UPPSC-AE 2020

Uttar Pradesh Public Service Commission

Combined State Engineering Services Examination

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Civil Engineering

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Contents

CHAPTER 5

Soil Compaction

5.1 Introduction

Construction of many structures requires "stabilisation" of the soil mass i.e. an artificial improvement of its engineering properties. There are various methods of soil stabilisation, the most common being the mechanical stabilisation and the simplest technique of mechanical stabilisation is compaction.

Compaction is a process by which the soil particles are artificially rearranged and packed together into a closer state of contact by mechanical means in order to reduce the volume of air voids of the soil and thus increase its dry density.

A soil mass can be compacted by either a dynamic process or a static one. In the dynamic method the soil mass is compacted by repeated applications of a dead load, while in static method, compaction is done by a steady increase of static load.

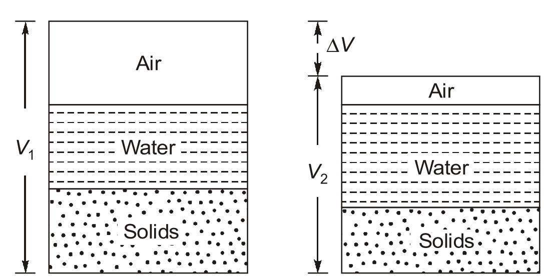
Do you know? The dynamic method gives better result in coarse grained soils and static method is suitable for less permeable fine grained soils.

5.2 Principles of Compaction

Usually when soil is excavated from one place, transported and dumped in another place it is loosened up to a great extent. In an uncompacted fill, the void ratio is relatively high and the corresponding density is low. Consequently, the shearing strength of uncompacted soil is low while its permeability is high. A structure on such a fill may crack extensively due to non uniformity of settlement. Therefore, it is necessary to artificially compact the fill.

Soil compaction is the process where soil particles are forced to pack more closely by reducing air voids. This can be achieved by applying some mechanical energy (static or dynamic) on soil fill.

The degree of compaction of a soil is measured in terms of dry unit weight i.e. the amount of soil solids that can be packed in a unit volume of the soil.



(a) Before compaction (b) After compaction

Remember: Compaction is somewhat different from consolidation. In consolidation volume reduction takes place due to expulsion of pore water from saturated voids.

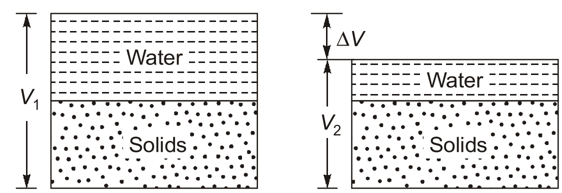
5.3 Difference between Compaction and Consolidation

5.3.1 Compaction

- Almost an instantaneous phenomenon.
- Soil is always unsaturated.
- Densification is due to a reduction in the volume of air voids at a given water content.
- Specified compaction techniques are used in this process.

5.3.2 Consolidation

- It is a time dependent phenomenon.
- Soil is completely saturated.
- Volume reduction is due to expulsion of pore water from voids.
- Consolidation occurs on account of a load placed on the soil.



(a) Before consolidation (b) After consolidation

5.4 Advantages of Compaction

Proper compaction of a soil mass lead to

- Increase in shear strength of soil.
- Improved stability and bearing capacity of soil.
- Reduction in compressibility and permeability of soil.
- Increase in the load carrying capacity of soil subgrade.
- Prevention of determental-settlements and undesirable volume changes through swelling and shrinkage.

5.5 Settlement During Compaction

Let e_0 be the initial void ratio before compaction has been started. After compaction, the void ratio of soil be e_f.
We know,

Void ratio, $$e = \frac{V_v}{V_s} = \frac{H_v}{H_s} \quad (\because V \propto H)$$

$\therefore$ $$e_0 = \frac{H_{V_1}}{H_s}$$

$\Rightarrow$ $$H_{V_1} = e_0 H_s$$

Similarly, $$H_{V_2} = e_f H_s$$

$\therefore$ change in the thickness of soil layer

$$\Delta H = H_{V_1} - H_{V_2} = (e_0 - e_f)H_s$$

$\therefore$ $$\frac{\Delta H}{H} = \frac{(e_0 - e_f)H_s}{H_s + e_0 H_s} = \frac{e_0 - e_f}{1 + e_0}$$

$$\Delta H = \left(\frac{e_0 - e_f}{1 + e_0}\right)H$$

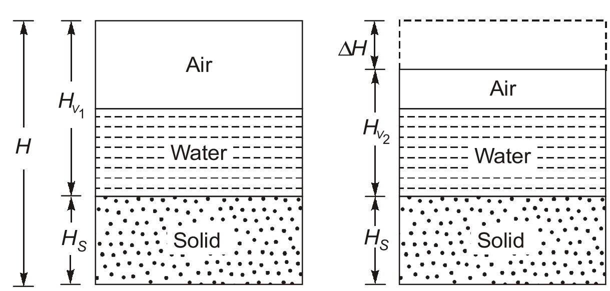


Fig. Settling compaction

5.6 Proctor Test

(A) Standard Proctor Test

- Standard volume mould (944 cc or 1/30 cubic feet).
- Filled up with soil in three layers.
- Each layer is compacted by 25 blows of standard hammer (weight 2.495 kg or 5.5 lbs) falling through 304.8 mm (12 inch).
- Dry weight is calculated by knowing the wet weight of compacted soil and its water content.

