
SILT	6+/-	Good	Good	Poor	Excellent
CLAY	6+/-	Excellent	Very Good	No	Good

Source – Multiquip Soil Compaction Handbook

EQUIPMENT APPLICATIONS

	Granular Soils	Sand and Clay	Cohesive Clay	Asphalt
Rammers		B	A	
Vibratory Plates	A	B		A
Reversible Plates	B	A	C	C
Vibratory Rollers	B	A	C	A
Rammax Rollers	C	A	A	

A — Provides optimum performance for most applications.
B — Provides acceptable performance for most applications.
C — Limited performance for most applications. Testing required.

Source – Multiquip Soil Compaction Handbook

COMPACTION EQUIPMENT – FINE GRAINED SOILS

COMPACTION EQUIPMENT – COARSE GRAINED SOILS

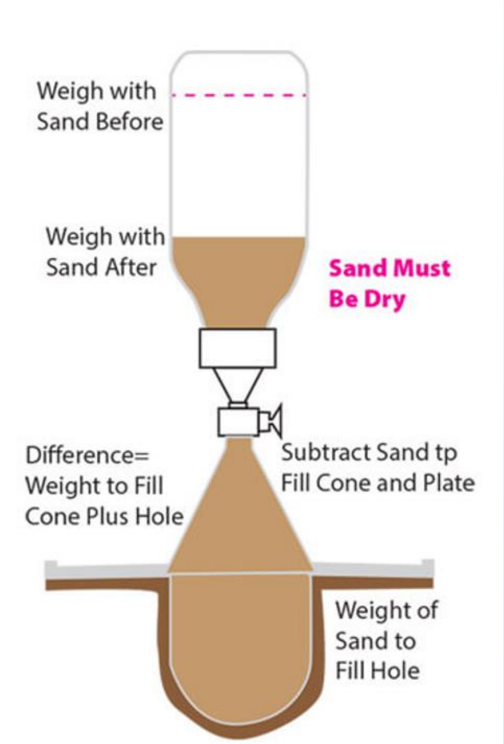
FIELD TESTING/CONTROL OF COMPACTION

Careful control of the entire compaction process is necessary if the required density is to be achieved with ease and economy. Control generally takes the form of field checks of moisture and density to:

- Determine if the specified density is being achieved.
- Control the rolling process.
- Permit adjustments in the field, as required

FIELD TESTING/CONTROL OF COMPACTION

Types of field compaction test equipment include:



Sand Cone Test

Balloon Density Test

Nuclear Density Test

Source – Gilson Company; Humboldt

REASONS FOR FAILED COMPACTION

When the density and/or moisture of a soil does not meet specifications, corrective action must be taken. The appropriate corrective action depends on the specific problem situation. There are four fundamental problem situations:

- Overcompaction
- Undercompaction
- Too wet
- Too dry

REASONS FAILED COMPACTION

Overcompaction –

This occurs when the material is densified in excess of the specified density range. An overcompacted material may be stronger than required, which indicates:

Wasted construction effort (but not requiring corrective action to the material) and sheared material (which no longer meets the design CBR criteria).

In the latter case, scarify the overcompacted lift and recompact to the specified density.

REASONS FOR FAILED COMPACTION

Undercompaction –

This occurs as a result of the following:

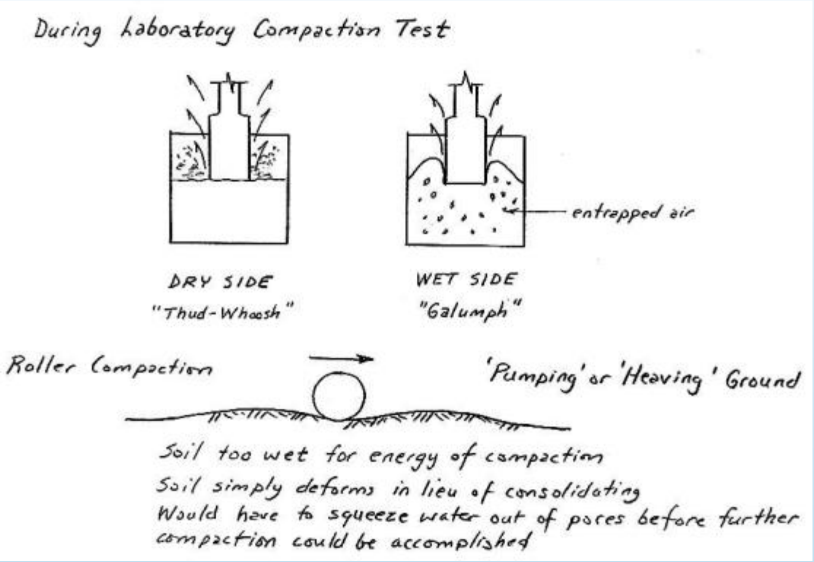
- Insufficieant roller passes.
- A change in soil type.
- Insufficient roller weight.
- The correct roller is not being used for the soil type.
- A change in the compaction procedures.

