MATERIALS
COMPACTION

References:

1. Rajapakse, Ruwan. Geotechnical Engineering Calculations and Rules of Thumb.
2. Schroeder, W.L., Dickenson, S.E, Warrington, Don, C. Soils in Construction. Fifth Edition. Upper Saddle River, New Jersey; Prentice Hall, 2004.

Learning objectives: (also review Borrow Pit and Equipment production in the Construction engineering module for more information)

1. Understanding the moisture-density relationship in respect to compaction.
   - Cohesionless/Cohesive Soils
2. Determining compaction Standard/Modified Proctor Test
3. Important formulas and equipment for compaction.

Learning objective #1: Understanding the moisture-density relationship

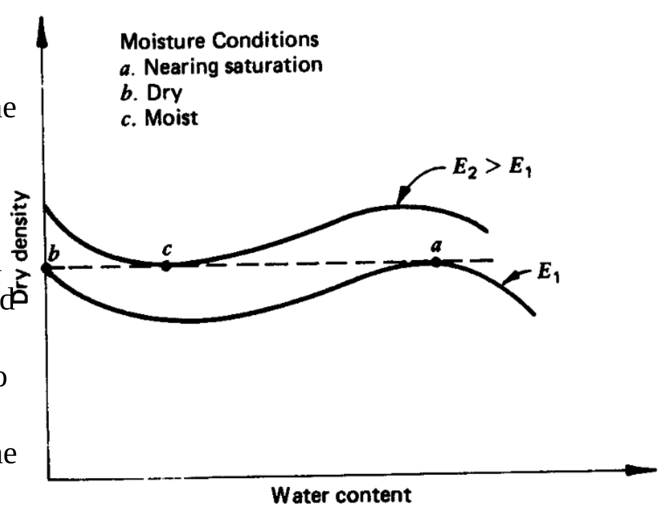
The moisture-density relationship: The amount of compaction, which is just creating more dense (higher pcf) soils depends on four things;

1. Amount of energy used (ex. How many times a compactor roller over the soil)
2. How the energy is applied (ex. Is the compactor a vibrating or sheepfoot)
3. The type of soil involved (ex. cohesive, non cohesive)
4. The soils water content (ex. What is the percentage of water with respect to soil.

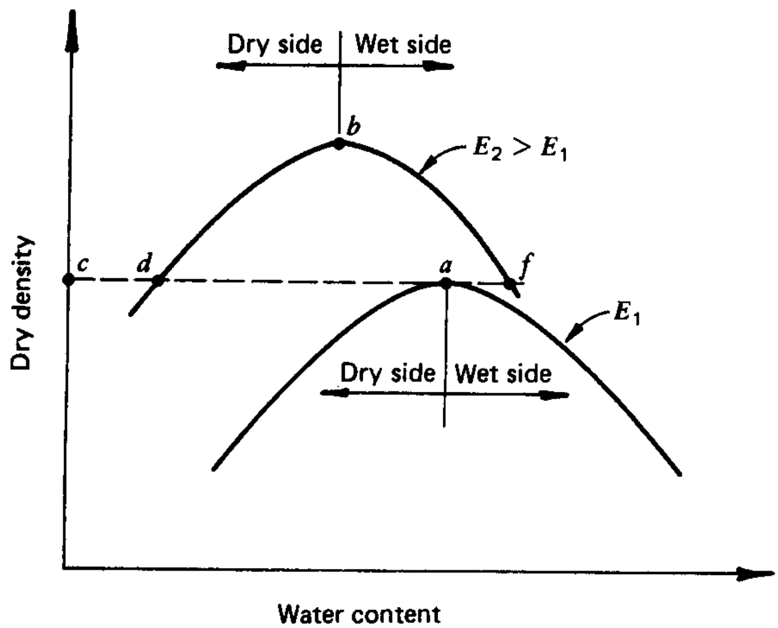
This section discusses the relationships among these factors;

Cohesionless Soils. First it is pretty intuitive that the more energy applied to the soil during compaction the more dense you will make it. This is the case with Cohesionless (sand/gravel) which you can review the figure below. Also which is obvious is that cohesionless soil would require a vibratory roller to create the best results due to needing to move the soil particles around to fill the voids.

The figure to the right is a idealized moisture-density curves for clean sand. The two lines represent different energy levels for compaction. The curves are S shaped, which means the highest density are with very little water content and then very high water content. If the dotted line represented the required density level you can clearly see that there are multiple potential ways to achieve that. In the end, it is the project manager job to get the soil compacted in the most economical way.



Cohesive Soils. Below is the Moisture-density curves characteristic of a cohesive soil. As expected increased compactive energy results in increased densification. The maximum density for a given effort is obtained at a optimum water content, as shown at point a and b. Again if the dotted line represents the required dry density, the you can see there are a few options that the could used to achieve the desired results.



