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SOIL MECHANICS

CHAPTER THREE

2020-2021

Third

Stage Students

Undergraduate students (3th stage students)
Faculty of Engineering
Mustansiriyah University
Water Resources Engineering Department

CHAPTER THREE

SOIL COMPACTION

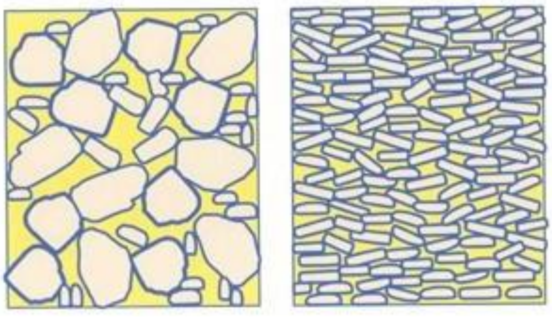
1. Introduction

Soil compaction is one of the most critical components in the construction of roads, airfield, embankments and foundations. The durability and stability of a structure are related to the achievement of proper soil compaction. Structural failure of roads, airfield and the damage caused by foundation settlement can often be traced back to the failure to achieve proper soil compaction.

2. What is Soil Compaction?

Soil compaction is the compression of soil particles. Compaction reduces total pore space of a soil. More importantly it significantly reduces the amount of large pore space, restricting air and water movement into and through the soil. Low soil oxygen levels caused by soil compaction are the primary factor limiting plant growth in landscape soils. Soil conditions, primarily soil compaction, contribute to a large portion of plant disorders in the landscape setting. Figure 1 illustrates comparison of large pore spaces in a non-compacted versus a compacted soil.

Figure 1. Comparison of large pore space in non-compacted soil (left) and compacted soil (right).



3. Soil Compaction

Compaction is the process of increasing the density of a soil by packing the particles closer together with a reduction in the volume of air only. However, compaction increases the dry density and decreases the void ratio. Soil compaction is defined as the method of mechanically increasing the density of soil. In construction, this is a significant part of the building process.

If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of building sites and construction projects utilize mechanical compaction

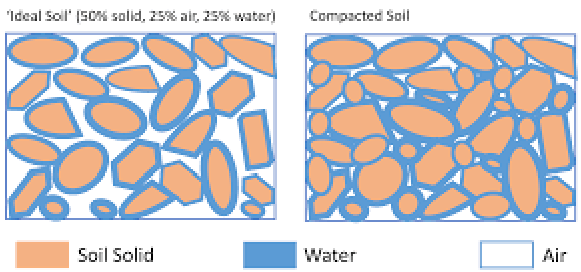
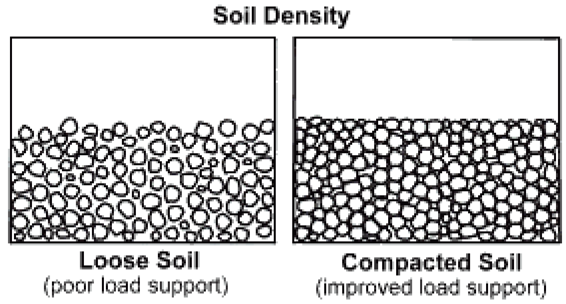
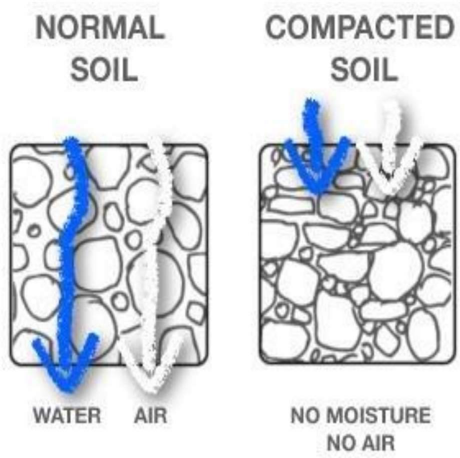
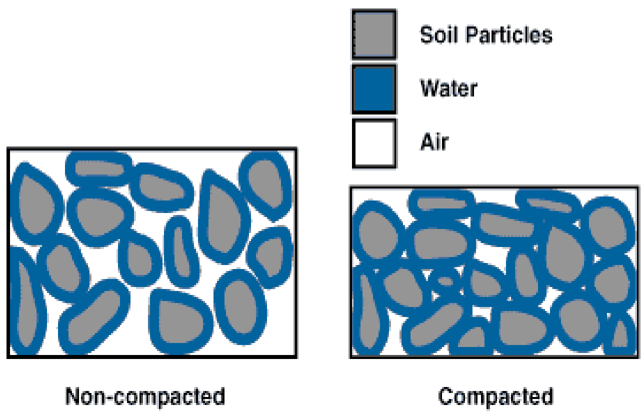


