

DYNAMIC COMPACTION

VIBROCOMPACTION

BLASTING

Module 3: Compaction

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Spring 2022

February 11, 2022

COURSE CONTENTS AND SCHEDULE

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Tentative schedule

Day	Date	Topic	Lab.
W	1/19/2022	Class introduction, syllabus, policies	Soil components
F	1/21/2022	Invited speaker: Topic TBD	
M	1/24/2022	Introduction: The geological cycle, soil origin	Grain size dist.
W	1/26/2022	Introduction: Site investigation	
F	1/28/2022	Index properties: Phase relationships	
M	1/31/2022	Index properties: Grain size distribution, Atterberg limits	Atterberg limits
W	2/2/2022	Index properties: Soil classification	
F	2/4/2022	Compaction	
M	2/7/2022	Quiz 1: Introduction, index properties, compaction, in-situ testing	Visual classification
W	2/9/2022	Water in soils: Groundwater table, pore pressure, total and effective stresses	
F	2/11/2022	Water in soils: Darcy's law	
M	2/14/2022	Water in soils: Permeability and hydraulic conductivity	Compaction
W	2/16/2022	Water in soils: One-dimensional seepage	
F	2/18/2022	Water in soils: 2D-3D seepage, flow nets, pore pressure, uplift force, seepage force	
M	2/21/2022	Piezometer's day: no class	In-situ density
W	2/23/2022	Water in soils: piping	
F	2/24/2022	Quiz 2: Water in soils	
M	2/28/2022	Induced stress: Approximations, Bousinesq's elastic solution	Permeability
W	3/2/2022	Induced stress: Bousinesq's elastic solution, superposition	
F	3/4/2022	Induced stress: Stress tensor, elastic deformations	
M	3/7/2022	Consolidation: Oedometer test, primary and secondary consolidation	Site investigation
W	3/9/2022	Consolidation: Preconsolidation pressure, OCR	
F	3/11/2022	Consolidation: Primary consolidation parameters	
M	3/14/2022	Spring break: no class	
W	3/16/2022	Spring break: no class	
F	3/18/2022	Spring break: no class	
M	3/21/2022	Consolidation: rate of consolidation	Bonus
W	3/23/2022	Consolidation: preloading, radial consolidation	
F	3/25/2022	Quiz 3: Induced stress and consolidation	
M	3/28/2022	State of stress: 2D stresses and Mohr's circle	Consolidation
W	3/30/2022	State of stress: principal stresses, stress invariants, rotations	
F	4/1/2022	State of stress: Usage of Mohr's circle	
M	4/4/2022	State of stress: stress paths, simple shear, triaxial compression	Settlement estimates
W	4/6/2022	State of stress: Shear strength: Mohr-Coulomb failure criteria	
F	4/8/2022	Shear strength: drained and undrained behavior	
M	4/11/2022	Shear strength: drained and undrained behavior	Unconfined compression test
W	4/13/2022	Shear strength: Shear strength of clays	
F	4/15/2022	Shear strength: Shear strength of sands	
M	4/18/2022	Quiz 5: Shear strength	Direct shear
W	4/20/2022	Lateral earth pressure, at-rest, passive, and active conditions ²	
F	4/22/2022	Intro to slope stability ²	
M	4/25/2022	Intro to bearing capacity ²	Direct shear
W	4/27/2022	Maine's day: no class	
F	4/29/2022	Classes end: Q&A session	
M	5/2/2022	Final exam (1:30 PM- 3:30 PM) Williams Hall 110	

M: Monday - W: Wednesday - F: Friday

²This items may or may not be covered. It will be determined by how far the course has progressed.

RECAP

- We discussed soil particles characteristics and the grain size distribution.
- We learned about the tests to determine the GSD.
- We learned to quantify soil fractions.
- We learned about clay mineralogy, activity, and consistency.
- We learned how to classify soils according to the USCS.
- Today we will learn about soil compaction.

