MODULE 2

STRUCTURE

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1. Introduction

A soil particle may be a mineral or a rock fragment. A mineral is a chemical compound formed in nature during a geological process, whereas a rock fragment has a combination of one or more minerals. Based on the nature of atoms, minerals are classified as silicates, aluminates, oxides, carbonates and phosphates.

Out of these, silicate minerals are the most important as they influence the properties of clay soils. Different arrangements of atoms in the silicate minerals give rise to different silicate structures.

2. **Objectives**

- To identify the clay structures present in the soil
- To determine the different types of bonding present in the clay structures
- To study about compaction of a soil and maximum density determination

3. Basic Structural Units

Soil minerals are formed from two basic structural units: tetrahedral and octahedral. Considering the valencies of the atoms forming the units, it is clear that the units are not electrically neutral and as such do not exist as single units.

The basic units combine to form sheets in which the oxygen or hydroxyl ions are shared among adjacent units. Three types of sheets are thus formed, namely ***silica sheet, gibbsite sheet*** and ***brucite sheet.***

Isomorphous substitution is the replacement of the central atom of the tetrahedral or octahedral unit by another atom during the formation of the sheets.

The sheets then combine to form various two-layer or three-layer sheet minerals. As the basic units of clay minerals are sheet-like structures, the particle formed from stacking of the basic units is also plate-like. As a result, the surface area per unit mass becomes very large.

4 Formation of Clay Minerals:

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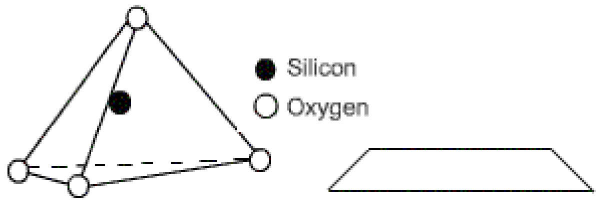
Out of these, silicate minerals are the most important as they influence the properties of clay soils. Different arrangements of atoms in the silicate minerals give rise to different silicate structures

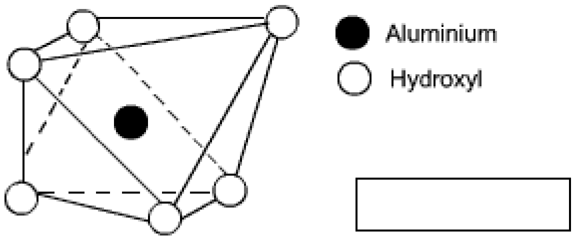
Structure of Clay Minerals:

A tetrahedral unit consists of a central silicon atom that is surrounded by four oxygen atoms located at the corners of a tetrahedron. A combination of tetrahedrons forms a silica sheet**.**



Silica Tetrahedron   Silica Sheet

An octahedral unit consists of a central ion, either aluminium or magnesium, that is surrounded by six hydroxyl ions located at the corners of an octahedron. A combination of aluminium-hydroxyl octahedrons forms a ***gibbsite sheet***, whereas a combination of magnesium-hydroxyl octahedrons forms a ***brucite sheet.***



Alumina Octahedron   Alumina Sheet

Two-layer Sheet Minerals:

Kaolinite and halloysite clay minerals are the most common.

Kaolinite Mineral The basic kaolinite unit is a two-layer unit that is formed by stacking a gibbsite sheet on a silica sheet. These basic units are then stacked one on top of the other to form a lattice of the mineral. The units are held together by hydrogen bonds. The strong bonding does not permit water to enter the lattice. Thus, kaolinite minerals are stable and do not expand under saturation.Kaolinite is the most abundant constituent of residual clay deposits.

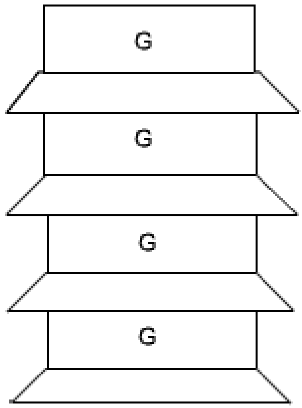


Fig: Kaolinite Mineral

Halloysite Mineral:

The basic unit is also a two-layer sheet similar to that of kaolinite except for the presence of water between the sheets.