Figure 1. Soil compaction causes a reduction in available space for soil air and water, and limits pathways for crop roots.







4. Why compact?

There are five principle reasons to compact soil:

- Increases load-bearing capacity
- Increase shear strength of soil
- Prevents soil settlement and frost damage
- Provides stability
- Reduces water seepage, swelling and contraction
- Reduces settling of soil
- Reduce void ratio thus reduce permeability
- Controlling the swell-shrinkage movement
- Reduce settlement under working load

5. Types of compaction

There are four types of compaction effort on soil or asphalt:

- Vibration
- Impact
- Kneading
- Pressure

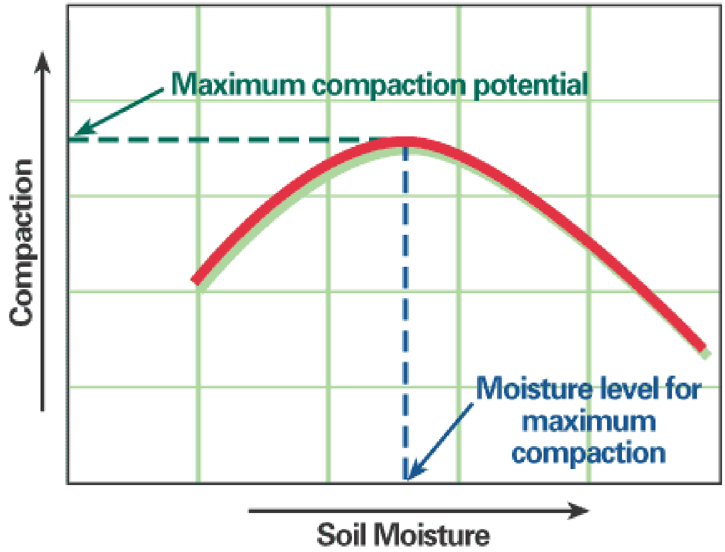
6. Factors affecting compaction:

- Water content
- Type of soil
- Compaction energy or effort
-

All these factors are shown in the following figures:

7.Soil density tests

To determine if proper soil compaction is achieved for any specific construction application, several methods were developed. The most prominent by far is soil density