CONTENTS

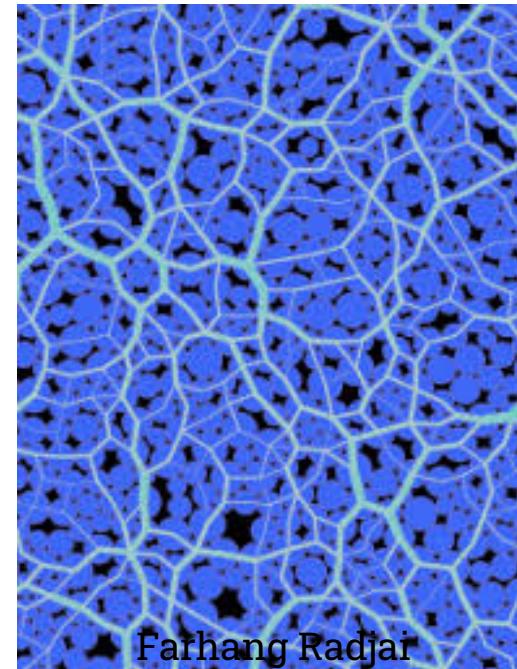
- Soil fabric.
- Compaction definition.
- Proctor test and compactive effort.
- Zero air voids, saturation lines, and line of optimums.
- Effect of water content.
- Field compaction equipment.
- Compaction control and specifications.
- Other soil compaction techniques.

More in chapter 5 of Holtz et al. (2013)

FABRIC OF GRANULAR SOILS

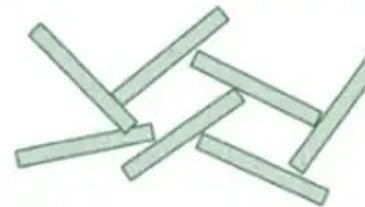
Soil fabric refers to the spatial distribution of pore spaces and individual particles in a soil.

- Defines how strong the soil is because it configures force chains.
- It is difficult to measure directly. We use proxies (e.g., D_r).
- Soil fabric is unique. Different soil fabric configurations might lead to same D_r .

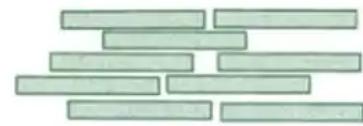


CLAY FABRIC

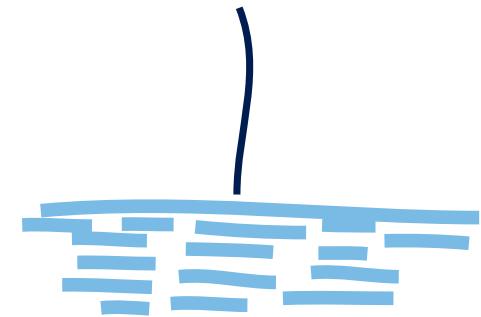
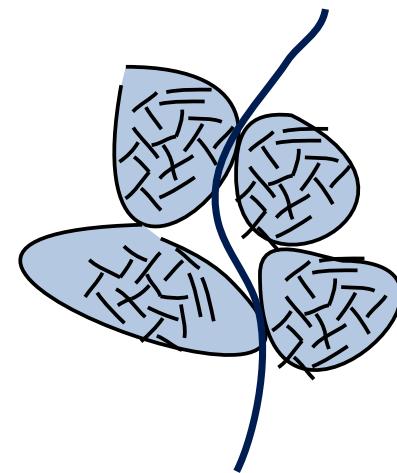
- Interaction scales range from elementary particles to mixed particle assemblages.
- Two main arrangements:
 1. Flocculated .
 2. Disperse .
- Electric attraction forces particles joint and form a floccule.
- Floccules act as particles of larger size.
- Clay particles behave individually in a dispersed fabric.



Flocculated



Dispersed
Theconstructor.com

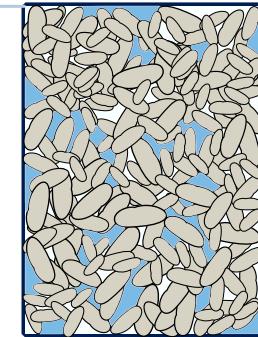
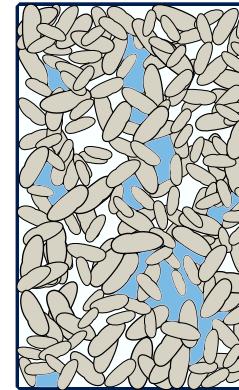


SOIL COMPACTION

It is a form of soil improvement that consists of densifying the soil mechanically , primarily with dynamic or vibratory loads.