Learning objective #2: Determining compaction Standard/Modified Proctor Test

→ All test methods for compaction are similar. They specify the soil to be used and the compactive effort to be exerted in developing the moisture density relationship.

→ For plastic soils, the most widely used test method is the Standard Proctor Test (SPT). For soils where very high densities are to be specified (for most road and foundation work) then the Modified Proctor test is used. Below is a quick comparison of the two tests. You should notice that the modified uses a significantly higher energy level than the SPT, which will result in higher densities than the SPT.

Comparison of Compaction Test Procedures

Designation	*Standard* *ASTM D698*	*Modified* *ASTM D1557*
Mold		
Diameter (in.)	4	4
Height (in.)	4 5/8	4 5/8
Volume (ft^3)	1/30	1/30
Tamper		
Weight (lb)	5.5	10.0
Free drop (in.)	12	18
Face diameter (in.)	2	2
Face area ($in.^2$)	3.1	3.1
Layers		
Number, total	3	5
Surface area, each ($in.^2$)	12.6	12.6
Compacted thickness, each (in.)	1 5/8	1
Effort		
Tamper blows per layer	25	25
($ft\text{-}lb/ft^3$)	12.375	56.250

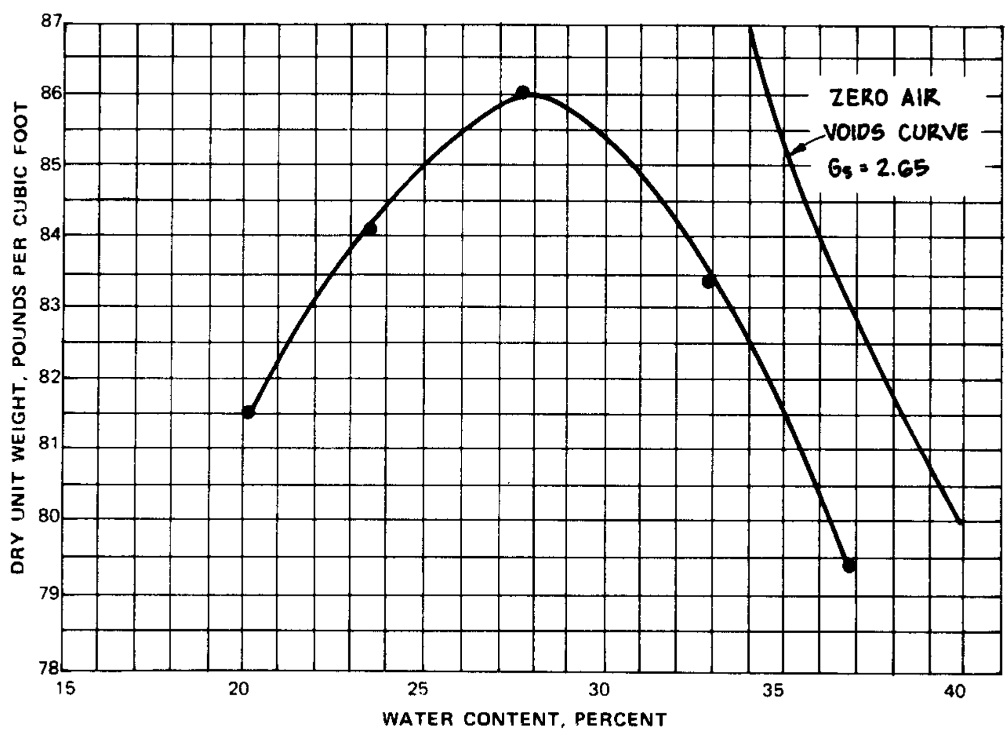
SOIL MECHANICS ANALYSIS
COMPACTION

→ Below is an example input and output of an Standard Proctor Test

SAMPLE IDENTIFICATION Red-brown Silty Clay

COMPACTIVE EFFORT ASTM D698

TRIAL NUMBER	1	2	3	4	5	6
Wt. of Wet Soil & Cylinder	12.92	13.12	13.32	13.35	13.28	
Wt. of Cylinder	9.66	9.66	9.66	9.66	9.66	
Wt. of Wet Soil	3.26	3.46	3.66	3.69	3.62	
Vol. of Cylinder	1/30	1/30	1/30	1/30	1/30	
Unit Wet Weight	97.9	103.9	109.9	110.8	108.7	
Unit Dry Weight	81.5	84.1	86.1	83.4	79.4	
Pan Number	161	181	189	185	170	
Wt. of Wet Soil & Pan	80.58	92.92	88.92	101.65	93.45	
Wt. of Dry Soil & Pan	72.57	81.43	76.68	84.49	76.99	
Wt. of Water	8.01	11.49	12.24	17.16	16.46	
Wt. of Dish	32.73	32.46	32.44	32.37	32.40	
Wt. of Dry Soil	39.84	48.97	44.24	52.12	44.59	
Water Content, %	20.1	23.5	27.7	32.9	36.9	



For each test, the moist unit weight of compaction, γ, can be calculated as

$$\gamma = \frac{W}{V_{(m)}} \tag{5.1}$$

where W = weight of the compacted soil in the mold
$V_{(m)}$ = volume of the mold [944 cm^3 ($\frac{1}{30} ft^3$)]

For each test, the moisture content of the compacted soil is determined in the laboratory. With the known moisture content, the dry unit weight can be calculated as

$$\gamma_d = \frac{\gamma}{1 + \frac{w\,(\%)}{100}} \tag{5.2}$$

where w (%) = percentage of moisture content.