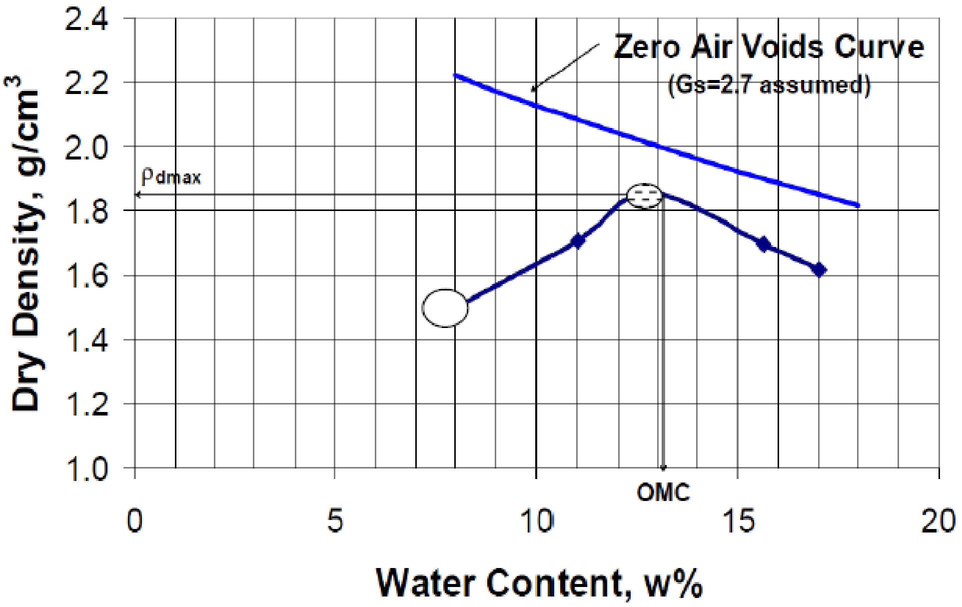
8. Theory of compaction

Compaction is the process of reducing the air content by the application of energy to the moist soil. From compaction test we can find:

1- There is a unique relationship between the water content and the dry density for specific compaction energy.

2- There is one water content (O.M.C.) (Optimum moisture content) at which the max dry density is achieved

The two above points can be clearly shown through the following Figure



MOISTURE-DENSITY RELATION (*COMPACTION TEST*)

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test.

Two types of compaction tests are routinely performed: (1) **The standard Proctor** and (2) **The modified Proctor test**.

Type of test	No. of layer	No. of blows per layer	Volume of mold (cm^3)	Weight of hammer (kg)	Height of drops cm
Standard Proctor	3	25	1000	2.5	30
Modified Proctor	5	25	1000	4.5	45

$$\text{Compaction Effort} = \frac{wt\ of\ hammer * drops\ height * No.of\ blows * No.of\ layer}{Volume\ of\ mold}$$

Test Procedure :

1- a sufficient quantity of air-dried soil in large mixing pan (say 3 kg)

2- Determine the weight of the compaction mold with its base (without the collar).

3- Start with initial water such (3% of Soil weight)

4- Add the water to the soil and mix it thoroughly into the soil until the soil gets uniform color (see figure B and C).

5- Assemble the compaction mold to the base, place soil in the mold and compact the soil in the number of equal layers specified by the type of compaction method (see photo D and E).

The number of drops per layer is dependent upon the type of compaction.

The drops should be applied at a uniform rate not exceeding around 1.5 seconds per drops, and the rammer should provide uniform coverage of the specimen surface.

6- The soil should completely fill the cylinder and the last compacted layer must extend slightly above the collar joint. If the soil below the collar joint at the completion of the drops, the test point must be repeated.

7- Carefully remove the collar and trim off the compacted soil so that it is completely even with the top of the mold.(see photo F).

8- Weigh the compacted soil while it's in the mold and to the base, and record the mass (see Photo G). Determine the wet mass of the soil by subtracting the weight of the mold and base.

9- Remove the soil from the mold using a mechanical extruder (see Photo H) and take the soil moisture content samples from the top and bottom of the specimen (see Photo i). Determine the water content.

10- Place the soil specimen in the large tray and break up the soil until it appears visually as if it will pass through the #4 sieve, add 3% more water on the soil and remix as in step 4. Repeat step 5 through 9 until a peak value is reached followed by two slightly lesser compacted

Analysis:

1- Calculate the moisture content of each compacted soil specimen.

2- Compute the wet density in grams per cm3 of the compacted soil by dividing the wet mass by the volume of the mold used.