Montmorillonite and illite clay minerals are the most common. A basic three-layer sheet unit is formed by keeping one silica sheet each on the top and at the bottom of a gibbsite sheet. These units are stacked to form a lattice as shown. **Montmorillonite Mineral:** The bonding between the three-layer units is by van der Waals forces. This bonding is very weak and water can enter easily. Thus, this mineral can imbibe a large quantity of water causing swelling. During dry weather, there will be shrinkage.

Illite Mineral: Illite consists of the basic montmorillonite units but are bonded by **secondary valence forces** and **potassium ions**, as shown. There is about 20% replacement of aluminium with silicon in the gibbsite sheet due to ***isomorphous substitution***. This mineral is very stable and does not swell or shrink.

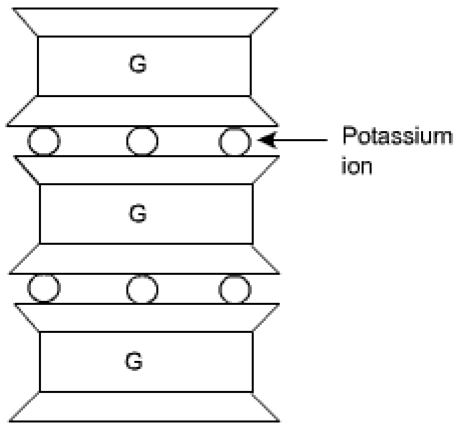


Fig: Illite Mineral

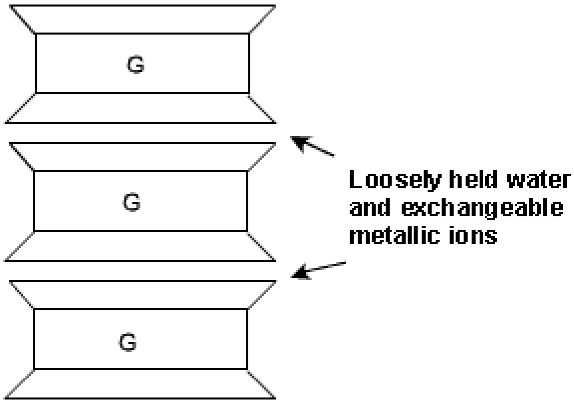
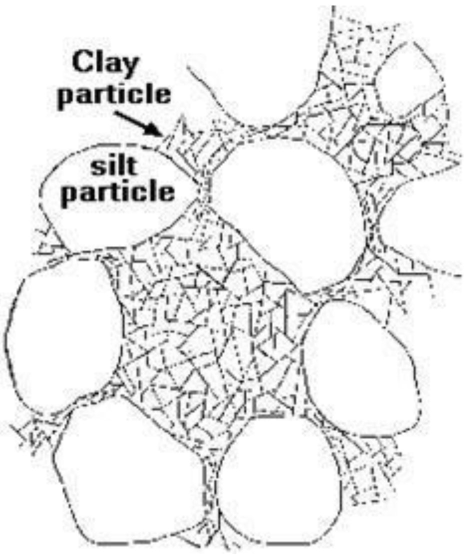


Fig:Montmorillonite Mineral

Fine Soil Fabric:

Natural soils are rarely the same from one point in the ground to another. The content and nature of grains varies, but more importantly, so does the arrangement of these. The arrangement and organisation of particles and other features within a soil mass is termed its **fabric.**

CLAY particles are **flaky**. Their thickness is very small relative to their length & breadth, in some cases as thin as 1/100th of the length. They therefore have high specific surface values. These surfaces carry negative electrical charge, which attracts positive ions present in the pore water. Thus a lot of water may be held as adsorbed water within a clay mass