Dry unit weight,

$$\gamma_d = \frac{\gamma}{1+w}$$

where, γ = bulk unit weight

$$= \frac{\text{weight of compacted soil}}{\text{volume of the mould}}$$

w = water content

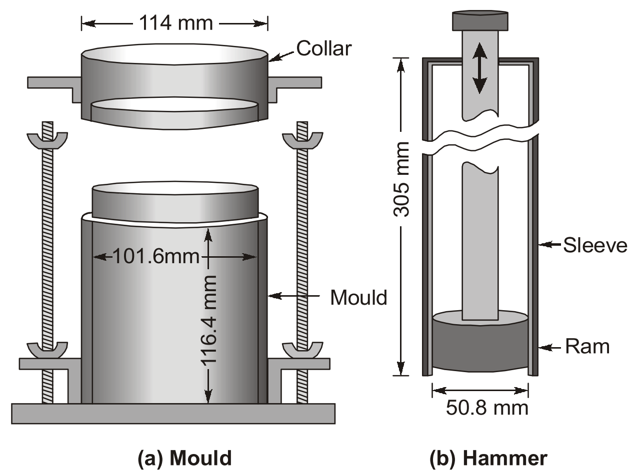


Fig. Standard Proctor

- Test is repeated at different water contents.
- Compaction curve is plotted between moisture content and dry unit weight.
- The peak of compaction curve corresponding to the maximum dry unit weight is referred as $\gamma_{d(max)}$.
- The moisture content corresponding to $\gamma_{d(max)}$ is known as optimum moisture content (OMC) at a given compactive effort.

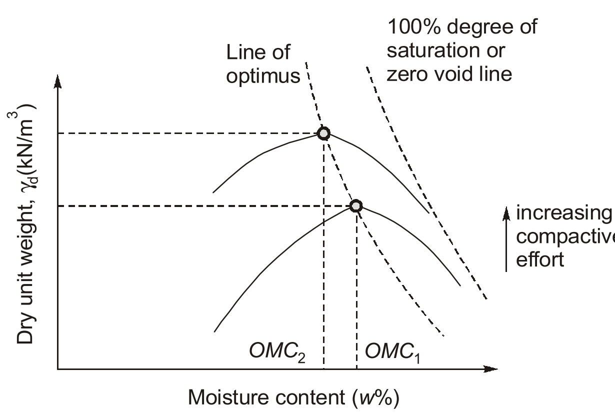


Fig. Compaction Curve

NOTE

- Typical values of maximum dry unit weights range from 16 to 20 kN/m^3 with the widest range being 13 to 24 kN/m^3.
- Typical optimum moisture content values ranges from 10 to 20% with a maximum range of 5 to 30%.
- Maximum dry unit weight so obtained is only for a given amount of compaction effort and method of compaction. It is also not necessary that the maximum dry unit weight can be obtained in the field.

  The specifications for compaction of fills in the field are usually based on maximum dry unit weight but sometimes on both the maximum dry unit weight and the OMC.

(B) Modified Proctor Test

- Developed during World War II, to simulate the compaction required for air fields to support heavier aircrafts.
- Standard volume mould (944 cc or 1/30 cubic feet).
- Filled up with soil in five layers.
- This test employs heavier hammer (4.54 kg or 10 lbs).
- Height of fall is 457.2 mm (18 inches) and each layer is tamped 25 times into a standard proctor mould.

5.7 Indian Standard Test

(A) Indian Standard Equivalent of Standard Proctor Test (Light Compaction Test)

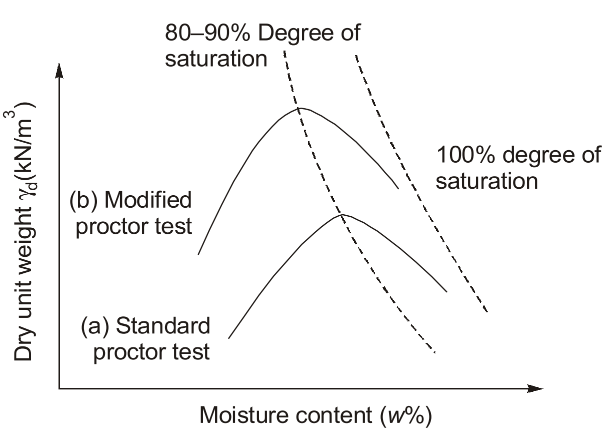
- Volume of mould is 1000 cc.
- Weight of hammer is 2.6 kg and drop is 310 mm.
- Mould is filled in three layers and each layer tamped by 25 blows.