3- Compute the dry density using the weight density and the water content determined in step 1. Use the following formula:

$$\rho_{dry} = \frac{\rho_{wet}}{1 + \omega_c}$$

4- Plot the dry density values on the y-axis and the moisture contents on the x-axis.

Draw a smooth curve connecting the plotted points.

5- On the same graph draw a curve of Saturation line (Zero air void line) using thefollowing Equation :

$$\rho_{dry} = \frac{G_s}{1+e} \rho_w$$

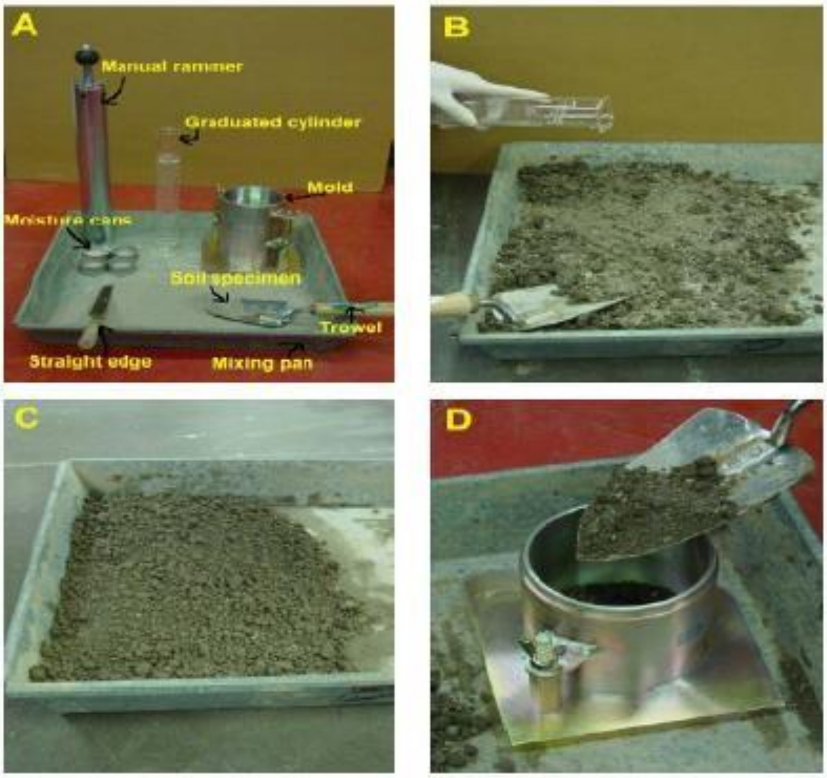
$$S.e = G_s.\omega_c \Longrightarrow \quad \text{For} \quad S=1 \quad \therefore \quad e = G_s\,\omega_c$$

Assume values of water content and find dry density, then plot the zero air void line which must be parallel to the moist side of compaction curve and never intersect it , If so that mean there is some error.

To plot Air content line (A%) use the following equation:

$$\rho_{dry} = \frac{G_s(1-A)}{1+\omega_C G_s}\rho_w$$

The following Figures give the steps used in the test:



Compaction Equipments:

1- Sheep's foot roller (for cohesive soil)

2- Pneumatic roller (many different soils)

3- Vibratory rollers (mainly for granular material)

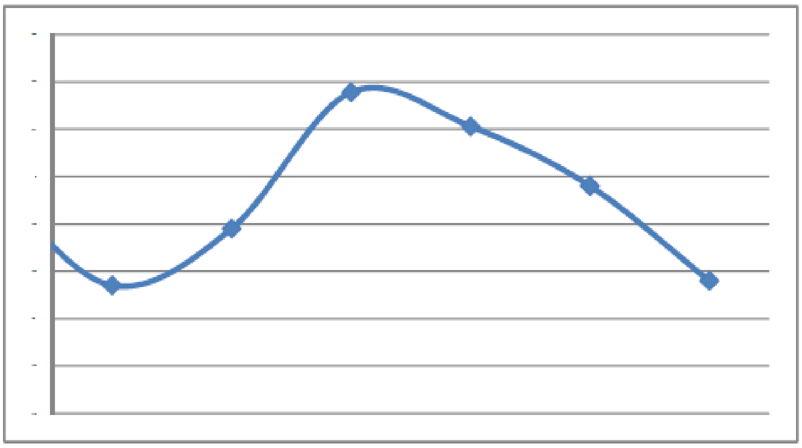
4- Grid rollers

5- Power Rammer

6- Vibratory plates.