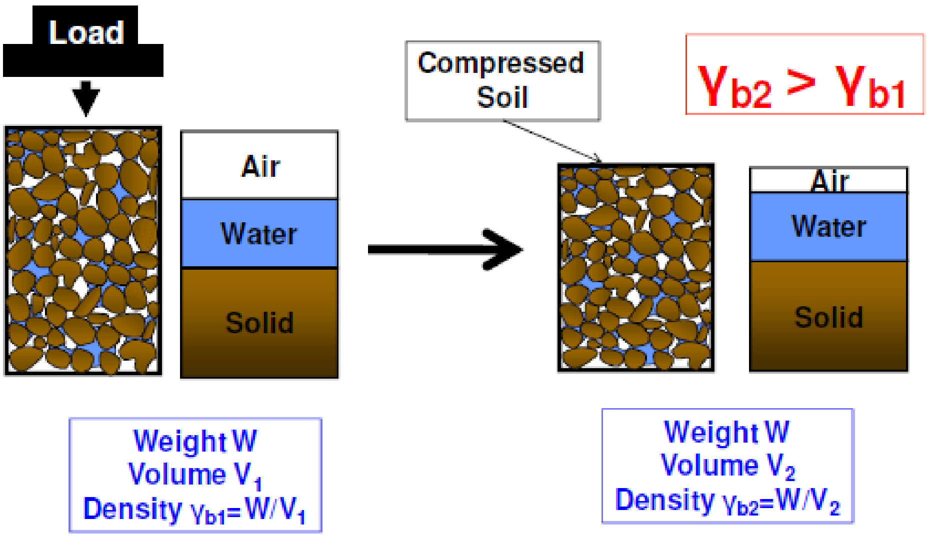


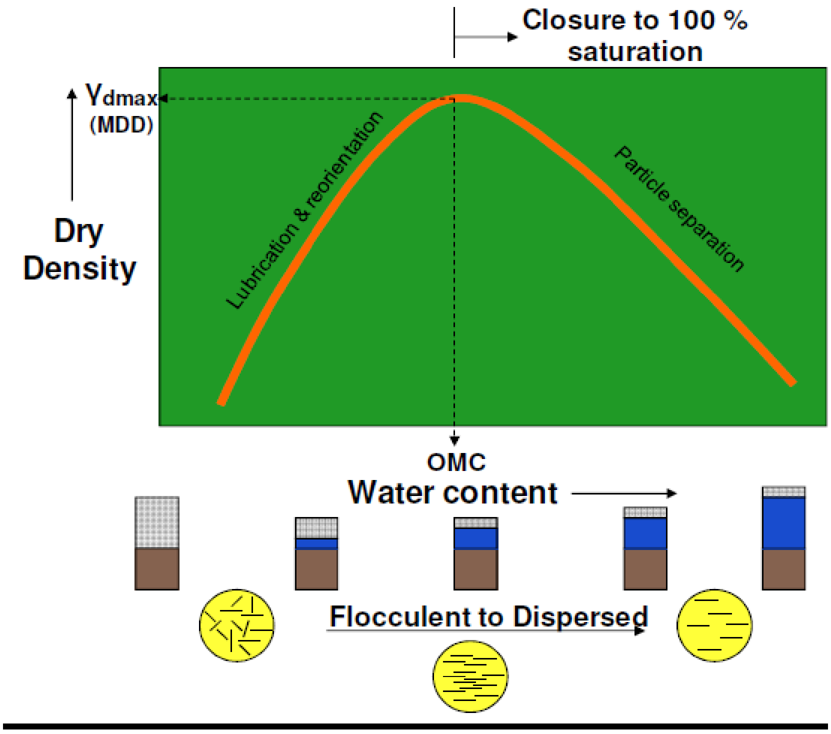
5. Compaction - Introduction

Compaction is the process of increasing the bulk density of a soil or aggregate by driving out air. For any soil, at a given compactive effort, the density obtained depends on the moisture content. An "Optimum Moisture Content" exists at which it will achieve a maximum density. Compaction is the method of mechanically increasing the density of soil. The densification of soil is achieved by reducing air void space. During compaction, air content reduces, but not water content It is not possible to compact saturated soil. It should be noted that higher the density of soil mass, stronger, stiffer, more durable will be the soil mass.

