DYNAMIC COMPACTION

VIBROCOMPACTION

BLASTING

Module 3: Compaction

Luis Zambrano-Cruzatty, Ph.D.

Spring 2022

February 11, 2022

COURSE CONTENTS AND SCHEDULE

Department of
Civil and Environmental Engineering

THE UNIVERSITY OF MAINE

308 Boardman Hall
Orono, Maine 04469-5711
Tel: 207.581.1277
Fax: 207.581.3888
Email: luis.zambranocruzatty@maine.edu

Tentative schedule

Day	Date	Topic	Lab.
W	1/19/2022	Class introduction, syllabus, policies	Soil
F	1/21/2022	Invited speaker: Topic TBD	components
M	1/24/2022	Introduction: The geological cycle, soil origin	Grain size
W	1/26/2022	Introduction: Site investigation	dist.
F	1/28/2022	Index properties: Phase relationships	
M	1/31/2022	Index properties: Grain size distribution, Atterberg limits	Atterberg
W	2/2/2022	Index properties: Soil classification	limits
F	2/4/2022	Compaction	
M	2/7/2022	Quiz 1: Introduction, index properties, compaction, in-situ testing	Visual
W	2/9/2022	Water in soils: Groundawater table, pore pressure, total and effective stresses	classification
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	President's day: no class	In-situ
W	2/23/2022	Water in soils: piping	density
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
W	3/9/2022	Consolidation: Preconsolidation pressure, OCR	investigation
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 consolidaiton	
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
W	4/6/2022	Quiz 4: State of stress	estimates
F	4/8/2022	Shear strength: Mohr-Coulomb failure criteria	
M	4/11/2022	Shear strength: drained and undrained behavior	Unconfined
W	4/13/2022	Shear strength: Shear strength of clays	compression
F	4/15/2022	Shear strength: Shear strength of sands	test
M	4/18/2022	Quiz 5: Shear strength	Direct
W	4/20/2022	Lateral earth pressure: at-rest, passive, and active conditions [2]	shear
F	4/22/2022	Intro to slope stability [2]	
M	4/25/2022	Intro to bearing capacity [2]	Direct
W	4/27/2022	Maine's day: no class	shear
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

[2] This 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

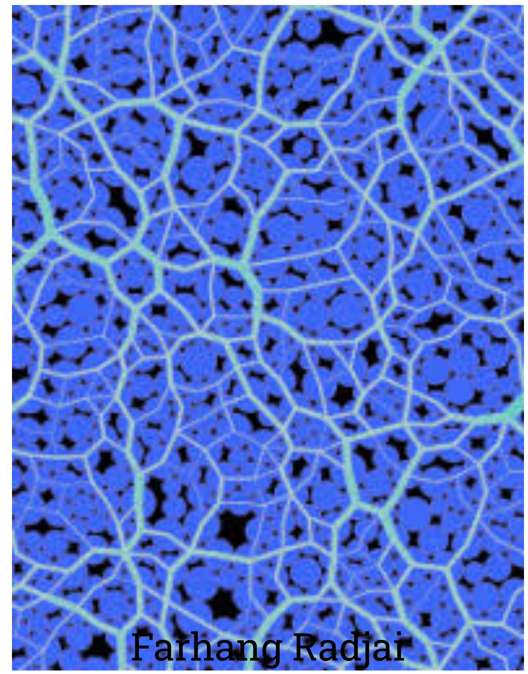
- Soil fabric.
- Compaction definition.
- Proctor test and compactive effort.
- Zero air voids, saturation lines, and line of optimums.
- Effect of water content.
- Field compaction equipment.
- Compaction control and specifications.
- Other soil compaction techniques.

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

FABRIC OF GRANULAR SOILS

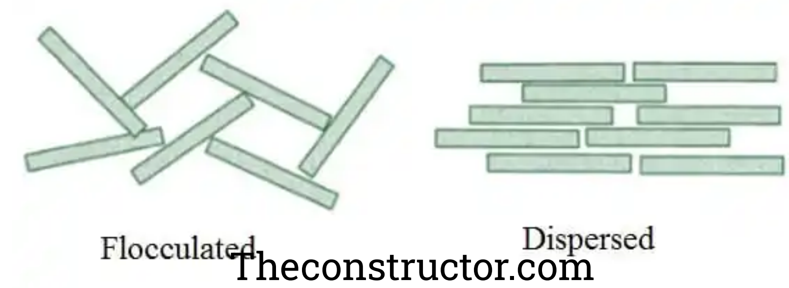
Soil fabric refers to the spatial distribution of pore spaces and individual particles in a soil.