REASONS FOR FAILED COMPACTION

Too Wet –

Soils that are too wet when compacted are susceptible to shearing and strength loss. Corrective action for a soil compacted too wet is to:

- Scarify and aerate.
- Retest the moisture content.
- A change in soil type.
- Recompact at specified moisture
- Chemically modify the soil using lime or cement stabilization.



REASONS FOR FAILED COMPACTION

Too Dry –

Soils that are too dry when compacted do not achieve the specified degree of compaction as do properly moistened soils. Corrective action
for a soil compacted too dry is to:

- Scarify, add water, mix thoroughly, and recompact.
- Retest the moisture content.
- Recompact at specified moisture.
- A change in soil type; retest for Proctor density.

STRUCTURE FAILURE EXAMPLES

BEATING THE HOLIDAY RUSH

Grading – Cuts > 40 ft; Fills > 30 ft

Fill Placement Specifications – Place fill material in 8-inch loose lifts and compact.

Actual Fill Placement – In order to advance the opening to pre-Christmas, the owner waived the compaction requirements.

Mall Opening – December brought rains and crowds of people. Portions of the pavement areas settled more than 6 inches.

STRUCTURE FAILURE EXAMPLES

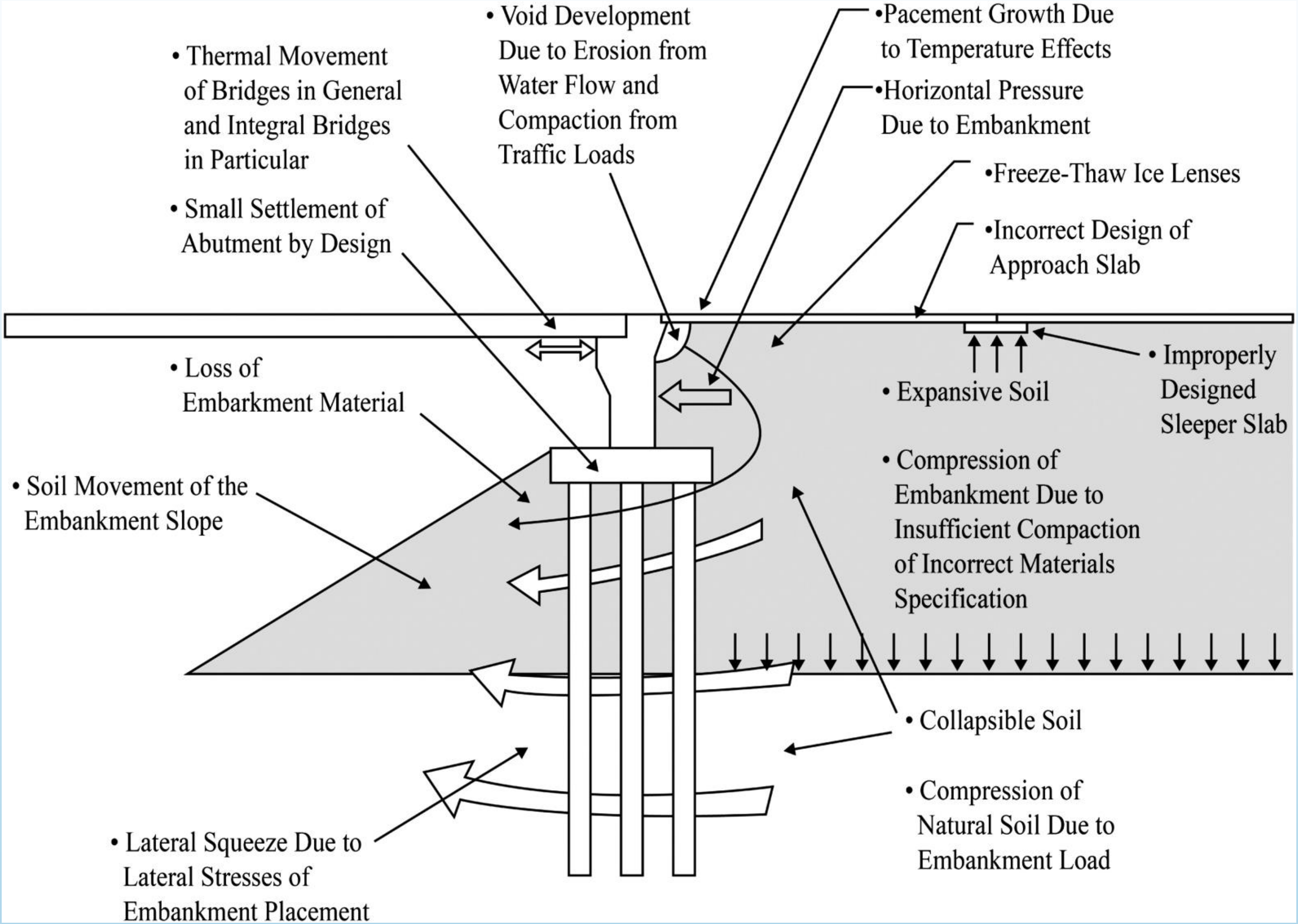
THE BUMP AT THE END OF THE BRIDGE

There is no one-size-fits-all solution to resolving "The Bump at the End of The Bridge". The findings assembled by several States include:

- Flowcharts for selecting appropriate abutment types.
- Sample calculations for design of integral or semi-integral abutments
- Design and support of approach slabs.
- Compaction methods and requirements for embankments.