Hence, Compaction

1) Increases density
2) Increases strength characteristics
3) Increases load-bearing capacity
4) Decreases undesirable settlement
5) Increases stability of slopes and embankments
6) Decreases permeability
7) Reduces water seepage
8) Reduces Swelling & Shrinkage
9) Reduces frost damage
10) Reduces erosion damage
11) Develops high negative pore pressures (suctions) increasing effective stress





Optimum Moisture Content (OMC) is the moisture content at which the maximum possible dry density is achieved for a particular compaction energy or compaction method. The corresponding dry density is called Maximum Dry Density (MDD). Water is added to lubricate the contact surfaces of soil particles and improve the compressibility of the soil matrix. It should be noted that increase in water content increases the dry density inmost soils up to one stage (Dry side). Water acts as lubrication. Beyond this level, any further increase in water (Wet side)will only add more void space, thereby reducing the dry density. Hence OMC indicates the boundary between the dry side and wet side. Hence the compaction curve as shown in figure indicates the initial upward trend up to OMC and the down ward trend.

Reasons for the shape of curve

1. On dry side of OMC, clayey soil shows high suction, lumps are difficult to break or compact. 2. Increasing the water content reduces suction, softens lumps, lubricates the grains for easy compaction.

3. As water content increases, lubrication improves compaction resulting in higher dry density.

4. Now nearly impossible to drive out the last of the air – further increase in water content results in reduced dry density (curve follows down parallel to the maximum possible density curve – the Zero Air Voids curve)

5. MDD and OMC depend on the compaction energy and are not unique soil properties.

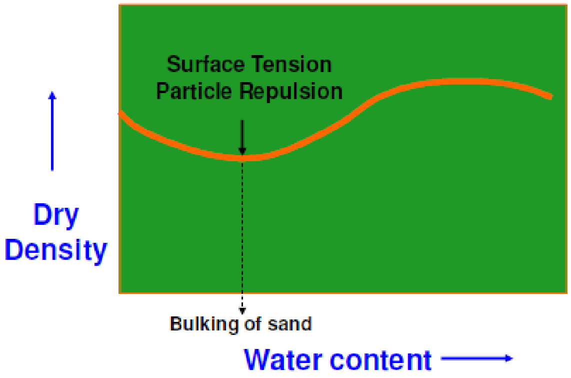
6. For sand, suction at low water contents also prevents compaction (but not if completely dry)

7. In cohesionless soils, MDD is achieved either when completely dry, or when completely saturated.

8. At low water content, grains are held together by suction (water at grain contacts only)

9. This prevents compaction.

10. Laboratory test for MDD on sand requires fully saturated sample, and involves vibration



Percent Air Voids

$$\gamma_d = \frac{(1 - n_a)G\gamma_\omega}{1 + \omega G}$$

6. Factors affecting Compaction

1. Water Content
2. Amount of Compaction
3. Method of Compaction
4. Type of Soil
5. Addition of Admixtures

Effect of Water Content-

1. With increase in water content, compacted density increases up to a stage, beyond which compacted density decreases.

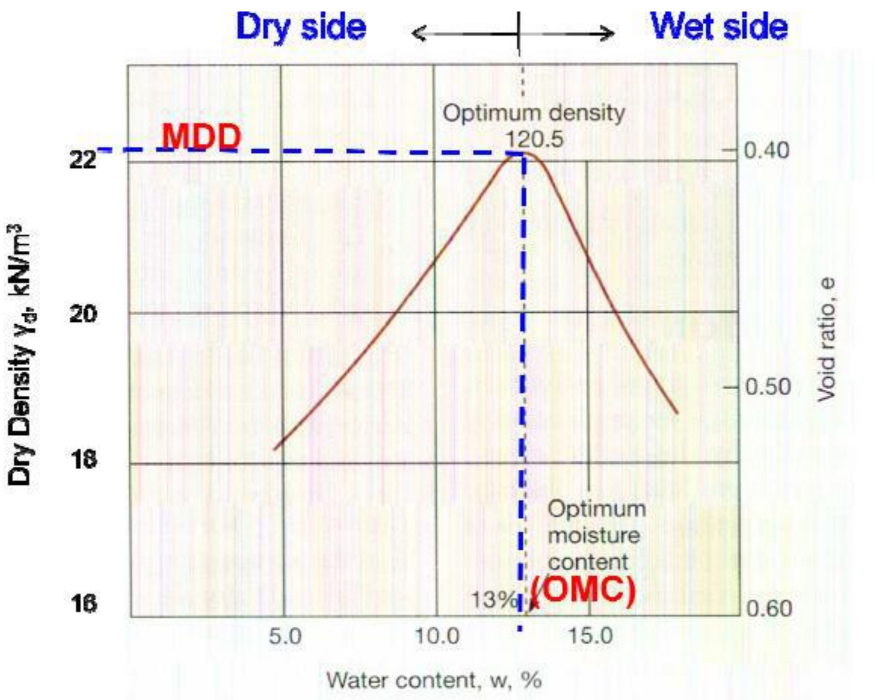
2. The maximum density achieved is called MDD and the corresponding water content is called OMC.