(B) Indian Standard Equivalent of Modified Proctor Test (Heavy Compaction Test)

- Volume of mould is 1000 cc.
- Weight of hammer is 4.9 kg and height of drop is 450 mm.
- Soil is compacted in 5 layers and each layer tamped by 25 blows.

Do you know? Under heavier compaction the moisture–density curve is shifted upward and simultaneously towards the left, resulting in a lower OMC but a greater $\gamma_{d(max)}$.

5.8 Comparison of Standard and Modified Proctor Test



Remember

- Compactive energy applied in proctor test per unit volume is given by

$$E = \frac{nNWh}{V}$$

where, n = Number of layer
N = Number of blows per layer
W = Weight of hammer
h = Height of free fall of hammer
V = Volume of mould

- Compactive energy per unit volume in Standard Proctor Test

$$E = \frac{3\times 25\times 2.495\times 0.3048\times 9.81}{944\times 10^{-6}} = 592.71 \text{ kJ/m}^3$$

- Compactive energy per unit volume in Modified Proctor Test

$$E = \frac{5\times 25\times 4.54\times 0.4572\times 9.81}{944\times 10^{-6}} = 2696.30 \text{ kJ/m}^3$$

- Compactive energy per unit volume in Light Compaction Test

$$E = \frac{3\times 25\times 2.6\times 0.310\times 9.81}{1000\times 10^{-6}} = 593.01 \text{ kJ/m}^3$$

- Compactive energy per unit volume in Heavy Compaction Test

$$E = \frac{5\times 25\times 4.9\times 0.45\times 9.81}{1000\times 10^{-6}} = 2703.88 \text{ kJ/m}^3$$

5.9 Zero Air Void Line

At constant moisture content, the dry unit weight reaches its theoretical maximum when all the air is expelled from the void spaces, i.e. when degree of saturation is 100%. Therefore the zero air void line is a line joining points having dry unit weights corresponding to 100% saturation at different moisture contents. Therefore, it is also called the saturation line.

Zero air void lines can be defined as “The lines showing the dry density as a function of water content for soil containing no air voids.”

We can derive its equation as follows:

$$\gamma_d = \frac{G_s\gamma_w}{1+e} \quad \text{...(i)}$$

For any degree of saturation, $e = \dfrac{wG_s}{S}$

Therefore we can write the expression for dry unit weight corresponding to any degree of saturation s as

$$\gamma_{d,s} = \frac{G_s\gamma_w}{1+\dfrac{wG_s}{S}} = \frac{\gamma_w}{\left(\dfrac{1}{G_s}\right)+\left(\dfrac{w}{S}\right)} \quad \text{...(ii)}$$

where, $\gamma_{d,s}$ = dry unit weight at degree of saturation; γ_w = unit weight of water, e = void ratio
w = water content, G_s = sp. gravity of solids

For zero air voids, degree of saturation becomes 100%. Therefore equation (ii) becomes

$$\gamma_{d_0} = \frac{\gamma_w}{\left(\frac{1}{G_s}\right) + w} \qquad \text{...(iii)}$$

where, γ_{d_0} = dry unit weight at zero air void

Remember: Zero air voids line or saturation line is always a steadily decreasing line.

5.10 Constant Percentage Air Void Lines

These are lines which shows the water content, dry density relation for the compacted soil containing a constant percentage air void is known as an air voids line.

By the definition of percentage air voids, we have

$$\frac{n_a}{100} = \frac{V_a}{V_v} = \frac{V_v - V_w}{V_v} = 1 - S$$

or

$$S = 1 - \frac{n_a}{100} \qquad \text{...(iv)}$$

Substituting value of S into equation (ii), we have

$$\gamma_{d,a} = \frac{G_s\gamma_w\left(1 - \frac{n_a}{100}\right)}{\left(1 - \frac{n_a}{100}\right) + wG_s}$$

where, $\gamma_{d,a}$ = dry unit weight at constant percentage air voids

Example - 5.1 The maximum dry density of a sample by the standard compaction test is 1.76 g/cc at an optimum moisture content of 14.5%. Find the air voids and the degree of saturation (G = 2.68).

What would be the corresponding value of dry density on the zero air void line at optimum moisture content?

