Period #25: Compaction of Soils (I)

A. What is Compaction?

In most instances in civil engineering and/or construction practice, whenever soils are imported or excavated and re−applied, they are **compacted**.

The terms **compaction** and **consolidation** may sound as though they describe the same thing, but in reality they do not.

<u>consolidation</u>: Static loads are applied to saturated soils, and over a period of time the increased stresses are transferred to the soil skeleton, leading to a reduction in void ratio.

Depending on the permeability of the soil and the magnitude of the drainage distance, this can be a very time−consuming process.

Tyically applies to existing, undisturbed soil deposits.

<u>compaction</u>: When loose soils are applied to a construction site, compressive mechanical energy is applied to the soil using special equipment to densify the soil (or reduce the void ratio).

Typically applies to soils that are being applied or re−applied to a site.

B. Motivation for Compaction:

- Compaction increases the skeletal (or dry) density of soils for a wide range of construction applications. As examples:
  - highway embankments
  - earthen dams
  - backfilled trenches
  - sub−foundation soils

- Compaction generally leads to the following desirable effects on soils:

1) increased shear strength;

   This means that larger loads can be applied to compacted soils since they are typically stronger.

2) reduced compressibility;

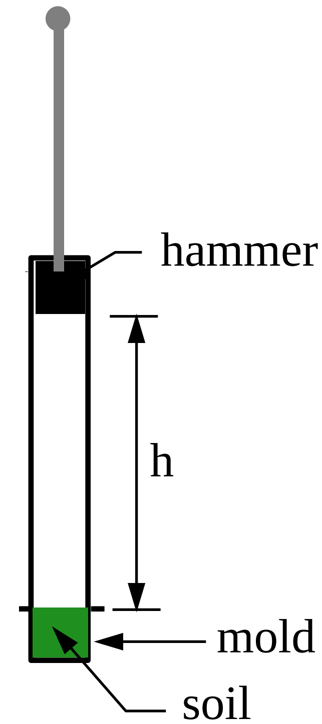
   This also means that larger loads can be applied to compacted soils since they will produce smaller settlements.

3) reduced permeability;

   This inhibits soils' ability to absorb water, and therefore reduces the tendency to expand/shrink and potentially liquefy.

C. Measuring Compaction of Soils in the Laboratory

1. The Standard Proctor Test



- Soil is compacted in a mold having a volume of (1/30)ft^3 or 944cm^3, and a diameter of 4in or 10.16cm.

- The soil is mixed with varying amounts of water to achieve different water contents.

- For each different water content, w:

  a) The soil is placed into the mold in three lifts (or layers) .

  b) For each lift, the soil is compacted by dropping a hammer of mass 2.5kg = 5.5lbs 25 times onto the confined soil from a height of 12in = 30.48cm.

  c) The compacted soil is removed from the mold and its dry density (or dry unit weight) is measured.

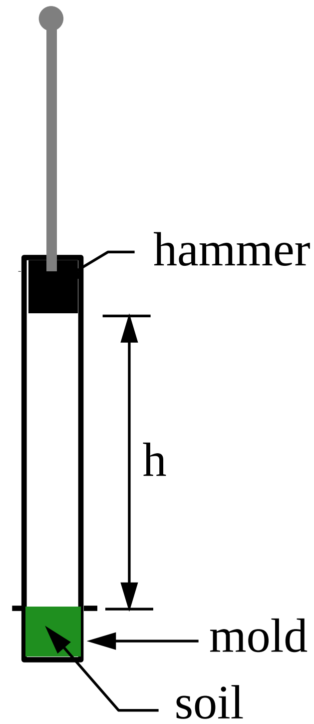
  d) Optionally, the unconfined compressive strength of the soil is also measured.