Compaction Of cohesion less soil:

Moisture content has little or no influence on the granular soils (except when the soil is fully saturated) .



Their state of compaction can be obtained by relating dry density to the minimum and maximum dry densities and as in the following equation:

$$RD = \frac{e_{max} - e_{natural}}{e_{max} - e_{min}} = \left(\frac{\gamma_{dmax}}{\gamma_d}\right)\frac{\gamma_d - \gamma_{min}}{\gamma_{max} - \gamma_{min}}$$

Where RD : Relative density

Compaction in the field:

The results of laboratory tests are not directly applicable to the field compaction, because

1- The Laboratory tests are carried out on material smaller than 20 mm size.

2- Compactive efforts are different and apply in different method.

<u>Relative compaction</u>:

Relative compaction or degree of compaction is a means of comparing the field density with Laboratory results and is defined as the ratio of the dry density in the field to the maximum dry density in the Laboratory and in most construction works, the degree of compaction is specified as 95 % or more.

$$\textit{Relative Compaction } R.C = \frac{\gamma_{dry}\, field}{\gamma_{max}\, at\ lab.} \geq 95\% \text{ or as specify in the works}$$

So by using sand replacement method, find dry density at field then check the R.C

The Optimum moisture content can be useful in field as follows :

If $\omega_{c\,field} < \omega_{opt}$ then add water and compact the soil

If $\omega_{c\,field} = \omega_{opt}$ then compact the soil directly

If $\omega_{c\,field} > \omega_{opt}$ then either postponed the compaction to other time or add some additive (such as cement or lime) to accelerate evaporation of extra water.

Measurement of field Density

1- Core cutter
2- Sand Replacement method
3- Air-Ball on method
4- Penetrating Needle
5- Radiation Technique.

Example 1 :

The following results were obtained from a standard compaction test. Determine the Optimum moisture content and maximum dry density. Plot the curves of 0%, 5% and 10% air content and gives the value of air content at the maximum dry density. Given the volume of standard mold is 1000 cm^3 and $G_s = 2.7$.

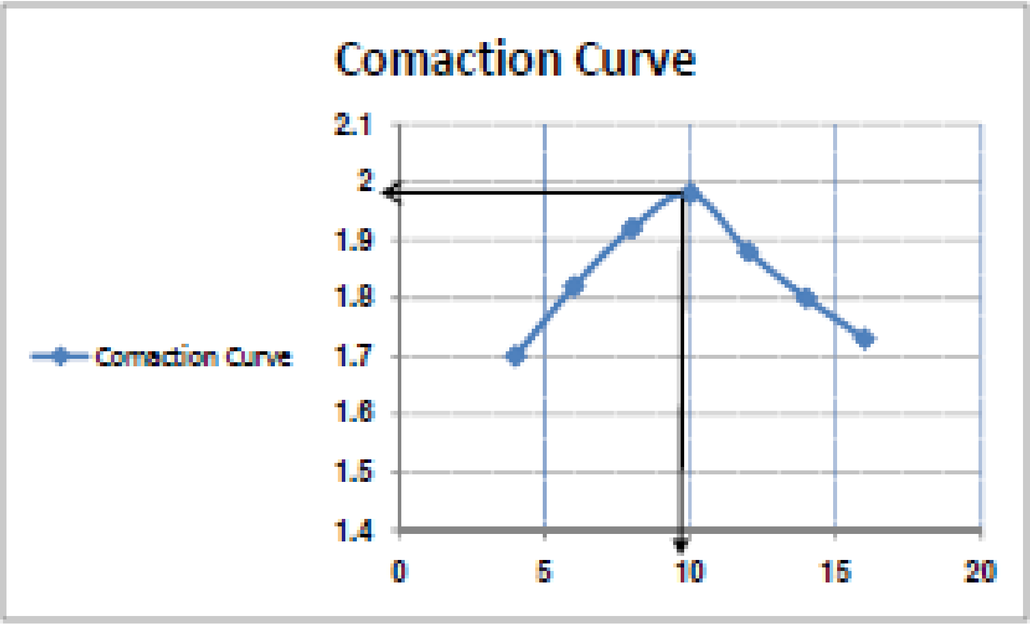
Mass (gm)	1768	1929	2074	2178	2106	2052	2007
Water content (%)	4	6	8	10	12	14	16