Solution:

(i) We know,

$$\rho_d = \frac{\left(1 - \frac{n_a}{100}\right)G\rho_w}{1 + wG}$$

$$1.76 = \frac{\left(1 - \frac{n_a}{100}\right) \times 2.68 \times 1}{1 + 0.145 \times 2.68}$$

$\therefore$ n_a = 0.088 or 8.80%

(ii)

$\because$ $$\rho_d = \frac{G\rho_w}{1 + e} = \frac{G\rho_w}{1 + \frac{wG}{S}}$$

$$1.76 = \frac{2.68 \times 1}{1 + \left(\frac{0.145 \times 2.68}{S}\right)}$$

$$1.76 + \frac{0.683}{S} = 2.68$$

$$S = 0.7423 \text{ or } 74.23\%$$

(iii) At zero air void line, $S = 100\%$

$$\therefore \quad \rho_{d(\text{theo, max})} = \frac{G\rho_w}{1+\frac{wG}{S}} = \frac{G\rho_w}{1+wG} = \frac{2.68\times 1}{1+0.145\times 2.68} = 1.93 \text{ g/cc}$$

5.11 Factors Affecting Compaction

The major factors which affect compaction are:

(i) Water Content: At lower water contents, the soil particles offer more resistance to compaction and soil behaves like a stiff material. Increasing the moisture content helps the particles to move closer because of the lubrication effect. On further increasing the moisture content beyond a certain limit, the water starts to replace the soil particles. Thus the dry unit weight continuous to increase till the Optimum Moisture Content (OMC) is reached and with further increase in moisture content beyond OMC, unit weight starts decreasing.

DO YOU KNOW?

Using,

$$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{G\gamma_w}{1+\frac{wG}{S}}$$

we conclude $\gamma_d \propto S$ i.e. degree of saturation.

Therefore for a given water content, the theoretical maximum value of dry unit weight for a compacted soil is obtained corresponding to the situation when no air voids are left i.e. when degree of saturation becomes 100%.

(ii) Compactive Effort: For a given type of compaction, an increase in the amount of compaction will initially result in closer packing of the soil particles and maximum dry unit weight increase while the optimum moisture content at which it is attained decreases.

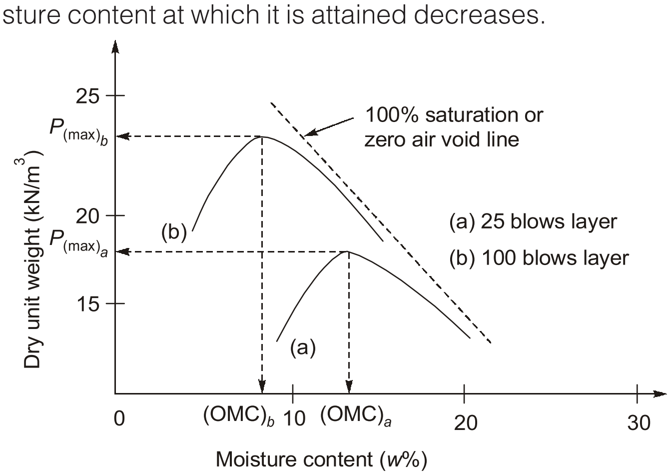


Fig. Effect of compactive effort

(iii) Type of Soil

- Coarse grained soils, well graded can be compacted to high dry unit weight, especially if they contains some fines.
- However, if quantity of fines is excessive the maximum dry unit weight decreases.
- Poorly graded or uniform sands lead to lowest dry unit weight value.
- In clayey soils, maximum dry unit weight tends to decrease as plasticity increases.
- Cohesive soils have generally high value of OMC.
- Heavy clays with high plasticity have very low value of maximum dry unit weight and very high value of OMC.

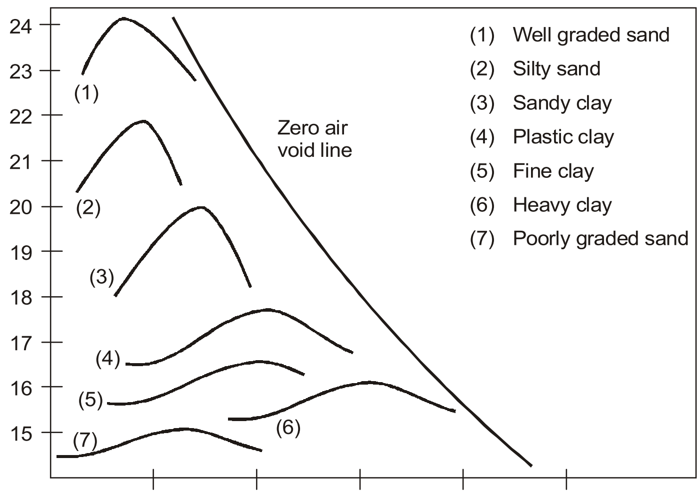


Fig. Typical proctor compaction curve for different soils

(iv) Method of Compaction: Since the field compaction is essentially a kneading or rolling type compaction whereas the laboratory tests are dynamic-impact type compaction, therefore, laboratory compaction tests have more value of maximum dry unit weight.

5.12 Compaction Behaviour of Sand

The moisture-dry density relationship, as obtained from a laboratory test on a cohesionless sand is shown in figure below:

- Initially there is decrease in dry unit weight with the increase in water content. This is due to bulking of sand i.e. capillary tension in pore water prevents soil particles coming closer. *The maximum bulking occurs at 4 - 5% water content.*
- The maximum dry unit weight occurs when soil is either completely saturated or dry.
- When water content is increased further, there is fall in dry unit weight again.