- Compactive Energy (E) applied to soil per unit volume:

$$E = \frac{(\#\text{ blows/layer}) * (\#\text{ of layers}) * (\text{hammer weight}) * (\text{height of drop})}{\text{Volume of mold}}$$

$$E_{SP} = \frac{(25\text{ blows/layer}) * (3\text{ layers}) * (5.5\text{lbs}) * (1.0\text{ft})}{(1/30)\text{ft}^3} = 12{,}375\text{ft}-\text{lb/ft}^3 = 594\text{kJ/m}^3$$

2. The Modified Proctor Test



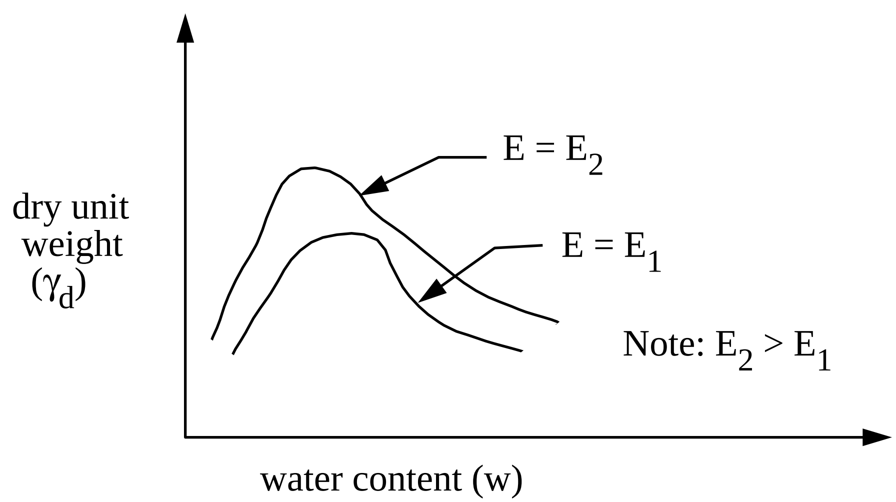
- This test is essentially the same as the Standard Proctor Test with the following exceptions:
  - The soil is compacted in five (not three) layers;
  - Weight of hammer is (4.54kg or 10lbs);
  - Drop height h is 18inches or 45.72cm.

- $E_{MP} = \dfrac{(25 \text{ blows/layer}) * (5 \text{ layers}) * (10\text{lbs}) * (1.5\text{ft})}{(1/30)\text{ft}^3}$
  $= 56{,}250 \text{ft-lb/ft}^3 = 2670 \text{kJ/m}^3$

3. Display of test results

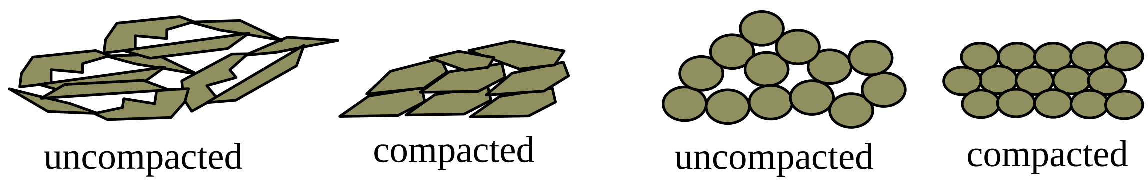
- Results of compaction tests are plotted as below:

Experimental Moisture−Density Relations



D. Principles of Compaction and Moisture−Density Relations

- Compaction of soils is achieved by reducing the volume of voids. It is assumed that the compaction process does not decrease the volume of the solids or soil grains.



- The degree of compaction of a soil is measured by the dry unit weight of the skeleton. The dry unit weight correlates with the degree of packing of the soil grains.