3. At lower water contents than OMC, soil particles are held by the force that prevents the development of diffused double layer leading to low inter-particle repulsion.

4. Increase in water results in expansion of double layer and reduction in net attractive force between particles. Water replaces air in void space

5. Particles slide over each other easily increasing lubrication, helping in dense packing.

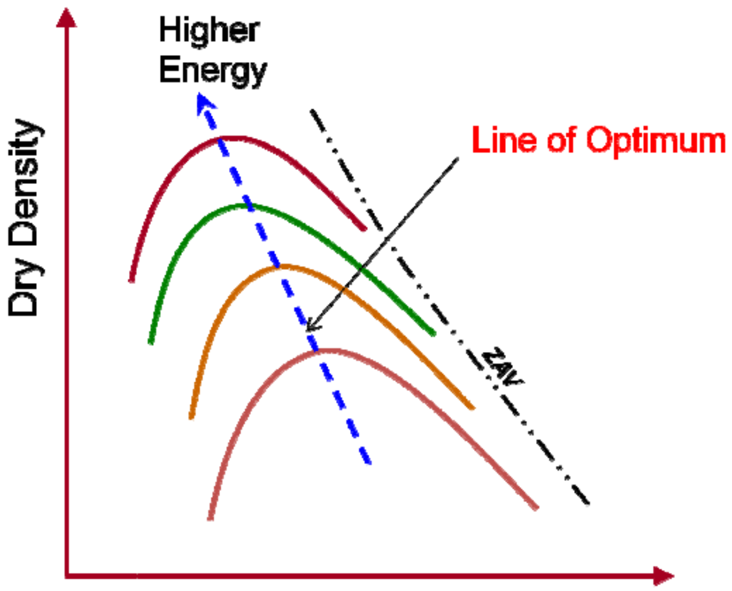
6. After OMC is reached, air voids remain constant. Further increase in water, increases the void space, thereby decreasing dry density.



Effect of Amount of Compaction-

1. As discussed earlier, effect of increasing compactive effort is to increase MDD And reduce OMC (Evident from Standard & Modified Proctor’s Tests).

2. However, there is no linear relationship between compactive effort and MDD.



Effect of Method of Compaction-

The dry density achieved by the soil depends on the following characteristics of compacting method.

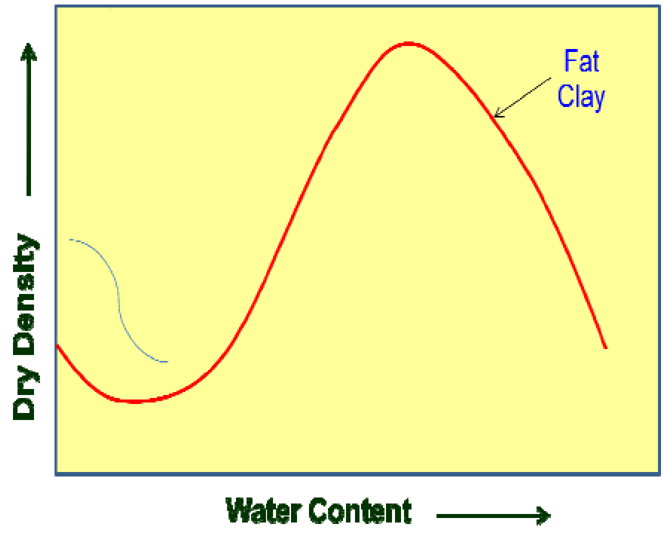
1. Weight of compacting equipment
2. Type of compaction
3. Area of contact of
4. Time of exposure
5. Each of these approaches will yield different compactive effort.