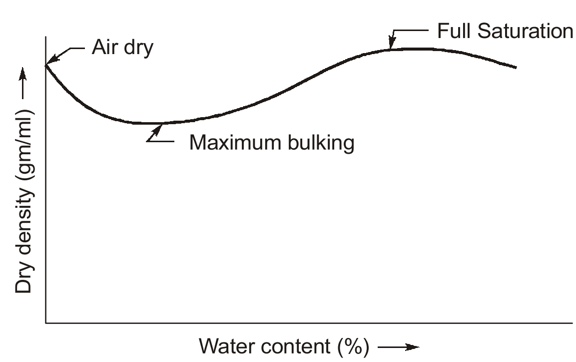


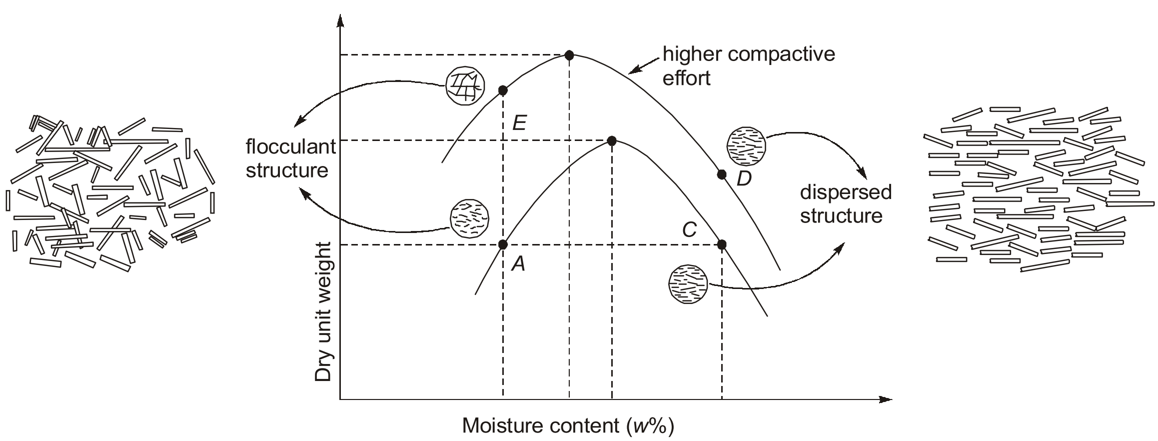
Fig. Compaction Behaviour of Sand

Remember: Coarse grained soils do not absorb water, but fine grained soils do and hence the Lambe's double layer theory is not applicable to them.

5.13 Effect of Compaction on Properties of Soils

5.13.1 Soil Structure

- The water content at which the soils is compacted plays an important role in the engineering properties of the soils.
- At low water content, attractive forces between the particles are stronger than repulsive forces. Hence, soils compacted at a water content less than the optimum water content generally have a flocculated structure.
- Increasing the water content, increases the repulsive forces. Hence, soils compacted at water content more than the optimum water content usually have a dispersed structure.
- If the compactive effort is increased there is a corresponding increase in the orientation of the particles and higher dry densities are obtained, as shown by the upper curve.



5.13.2 Permeability

- The permeability of a soil depends upon the size of voids. Due to increase in water content for a given compactive effort there is an improved orientation of the particles and a corresponding reduction in the size of voids which cause a decrease in permeability.
- For a given compactive effort, the permeability decreases sharply with increase in water content on the dry side of optimum. The minimum permeability occurs at or slightly above the OMC. Beyond OMC, the permeability may show a slight increase, but always remain much smaller than on the dry side of optimum.
- If the compactive effort is increased, the permeability of the soil decrease due to increased dry density and better orientation of particle.

5.13.3 Compressibility

- At relatively low stress levels, a soil compacted wet side (dispersed soil) of optimum is more compressible than the soil compacted dry side (flocculated soil) of optimum. Therefore, for construction of embankment, the soil is compacted on the dry side of optimum.
- At high stress levels, the compressibility increase due to breakdown of the structure, now the flocculated structures with larger void volume, can undergo a large volume decrease.

5.13.4 Swelling

A soil on the dry side of optimum has a higher water deficiency and a more random particle arrangement. It can therefore, imbibe more water than a soil on the wet of optimum, therefore more swelling occur on dry side of optimum.

5.13.5 Shrinkage

- Soils compacted on the wet of optimum, have nearly parallel orientation of particles which allows the particles to pack more efficiently as compared to the randomly oriented particles on the dry side of optimum.
- Therefore, soils compacted on the wet of optimum tend to exhibit more shrinkage upon drying than those compacted on the dry of optimum.