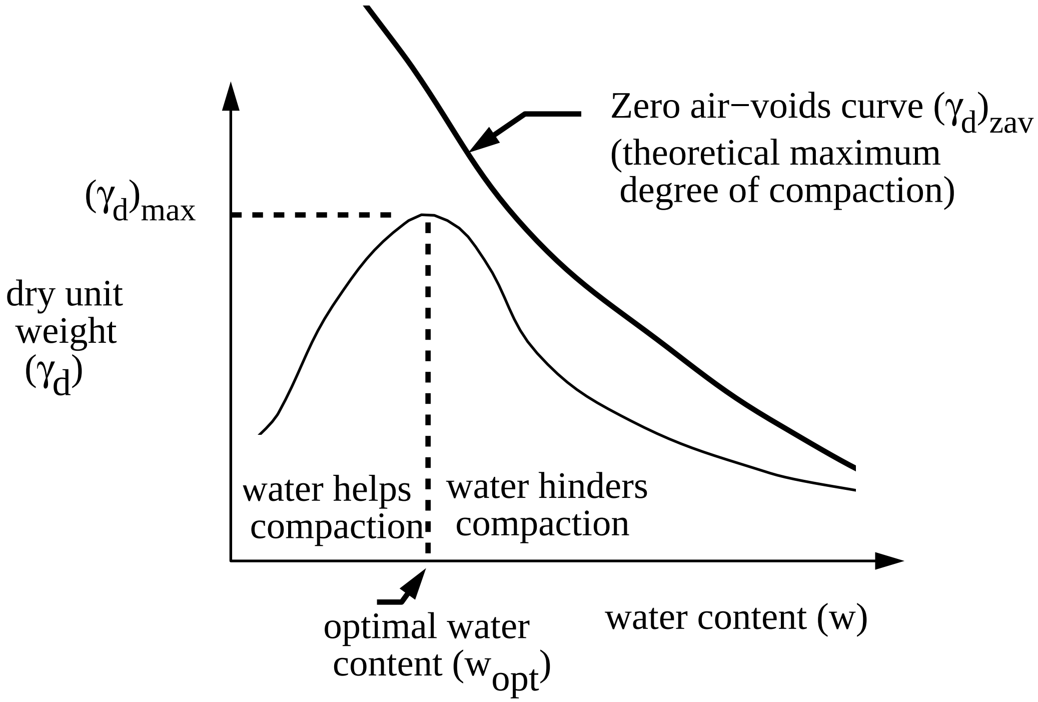
  - Recall that $\gamma_d = G_s \gamma_w/(1+e)$

  - The more compacted a soil is:
    - the smaller its void ratio (e) will be; and thus
    - the higher its dry unit weight (γ_d) will be.

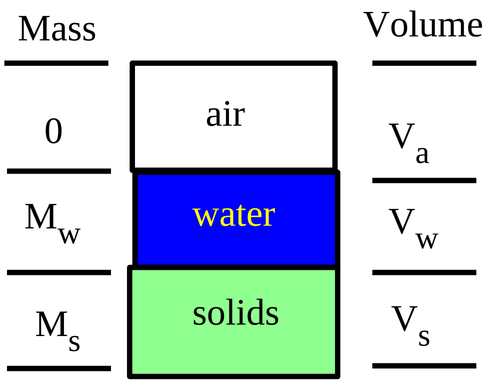
- Water plays a critical role in the soil compaction process:

  - It lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement.

  - While a little bit of water facilitates compaction, too much water inhibits . compaction. (This is shown schematically on the following page.)


Zero air−voids curve $(\gamma_d)_{zav}$
(theoretical maximum
degree of compaction)
$(\gamma_d)_{max}$
dry unit
weight
(γ_d)
water helps
compaction
water hinders
compaction
optimal water
content (w_{opt})
water content (w)

- To better understand soil compaction, consider the block diagram for soil shown below:



Total Mass $M = M_w + M_s$

Total Volume $V = V_w + V_s$

Void ratio $e = V_v / V_s$

Water content $w = M_w / M_s$

Saturation $S = V_w / V_v$

- Moist unit weight $= \gamma = (M_w + M_s) / V$
  $= (w + 1)\, M_s / V$
  $= (1+w)\, \gamma_d$

$$\therefore \quad \gamma_d = \gamma / (1+w) = G_s \gamma_w / (1+e)$$

- The goal of compaction is to reduce air−void volume V_a in soils as much as is possible.

- For a given water content w, the max. degree of compaction that can be achieved is when all of the air voids have been removed (S=1).