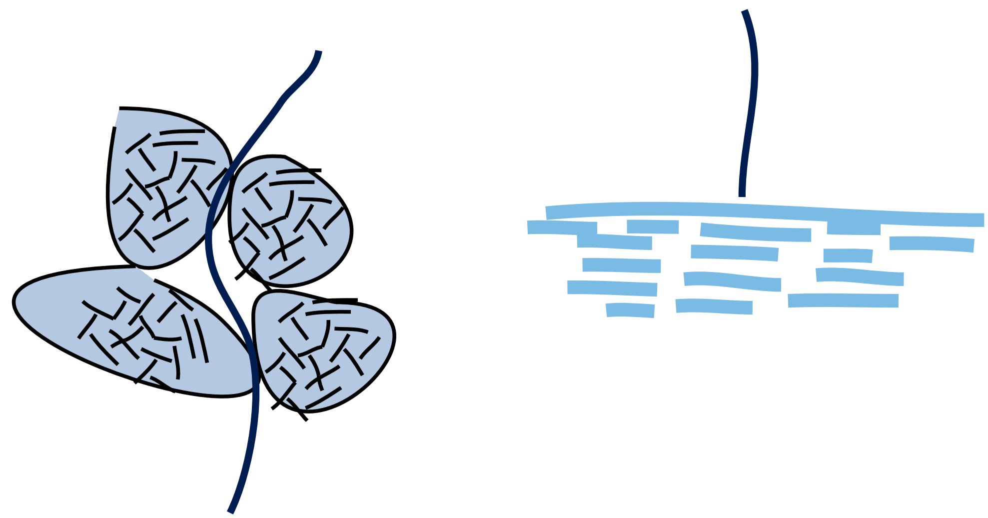
- Defines how strong the soil is because it configures force chains.
- It is dificult to measure directly. We use proxies (e.g., D_r).
- Soil fabric is unique. Different soil fabric configurations might lead to same D_r.



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.





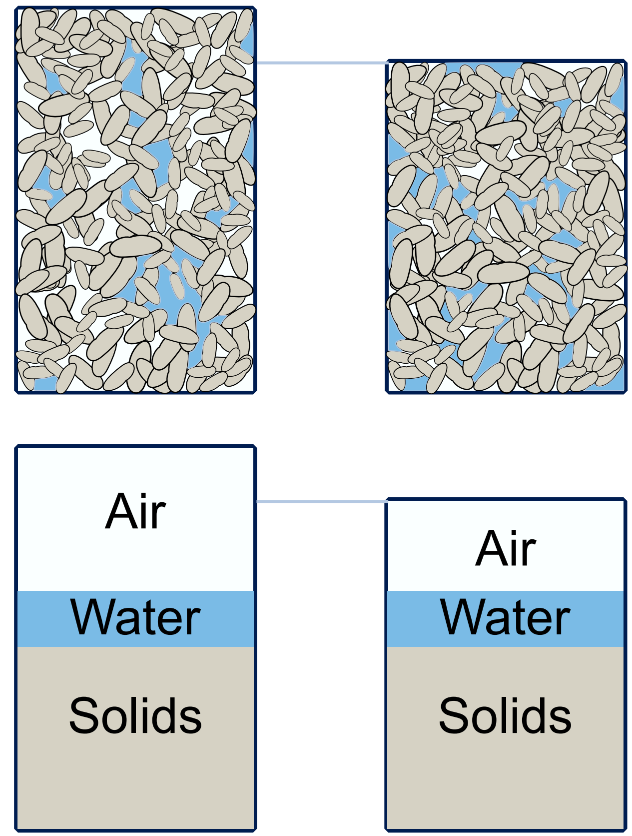
≡

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:

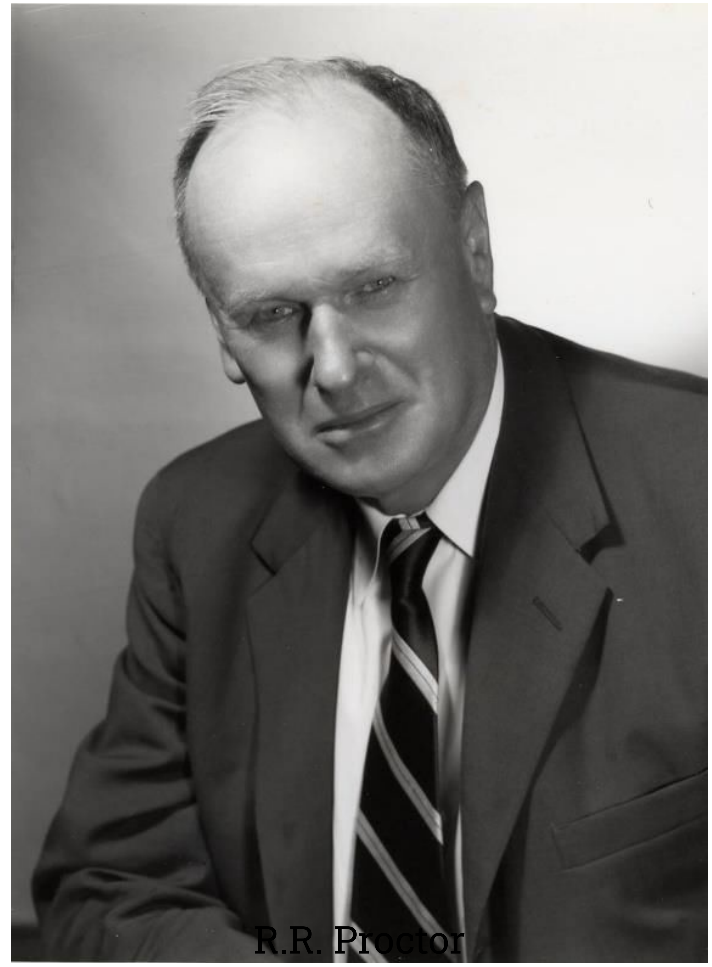
- Increased soil strength.
- Increased load-bearing capacity.
- Lower compressibility.
- Reduction of water flow.
- Increased soil stability.
- Reduction in frost damage .



≡

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 wih 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

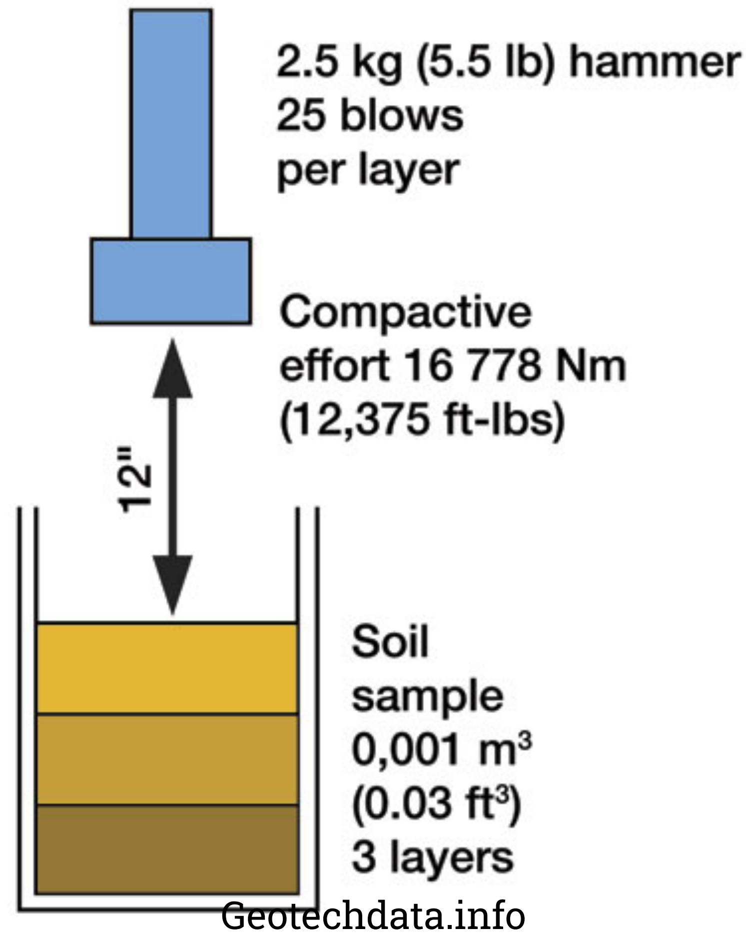
COMPACTIVE EFFORT

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 lb-ft/ft^3 and kJ/m^3.