For a given *moisture content* w and *degree of saturation* S, the dry unit weight of compaction can be calculated as follows:

$$\gamma_d = \frac{G_s \gamma_w}{1 + e} \qquad \gamma_d = \frac{G_s \gamma_w}{1 + \frac{G_s w}{S}}$$

where G_s = specific gravity of soil solids
γ_w = unit weight of water
e = void ratio

Learning objective #3: Important formulas and equipment for compaction.

→ Engineering properties of cohesionless soils are primarily a function of relative density. Relative density may be defined in terms of void ratio as

$$D_r = \frac{e_{(max)} - e}{e_{(max)} - e_{(min)}} \times 100\%$$

or in terms of unit weights as

$$D_r = \frac{\gamma_d(\max)}{\gamma_d} \frac{\gamma_d - \gamma_d(\min)}{\gamma_d(\max) - \gamma_d(\min)} \times 100\%$$

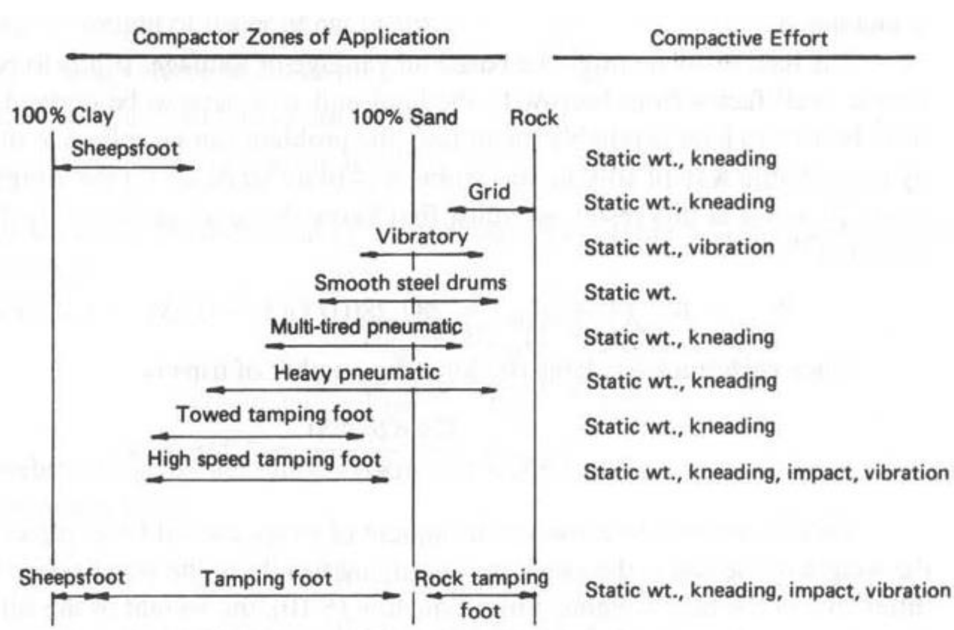
The following definitions apply:

e = void ratio measured,
$e_{(max)}$ = maximum void ratio determined by standard test method,
$e_{(min)}$ = minimum void ratio determined by standard test method,
γ_d = dry density measured,
$\gamma_d(\max)$ = maximum dry density determined by standard test method,
$\gamma_d(\min)$ = minimum dry density determined by standard test method.

→ In a contract a lot of times it will state that the soil has to be compacted at 95% of maximum dry density, it should also state which testing procedure that it has to be relative to.

Relative compaction **(RC) = γ_d / γ_d(max) x 100%**
Where:
γ_d = actual tested dry density ; γ_d(max) = SPT max dry density

→ Below is acceptable compaction equipment for different soil;



Example 5.1

For a compacted soil, $G_s = 2.72$, $w = 18\%$, and $\gamma_d = 0.9\gamma_{zav}$. Determine the dry unit weight of the compacted soil.

Solution

From Eq. (5.4),

$$\gamma_{zav} = \frac{\gamma_w}{w + \frac{1}{G_s}} = \frac{9.81}{\frac{18}{100} + \frac{1}{2.72}} = 17.9 \text{ kN/m}^3$$

Hence, for the compacted soil,

$$\gamma_d = 0.9\gamma_{zav} = (0.9)(17.9) = 16.1 \text{ kN/m}^3$$