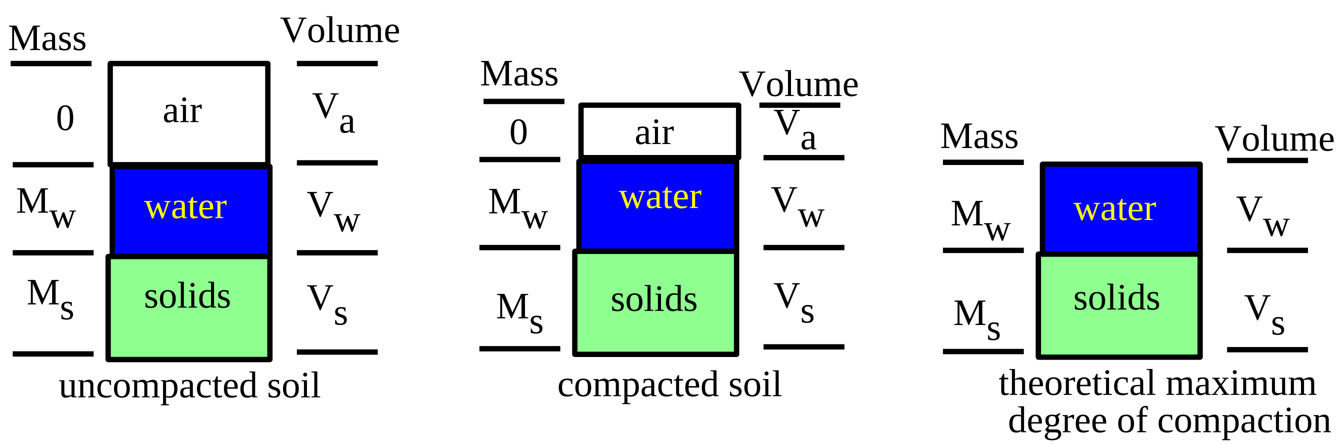
- Since $S = wG_s/e$, the corresponding void ratio (for S=1) will be: $e = wG_s$

- Recall that $\gamma_d = G_s\gamma_w/(1+e)$
- If for a given water content w, we insert the expression for void ratio ($e = wG_s$) that will give saturation ($S=1$) into this expression, we get:

$$(\gamma_d)_{zav} = G_s\gamma_w/(1+wG_s)$$

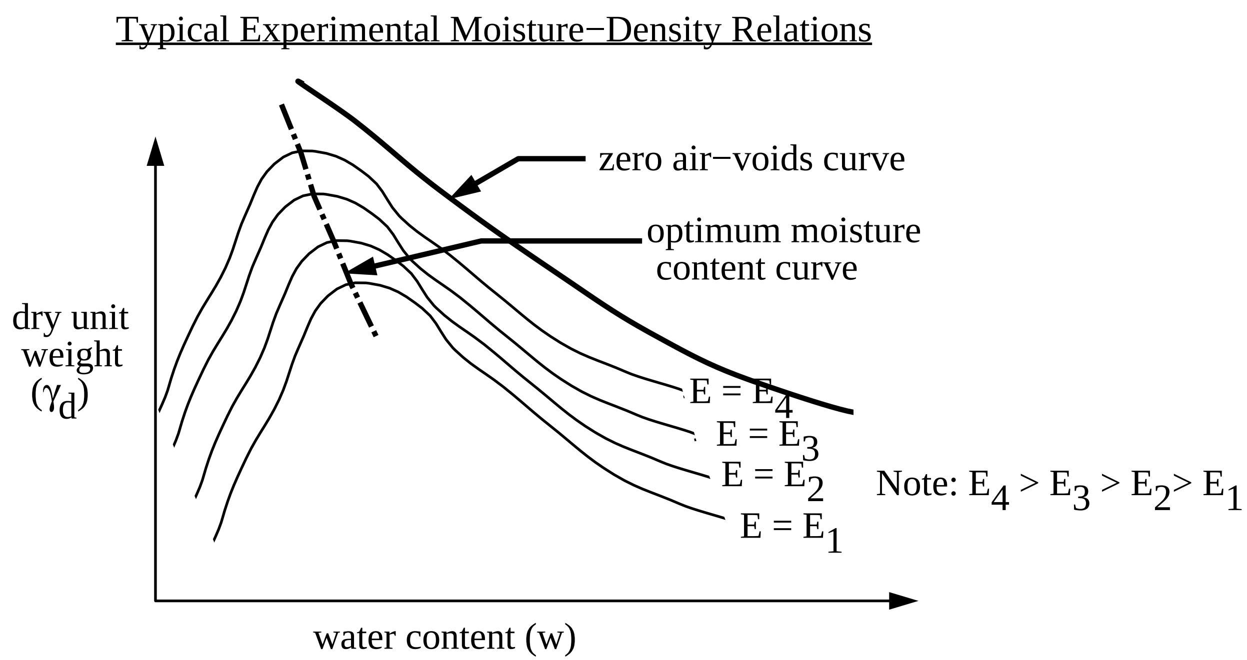
This represents the highest degree of dry density that can be possibly be achieved for a given water content w.