Solution :

Calculate dry density for each test and tabulate the results.

$\omega(\%)$	4	6	8	10	12	14	16
ρ_{wet}	1.768	1.929	2.074	2.178	2.106	2.052	2.007
$\rho_{dry}\ gm/cm^3$	1.7	1.82	1.92	1.98	1.88	1.8	1.73

$\omega(\%)$	A %	4	6	8	10	12	14	16
$\rho_{dry}\ gm/cm^3$	0	2.44	2.32	2.22	2.13	2.04	1.96	1.88
$\rho_{dry}\ gm/cm^3$	5	2.32	2.2	2.11	2.02	1.94	1.86	1.79
$\rho_{dry}\ gm/cm^3$	10	2.20	2.09	2.00	1.92	1.84	1.76	1.69



From Figure: The $\gamma_{dry\,max} = 1.98\ kN/m^3$,

and the Optimum Moisture content = 10%.

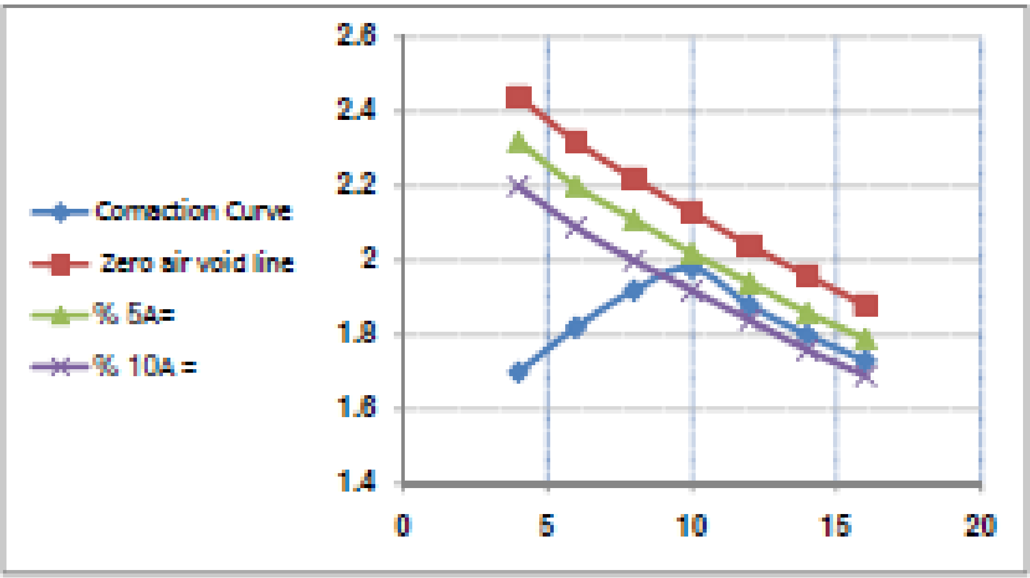


Figure show the Zero air void line and a line of 5 and 10% air content