≡

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

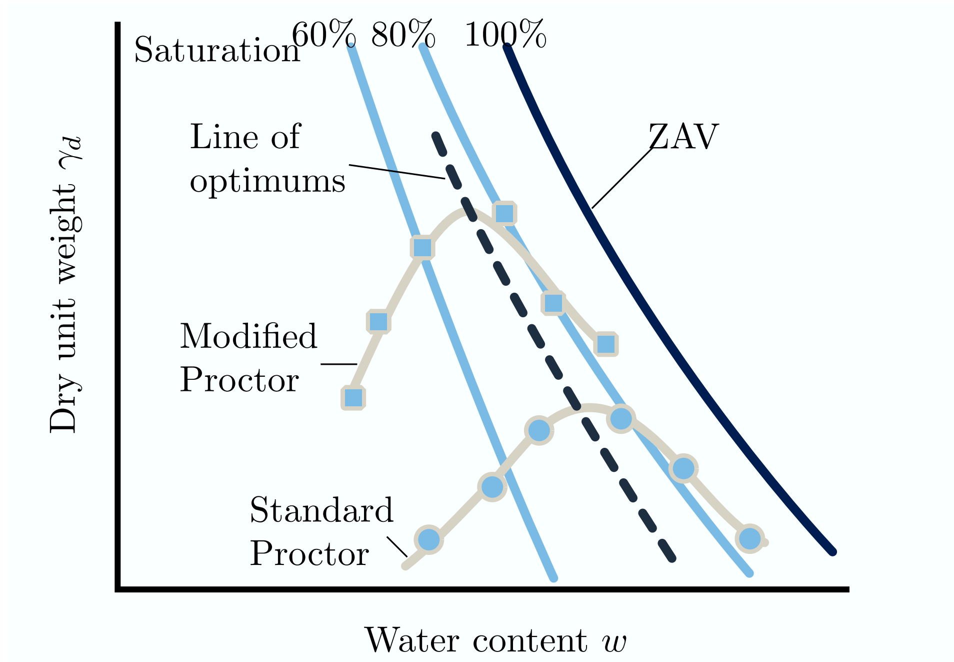
$$\gamma_{d,max} = \frac{\gamma_w G_s}{1 + wG_s}$$

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

≡

RESULTS OF COMPACTION TESTS

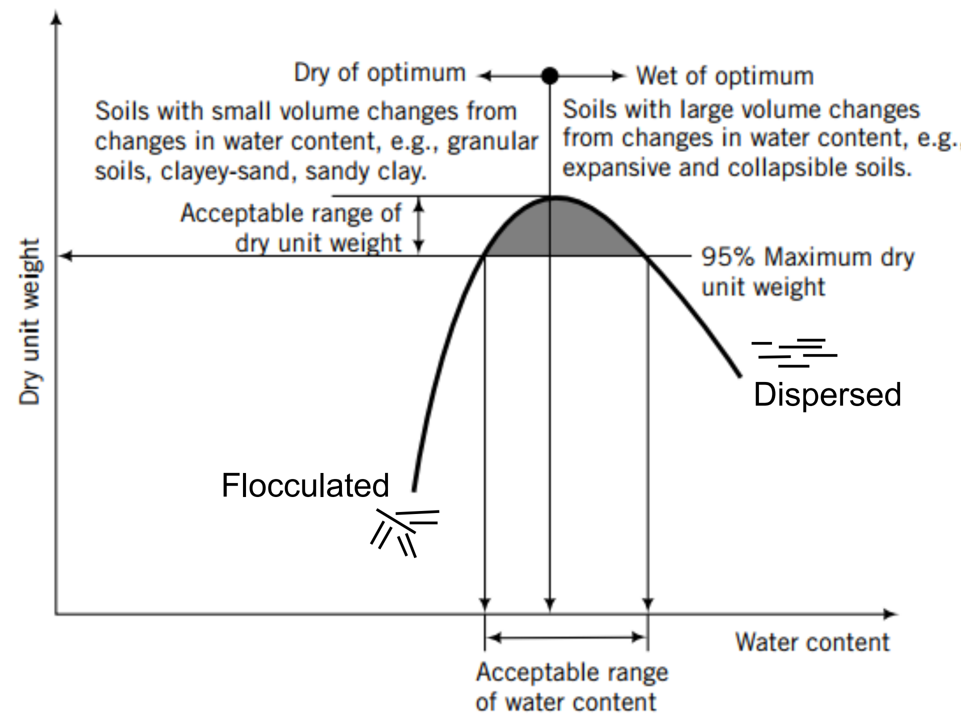
- Tests are conducted with varying water content.
- Typically shows a parabola shape.
- $\uparrow E_{comp} \longrightarrow \uparrow \gamma_d$
- $\uparrow E_{comp} \longrightarrow \downarrow w_{opt}$
- Line of optimums is the line of all possible combinations of E_{comp}, $\gamma_{d,max}$, and w_{opt}.