In practice this dry density is never achieved, but it represents a theoretical upper bound.



- For each compaction test performed on a given soil over a range of water contents, there will typically be a maximum dry density $(\gamma_d)_{max}$ of the soil and an optimal moisture content w_{opt}.

- For a given soil, both $(\gamma_d)_{max}$ and w_{opt} will typically depend on the compactive effort expended. This is shown in the schematic graph below.



E. Example Problems:

Example 25.1:

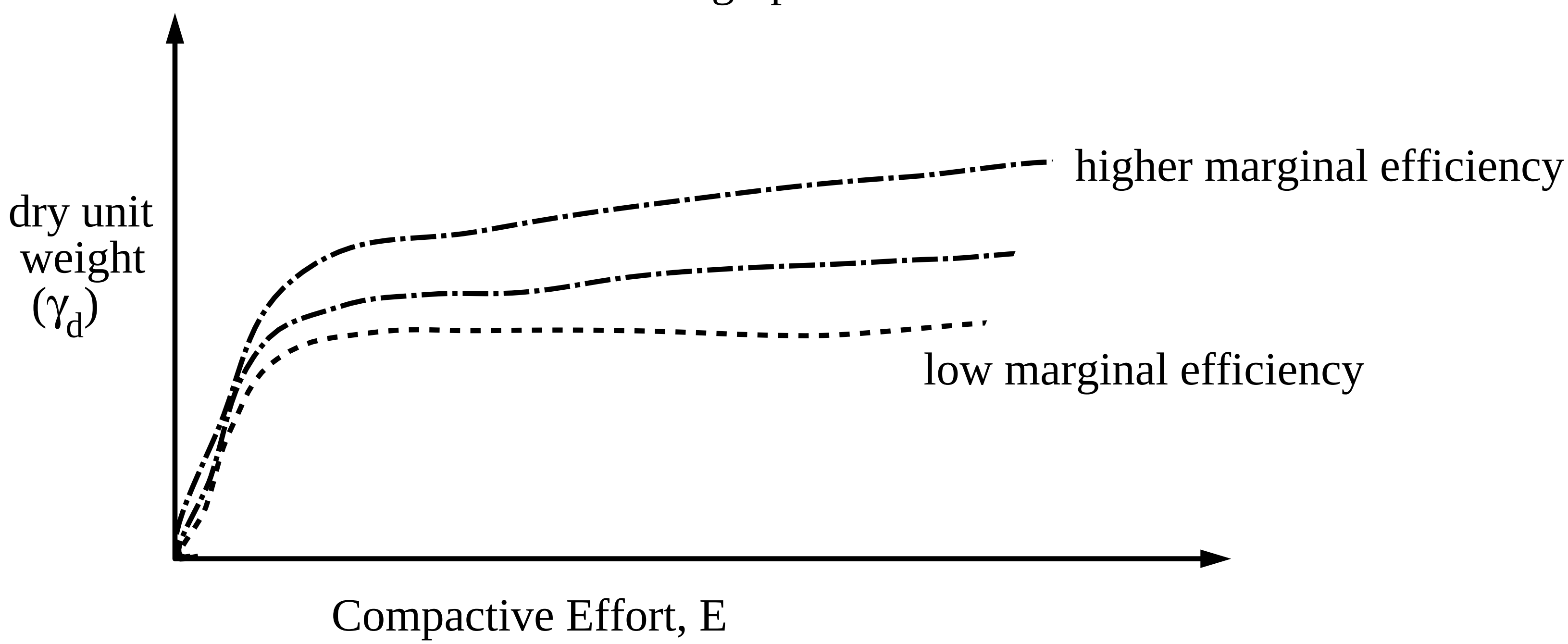
Example 25.2:

F. Efficiency of Compactive Effort:

- The degree of compaction achieved generally increases with increasing compactive effort.

- However, beyond a certain point, increased compactive effort produces only very small increases in dry density. That is, it takes a great deal of additional compactive effort (E) to see significant increases in dry unit weights γ_d.

- This is illustrated in the schematic graphs below.



G. Common Moisture−Density Curves Encountered in Practice