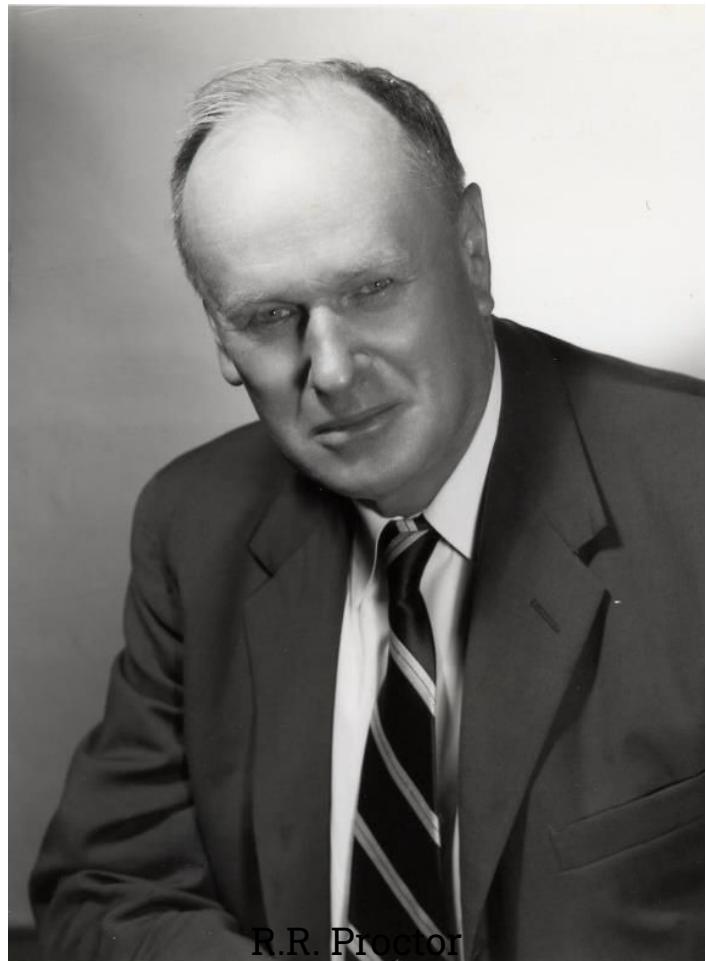
Benefits of soil compaction:

- Increased soil strength.
- Increased load-bearing capacity.
- Lower compressibility.
- Reduction of water flow.
- Increased soil stability.
- Reduction in frost damage .



PROCTOR TEST (ASTM D1140, D1557)

- Named after R.R. Proctor.
- He found compaction is function of:
 - Dry unit weight γ_d .
 - Water content w .
 - Compactive effort E_{comp} .
 - Soil GSD.
- Standard compaction effort is delivered to samples with different water content.
- We want to determine the maximum dry unit weight $\gamma_{d,max}$ possible and the optimum water content w_{opt} for compaction.