5.13.6 Shear Strength

- The shear strength of the compacted soils depends upon the soil type, the moulded water content, drainage conditions, the method of compaction etc.
- In general, at a given water content, the shear strength of the soil increases with an increase in the compactive effort till a critical degree of saturation is reached. With further increase in the compactive effort, the shear strength decreases.

5.14 Field Compaction and Equipment

In the construction of highway embankments and earth dams, soil is first dumped in the form of loose fills, and then compacted to improve the density and the strength characteristics. In the field, soil is compacted by applying energy through mechanical equipment. The energy is transmitted to the soil by applying pressure in any one of the following three ways

(i) Static pressure (using rollers)

(ii) Impact (using rammers)

(iii) Vibration (using vibrator)

The choice of equipment will depend on the type of soil and economic consideration. The main compaction equipment along with suitability of soil and nature of project are summarized below:

S.No.	Type of Equipment	Suitability for Soil type	Nature of Project
1	Rammer or Tampers	All soils	In confined areas such as fills behind retaining walls, basement walls, trench fills etc.
2	Smooth wheeled rollers	Crushed rocks, gravels, sands	Road construction
3	Pneumatic tyred rollers	Sand, gravels, silts, clayey soils	Base, sub-base and embankment compaction for highways, air field and earth dams
4	Sheep foot rollers	Clayey soils	Core of earth dams
5	Vibratory rollers	Sands	Embankments for oil storage tanks etc.

5.15 Evaluation of Compaction

The method adopted to assess the degree of compaction obtained in the field is the relative compaction. It is the ratio of the dry unit weight attained in the field to specified standard unit weight expressed as a percentage. The specified standard unit weight may be proctor unit weight, Indian standard light or heavy unit weight.

$$\text{Relative compaction} = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\text{max})}} \times 100$$

Example - 5.2 The unit weight of a compacted sand backfill was determined by field measurement to be 1738 kg/m³. The water content and void ratio of the laboratory compacted soil was 10.2% and 60.7% respectively. What was the degree of compaction achieved in field? Assume water content remain constant (G = 2.7).

Solution:

Given,
$$\gamma_{(\text{field})} = 1738 \text{ kg/m}^3$$
$$w = 10.2\%$$

For field,
$$\gamma_d = \frac{\gamma_{(\text{field})}}{1+w} = \frac{1738}{1+0.102} = 1577.13 \text{ kg/m}^3$$

For laboratory sample,
$$w = 10.2\%$$
$$e = 0.607$$

We know,
$$\gamma_{(\text{lab})} = \left(\frac{G+Se}{1+e}\right)\gamma_w = \frac{G(1+w)}{1+e}\gamma_w$$
$$= \frac{2.7(1+0.102)}{1+0.607} \times 1000 = 1851.5 \text{ kg/m}^3$$

$$\therefore \quad \gamma_{d(\text{lab})} = \frac{\gamma_{(lab)}}{1+w} = \frac{1851.5}{1+0.102} = 1680.12 \text{ kg/m}^3$$

$$\therefore \quad \text{Degree of compaction} = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\text{lab})}} \times 100 = \frac{1577.13}{1680.12} \times 100 = 93.87\%$$

Example - 5.3 Soil has been compacted in an embankment at a bulk density of 2.15 g/cc and the water content of 12%. The specific gravity of soil solids is 2.7. The water table is well below the foundation level. Estimate

(i) void ratio
(ii) the dry density
(iii) degree of saturation
(iv) air content of the compacted soil

Solution:

Given, $\rho = 2.15$ g/cc, $w = 12\%$ or 0.12, $G = 2.7$

(i) Using,
$$\rho = \frac{G(1+w)}{1+e}\rho_w$$
$$2.15 = \frac{2.7(1+0.12)}{1+e} \times 1$$

$$1+e = \frac{2.7(1+0.12)}{2.15} = 1.406$$

$\therefore$ $$e = 0.406$$

(ii) $$\rho_d = \frac{\rho}{1+w} = \frac{2.15}{1+0.12} = 1.92 \text{ g/cc}$$

(iii) Using, $$Se = wG$$

$$S = \frac{wG}{e} = \frac{0.12 \times 2.7}{0.406} = 0.708 \text{ or } 79.80\%$$

(iv) $$\text{Air content} = \frac{V_a}{V_v} = \frac{V_v - V_w}{V_v} = 1 - S = 1 - 0.798 = 0.202 \text{ or } 20.2\%$$

Example - 5.4 In Indian standard light compaction test, the bulk unit weight of soil sample was found to be 18 kN/m^3 at a moisture content of 13%. Determine

(i) degree of saturation of sample
(ii) additional moisture content required for complete saturation
(iii) maximum theoretical dry unit weight
G = 2.68

Solution:

(i) Given:

$$\gamma_t = \frac{G(1+w)}{1+\frac{wG}{S}}\gamma_w$$

$$18 = \frac{2.68(1+0.13)\times 9.81}{1+\frac{(0.13\times 2.68)}{S}}$$

$$1+\frac{0.3484}{S} = 1.65$$

$$S = 0.5356 \text{ or } 53.56\%$$

(ii) Void ratio at 53.56% saturation

$$e = \frac{w \cdot G}{S} = \frac{0.13 \times 2.68}{0.5356} = 0.65$$

At a given compactive effort, void ratio remain constant. The water content at full saturation may be given as

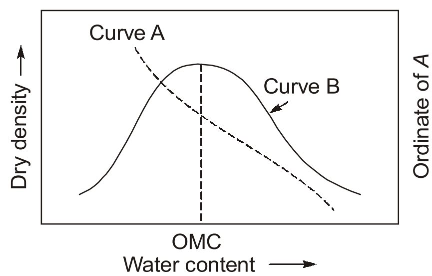
$$w = \frac{1 \times e}{G} = \frac{0.65}{2.68} = 0.242 \text{ or } 24.20\%$$

$\therefore$ Additional water content required for complete saturation

$$= 24.20 - 13 = 11.2\%$$

Student's Assignment

Q.1 Curve B shows the typical compaction curve of a soil in the Proctor test. Dotted curve A is shown superimposed on the same graph. Which one of the following expressions corresponds to the ordinate axis of curve A?



(a) Zero air voids
(b) Wet density
(c) Penetration resistance of Proctor needle
(d) 95% saturation

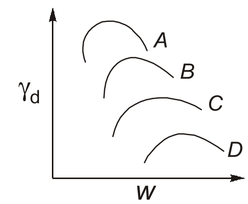
Q.2 At what value of saturation does the zero air voids curve in a compaction test represent the dry density?

(a) 0% (b) 80%
(c) 100% (d) 50%

Q.3 Which one of the following is the correct statements?
Vibratory rollers are suitable for compacting
(a) organic soil
(b) clays
(c) sands and gravels
(d) clayey silts

Q.4 Why are sheep foot rollers more effective in compacting clayey soils?
(a) There is differential expulsion of water under the roller
(b) Contact pressure is high
(c) Roller speed is high
(d) Drum width is large

Q.5 The results (curves A, B, C and D) of four compaction tests on different soils are shown in the graph:



1. Silty sand, modified test
2. Silty sand, standard test
3. Fat clay, modified test
4. Fat clay, standard test

Curves A, B, C and D correspond respectively to tests:
(a) 1, 3, 2 and 4 (b) 1, 2, 3 and 4
(c) 2, 1, 3 and 4 (d) 2, 1, 4 and 3

Q.6 Given below are methods of compaction:
1. Vibration technique
2. Flooding the soil
3. Sheep foot roller
4. Tandem roller
5. Heavy weights dropped from a height

The methods suitable for cohesionless soils include:
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 5 (d) 3, 4 and 5

Q.7 Match **List-I** (Type of soils) **List-II** (Compaction parameters) and select the correct answer using the codes given below the lists:

List-I		List-II
A. Sand	1.	OMC = 18%, $\gamma_{dry\ max}$ = 17 kN/m^3
B. Sandy clay	2.	OMC = 14%, $\gamma_{dry\ max}$ = 18.9 kN/m^3
C. Silty clay	3.	OMC = 15%, $\gamma_{dry\ max}$ = 17.4 kN/m^3
D. Heavy clay	4.	OMC = 10%, $\gamma_{dry\ max}$ = 20.5 kN/m^3

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	2	4	1	3
(c)	4	2	3	1
(d)	4	2	1	3

Q.8 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I
A. Optimum moisture content
B. Vibratory rollers
C. Zero air void line

List-II
1. Compaction of cohesive soil
2. Compaction of granular soil
3. Maximum dry density
4. Relative density
5. 100% saturation

Codes:

	A	B	C
(a)	4	1	3
(b)	3	2	5
(c)	4	1	5
(d)	3	2	4

Q.9 If specific gravity of soil solids of a soil having optimum moisture content 16.5% and maximum dry density 1.57 g/cc is 2.65, void ratio at optimum moisture content is
(a) 0.588 (b) 0.688
(c) 0.788 (d) 0.888

Q.10 The maximum dry density upto which any soil can be compacted depends upon
(a) amount of compaction energy alone
(b) moisture content alone
(c) both compaction energy and moisture content
(d) none of these

Q.11 At optimum moisture content of soil mass, the soil saturation will be around
(a) 100% (b) 90 – 95%
(c) 0% (d) none of these

Q.12 The insitu void ratio of a granular soil deposit is 0.50. The maximum and minimum void ratios of the soil were determined to be 0.75 and 0.35. G_s = 2.67 the relative density and relative compaction of the soil are respectively

(γ_w = 9.8 kN/m^3)
(a) 62.5%, 89.9% (b) 89.9%, 62.5%
(c) 62.5%, 96.6% (d) 89.9%, 96.6%

Q.13 The zero-air voids curve is non-linear owing to
(a) the standard proctor test data of dry density and corresponding water content plotting as a non-linear curve
(b) the dry density at 100% saturation being a non-linear function of the void-ratio
(c) the water content altering during compaction
(d) the soil being compacted with an odd number of blows

Q.14 Following statement are made on compacted soil, where DS stands for soil compaction on Dry Side of OMC and WS stands for soil compacted on Wet Side of OMC. Identify incorrect statement
(a) Soil structure is flocculated on DS and dispersed on WS.
(b) Construction of pore water pressure is low on DS and High on WS.
(c) Soil on drying, shrinkage is high on DS and Low on WS.
(d) On addition to water, swelling is high on DS and low on WS.