≡

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 increasses 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

- 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.

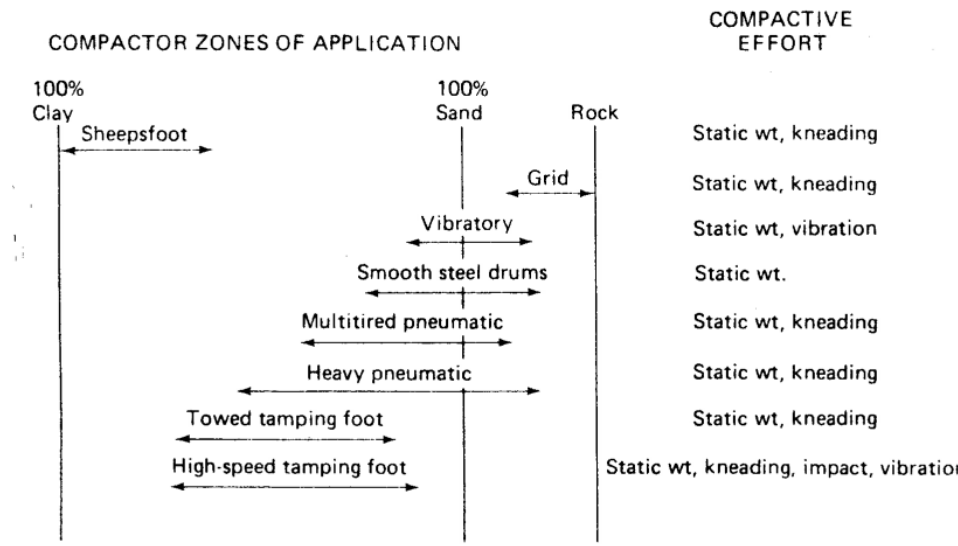


Fig. 5.20 Applicability of various types of compaction equipment for a given soil type (modified after Caterpillar Tractor Co., 1977).

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.

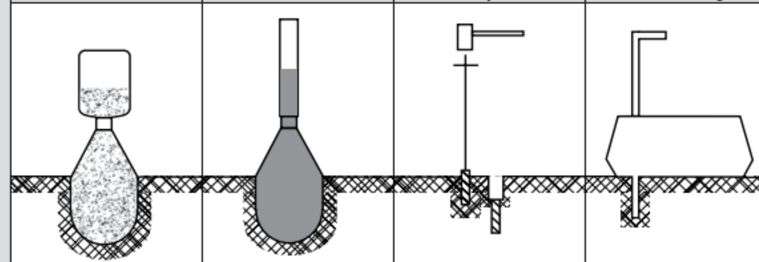
1. What is the compacted dry unit weight?, the compaction w?, The percent compaction? Does the sample meet the specifications?
2. If $G_s = 2.68$ what is the compacted S?, If the sample was saturated at constant density, what would be the water content?

γ_d pcf	w %
104	14
105.5	16
106	18
105	20
103.5	22
101	24

≡

COMPACTION Q&Q CONTROL

- Performed frequently (often using a volume threshold) in distributed, representatitive 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	• Large sample • Accurate	• Large sample • Direct reading obtained • Open graded material	• Fast • Deep sample • Under pipe haunches	• Fast • Easy to redo • More tests (statistical reliability)
Disadvantages	• Many steps • Large area required • Slow • Halt equipment • Tempting to accept flukes	• Slow • Balloon breakage • Awkward	• Small sample • No gravel • Sample not always retained	• No sample • Radiation • Moisture suspect • Encourages amateurs
Errors	• Void under plate • Sand bulking • Sand compacted • Soil pumping	• Surface not level • Soil pumping • Void under plate	• Overdrive • Rocks in path • Plastic soil	• Miscalibrated • Rocks in path • Surface prep required • Backscatter
Cost	• Low	• Moderate	• Low	• 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?

≡