R.R. Proctor

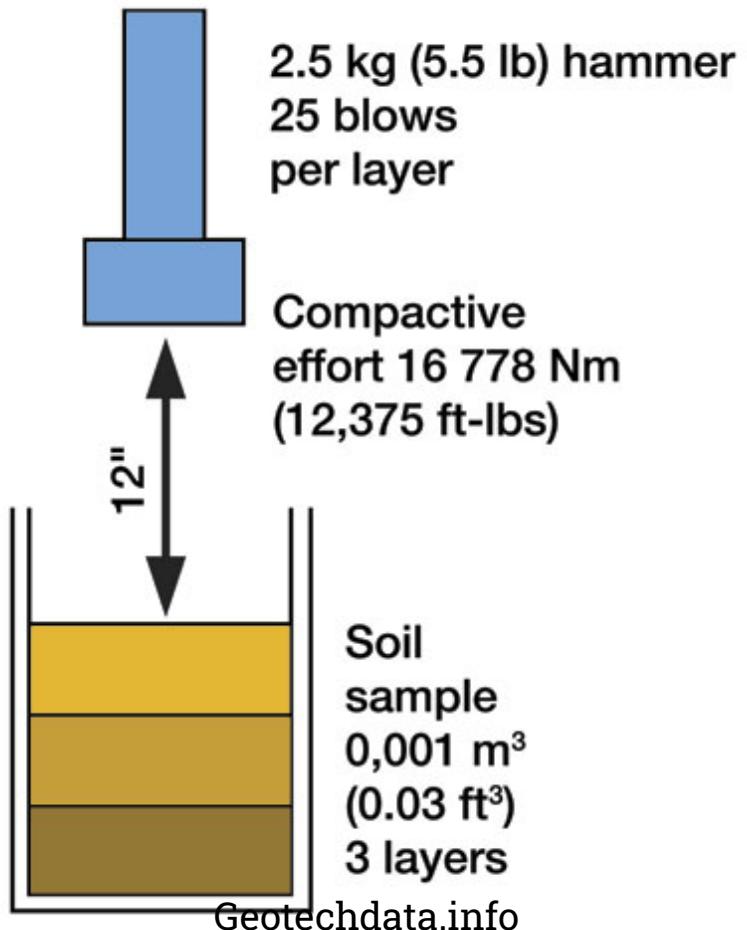
COMPACTIVE EFFORT

Compactive effort:

$$E_{comp} = m_h g \frac{h_d N_b N_l}{V}$$

- m_h = Hammer mass.
- h_d = drop height.
- N_b = number of blows per layer.
- N_l = number of layers.
- V = Volume of mold.

Standard Proctor test.



EXAMPLE 3.1

Find the compaction effort of the standard Proctor test knowing $h_d = 45.7\text{cm}$, $m_h = 4.54\text{kg}$, $N_b = 25$, $N_l = 3$. Compute the result in $\text{lb}\cdot\text{ft}/\text{ft}^3$ and kJ/m^3 .

THEORETICAL MAXIMUM DRY DENSITY

An expression relating γ_d with water content w and saturation S is:

$$\gamma_d = \frac{\gamma_w G_s}{1 + wG_s/S}$$

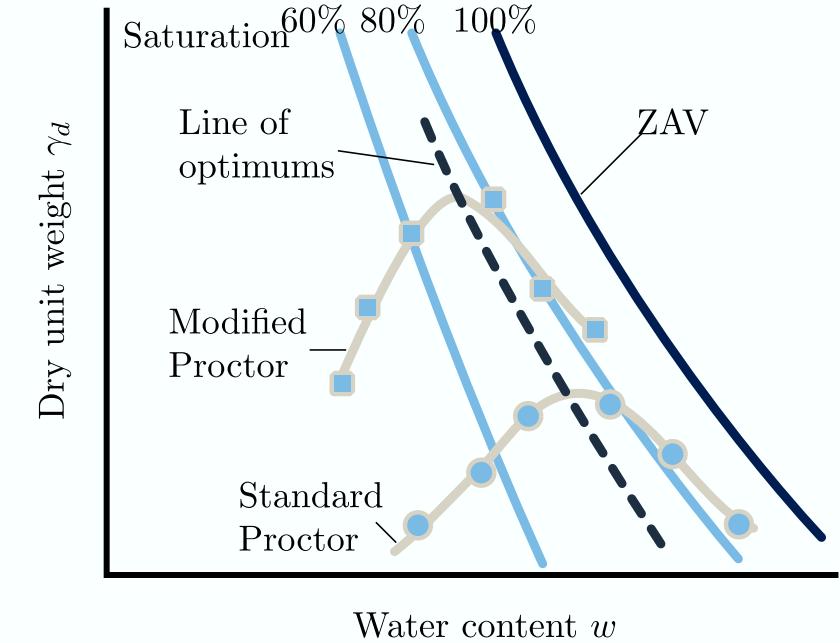
γ_d is maximized if $S = 100\%$ (i.e., all air is removed).

$$\gamma_{d,max} = \frac{\gamma_w G_s}{1 + wG_s}$$

Also known as the zero-air voids (ZAV) line.