Q.15 OMC-SP and MDD-SP denote the optimum moisture content and maximum dry density obtained from standard Proctor compaction test, respectively. OMC-MP and MDD-MP denote the optimum moisture content and maximum dry density obtained from the modified Proctor compaction test, respectively. Which one of the following is correct?
(a) OMC-SP < OMC-MP and MDD-SP < MDD-MP
(b) OMC-SP > OMC-MP and MDD-SP < MDD-MP
(c) OMC-SP < OMC-MP and MDD - SP >MDD-MP
(d) OMC-SP > OMC-MP and MDD-SP > MDD-MP

ANSWER KEY — STUDENT'S ASSIGNMENT

1. (c)	**2.** (c)	**3.** (c)	**4.** (b)	**5.** (b)
6. (c)	**7.** (c)	**8.** (b)	**9.** (b)	**10.** (c)
11. (b)	**12.** (a)	**13.** (b)	**14.** (c)	**15.** (b)

HINTS & SOLUTIONS — STUDENT'S ASSIGNMENT

4. (b)

Under sheep foot rollers the contact pressure is very high and this results in kneading action which is responsible for effective compaction of clayey soils.

5. (b)

With the increase of fine particles in sand, the OMC decreases and maximum dry density increases upto certain extent. Thereafter any further increase in fine particles will lead to increase of OMC and decrease of maximum dry density. Further in modified test, the OMC will be less and maximum dry density will be more compared to that in standard test. Therefore combining both:

OMC $1 < 2 < 3 < 4$

Maximum dry density

$1 < 2 < 3 < 4$

So A-1, B-2, C-3, D-4

6. (c)

Cohesionless soils can be compacted by vibration; flooding and dropping heavy weight from height. Kneading and tamping actions provided by sheep foot roller and tandem roller are not effective for cohesionless soils.

7. (c)

Heavy (fat) clay means pure clay.

As the fine particle content is increased in a cohesionless soil, the dry density achieved is very high compared to that in cohesionless soil. However when fine particles increase beyond a limit, the dry density decrease and OMC increases.

Thus OMC of D > C > B > A

So D – 1, C – 3, B – 2, A – 4

Maximum dry density of A > B > C > D

So A – 4, B – 2, C – 3, D – 1

8. (b)

A – 3; B – 2; C – 5

9. (b)

Given, $\gamma_d = 1.57$; $w = 0.165$; $G = 2.65$

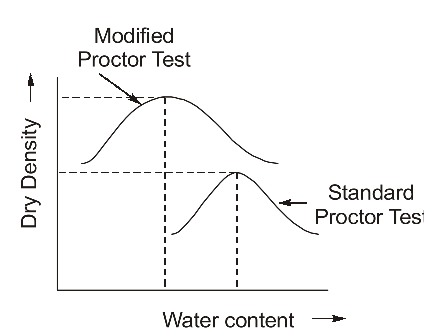
Using,
$$\gamma_d = \frac{G \cdot \gamma_w}{1+e}$$
$$1.57 = \frac{2.65 \times 1}{1+e}$$
$$1 + e = 1.688$$
$$\therefore \quad e = 0.688$$

12. (a)

Relative density
$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100\%$$
$$= \frac{0.75 - 0.50}{0.75 - 0.35} \times 100 = 62.5\%$$
$$\gamma_{d(max)} = \frac{G_s \gamma_w}{1+e_{min}}$$
$$= \frac{2.67 \times 9.8}{1+0.35} = 19.38 \text{ kN/m}^3$$
$$\gamma_{d(min)} = \frac{G_s \gamma_w}{1+e_{max}}$$
$$= \frac{2.67 \times 9.8}{1+0.75} = 14.95 \text{ kN/m}^3$$
$$\gamma_{d(insitu)} = \frac{G_s \gamma_w}{1+e_{insitu}}$$
$$= \frac{2.67 \times 9.8}{1+0.50} = 17.44 \text{ kN/m}^3$$

$\therefore$ Relative compaction,
$$\frac{\gamma_{d(insitu)}}{\gamma_{d(max)}} = \frac{17.44}{19.38} \times 100 = 89.9\%$$

15. (b)



OMC – SP > OMC – MP

MDD – SP < MDD – MP