STRUCTURE FAILURE EXAMPLES

THE BUMP AT THE END OF THE BRIDGE



STRUCTURE FAILURE EXAMPLES

CRUMBLING LOFTS

Stamford, CT, August 2022 – The signature Harbor Point building is cracking and sinking into the ground. It is the result of “dropping groundwater levels and settlement of underlying fill soil,” according to court documents.

The settlement of the soil fill has exposed the pilings to air, which has allowed bacteria and bugs to grow and consume the wood. (CT Examiner)

STRUCTURE FAILURE EXAMPLES

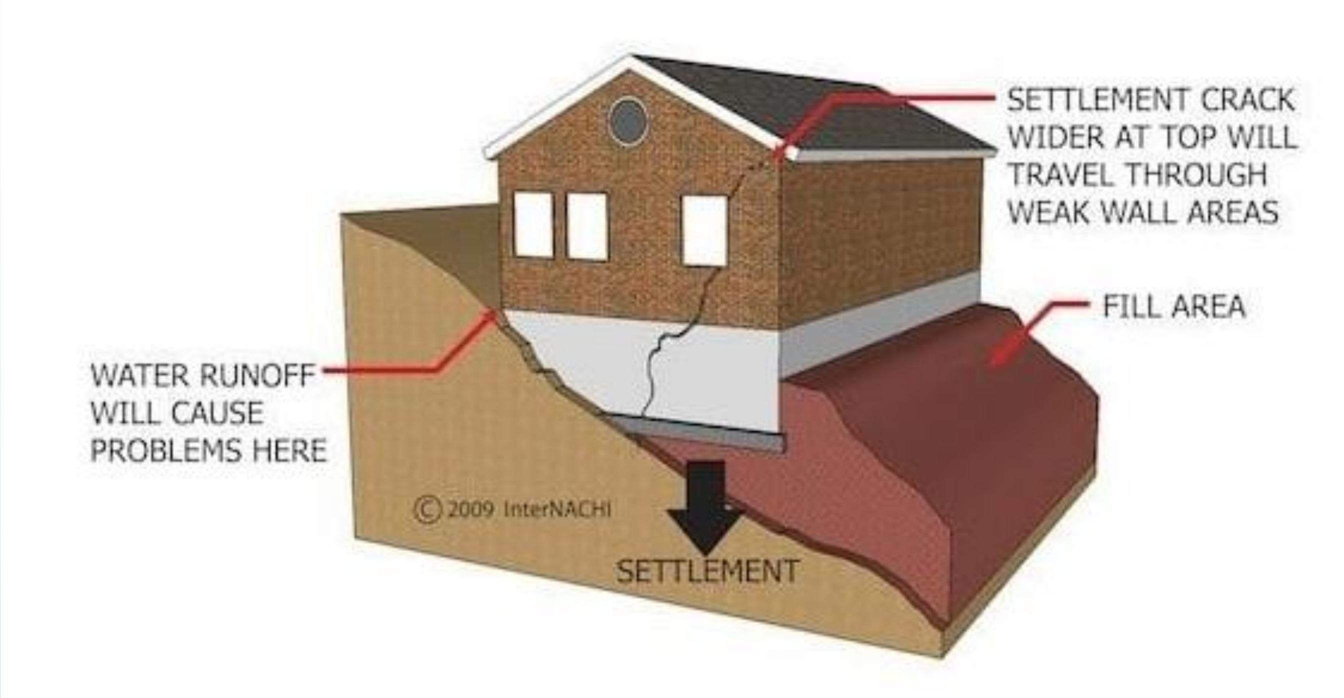
MISSION BAY SETTLEMENT

Mission Bay, CA, August 2022 - The Radiance, a 99-unit condominium building is suing the City of Mission Bay for damages caused by subsidence.

The issues identified goes beyond sidewalks to the invisible infrastructure underneath buildings. The legal action raises the larger question of whether it makes sense to build on bay fill in the first place. (The Potrero View)

STRUCTURE FAILURE EXAMPLES

BUILDING DIFFERENTIAL SETTLEMENT



One typical differential settlement problem generally results from the differential settlement between a native soil and a poorly compacted fill embankment.

QUESTIONS?