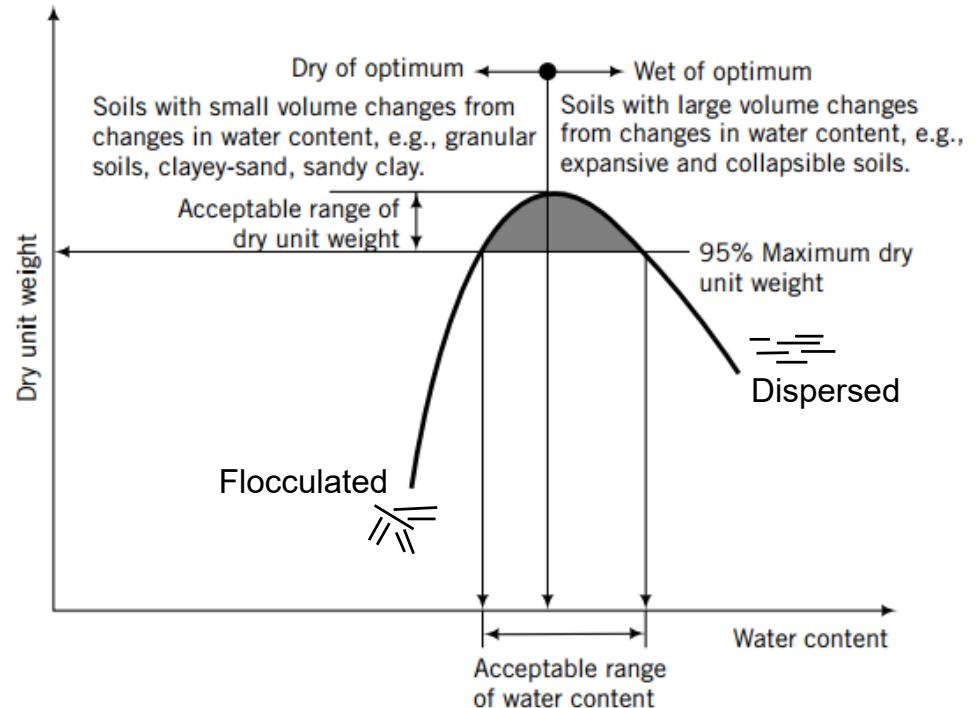
RESULTS OF COMPACTION TESTS

- Tests are conducted with varying water content.
- Typically shows a parabola shape.
- $\uparrow E_{comp} \rightarrow \uparrow \gamma_d$
- $\uparrow E_{comp} \rightarrow \downarrow w_{opt}$
- Line of optimums is the line of all possible combinations of E_{comp} , $\gamma_{d,max}$, and w_{opt} .



EFFECT OF WATER CONTENT

- Typically a range of γ_d and w is specified.
- Same density can be achieved for different w .
- Compaction on the dry side increases due to flocculated fabric.
- Compaction on the wet side changes the soil fabric to a dispersed configuration.
- Compaction on dry side is suitable for stable soils.
- Compaction on the wet side is more suitable for soils with large expansion potential.



After Budhu (2015)

FIELD COMPACTION EQUIPMENT

Smooth roller



Sheep foot rollers



Vibratory smooth roller



Impact roller



- Apply compaction energy by static pressure or vibration.
- Kneading with protrusions applies static pressure (sheep foot roller).
- Vibratory compaction is usually used for granular soils.
- Impact rollers have a deeper influence zone.

FIELD COMPACTION EQUIPMENT

Characteristics of the compactor:

- Mass, size.
- Operating frequency and frequency range.

Characteristics of soil:

- Initial density.
- Grain size and shape.
- Water content.

Construction procedures:

- Number of passes of roller.
- Lift thickness.
- Frequency of operation of vibrator.
- Towing speed.

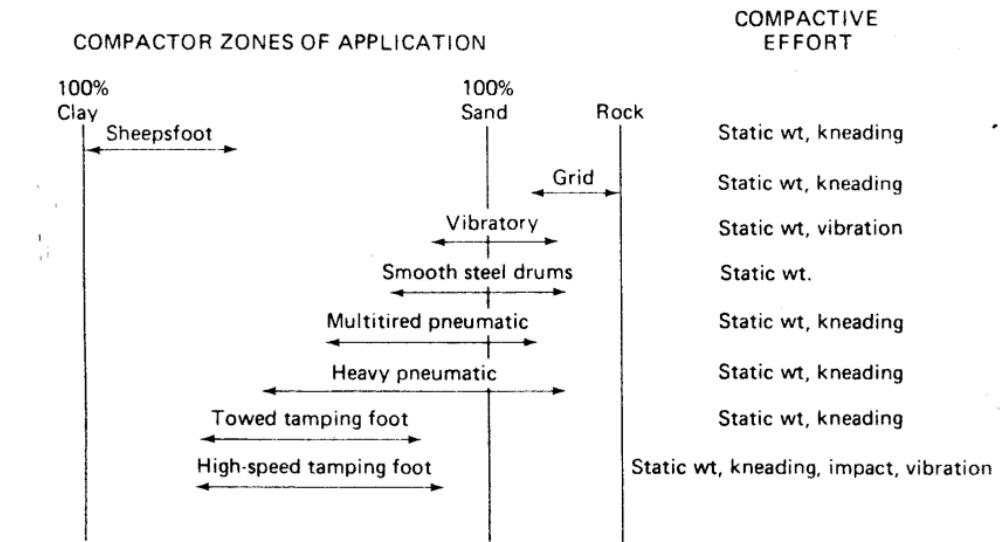


Fig. 5.20 Applicability of various types of compaction equipment for a given soil type (modified after Caterpillar Tractor Co., 1977).

Taken from Holtz et al. (2013)

COMPACTION SPECIFICATIONS

Two types:

- End product.
- Method specifications.

With the first type **relative compaction** is specified.

$$RC[\%] = \frac{\gamma_d \text{ field}}{\gamma_{d,max}} \times 100$$

Do not confuse with relative density, only used for **clean granular soils** ($F_F < 12\%$).

With the second type, all steps, equipment, and methods are specified by the engineer. Like a recipe.

EXAMPLE 3.2

You are checking a field compacted soil layer. The laboratory control curve is shown in the table below. The specification states the soil must be compacted to at least 95% of the laboratory's maximum dry unit weight and within optimum water content for the control curve. You dig a hole of 0.03 ft^3 and extract a sample that weights 3.8 lb wet and 3.1 lb dry.

1. What is the compacted dry unit weight?, the compaction w ? The percent compaction? Does the sample meet the specifications?
2. If $G_s = 2.68$ what is the compacted S ? If the sample was saturated at constant density, what would be the water content?

$\gamma_d \text{ pcf}$	$w \%$
104	14
105.5	16
106	18
105	20
103.5	22
101	24

COMPACTION Q&A CONTROL

- Performed frequently (often using a volume threshold) in distributed, representative in-situ sample.
- Two types available:
 - Destructive (requires excavation).
 - Non-destructive (radiation to determine unit weight indirectly).

	Sand Cone	Balloon Densometer	Shelby Tube	Nuclear Gauge
Advantages	<ul style="list-style-type: none">• Large sample• Accurate	<ul style="list-style-type: none">• Large sample• Direct reading obtained• Open graded material	<ul style="list-style-type: none">• Fast• Deep sample• Under pipe haunches	<ul style="list-style-type: none">• Fast• Easy to redo• More tests (statistical reliability)
Disadvantages	<ul style="list-style-type: none">• Many steps• Large area required• Slow• Halt equipment• Tempting to accept flukes	<ul style="list-style-type: none">• Slow• Balloon breakage• Awkward	<ul style="list-style-type: none">• Small sample• No gravel• Sample not always retained	<ul style="list-style-type: none">• No sample• Radiation• Moisture suspect• Encourages amateurs
Errors	<ul style="list-style-type: none">• Void under plate• Sand bulking• Sand compacted• Soil pumping	<ul style="list-style-type: none">• Surface not level• Soil pumping• Void under plate	<ul style="list-style-type: none">• Overdrive• Rocks in path• Plastic soil	<ul style="list-style-type: none">• Miscalibrated• Rocks in path• Surface prep required• Backscatter
Cost	<ul style="list-style-type: none">• Low	<ul style="list-style-type: none">• Moderate	<ul style="list-style-type: none">• Low	<ul style="list-style-type: none">• High

multiquip.com

EXAMPLE 3.3

In a field density test, using the oil method, the wet mass of soil removed from a small hole in the field was 1.65 kg. The mass of oil (with $\rho_{oil}/\rho_w = 0.92$) required to fill the hole was 0.75 kg, and the fill water content was 22%. If $G_s = 2.65$ what is the dry density and degree of saturation of the soil?