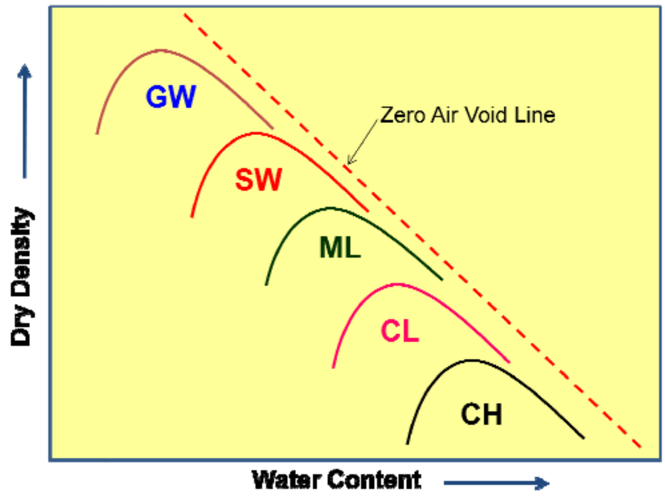
Effect of Type of Soil

1. Maximum density achieved depends on type of
2. Coarse grained soil achieves higher density at lower water content and fine grained soil achieves lesser density, but at higher water content

Further, suitability of a particular method depends on type of soil.

Typical Compaction Curve for Fat Clay





Effect of Addition of Admixtures-

1. Stabilizing agents are the admixtures added to soil.

2. The effect of adding these admixtures is to stabilize the soil.

3. In many cases they accelerate the process of densification.

Effect of compaction on soil properties-

1. Density

2. Shear strength

3. Permeability

4. Bearing Capacity

5. Settlement

6. Soil Structure

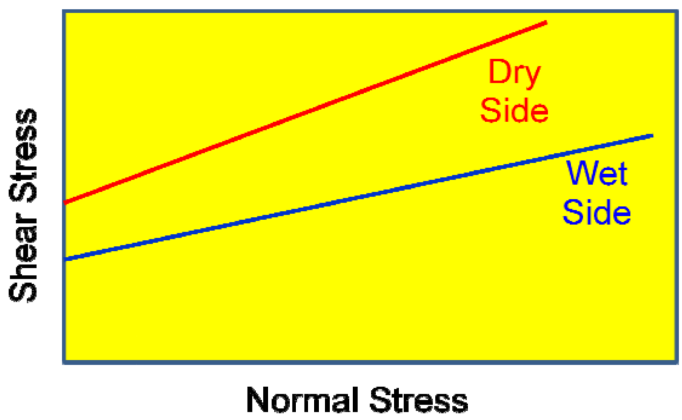
7. Pore Pressure
8. Stress Strain characteristics
9. Swelling & Shrinkage

Influence on Density:

Effect of compaction is to reduce the voids by expelling out air. This results in increasing the dry density of soil mass.

Influence on Shear strength:

Increase the number of contacts resulting in increased shear strength, especially in granular soils. In clays, shear strength depends on dry density, moulding water content, soil structure, method of compaction, strain drainage condition etc. Shear strength of cohesive soils compacted dry of optimum (flocculated structure) will be higher than those compacted wet of optimum (dispersed structure).



Effect of compaction on permeability

1. Increased dry density, reduces the void space, thereby reducing permeability.
2. At same density, soil compacted dry of optimum is more permeable.
3. At same void ratio, soil with bigger particle size is more permeable.
4. Increased compactive effort reduces permeability.

Effect on Bearing Capacity

1. Increase in compaction increases the density and number of contacts between soil particles.
2. This results in increased
3. Hence bearing capacity increases which is a function of density and

Effect on Settlement

1. Compaction increases density and decreases void ratio.

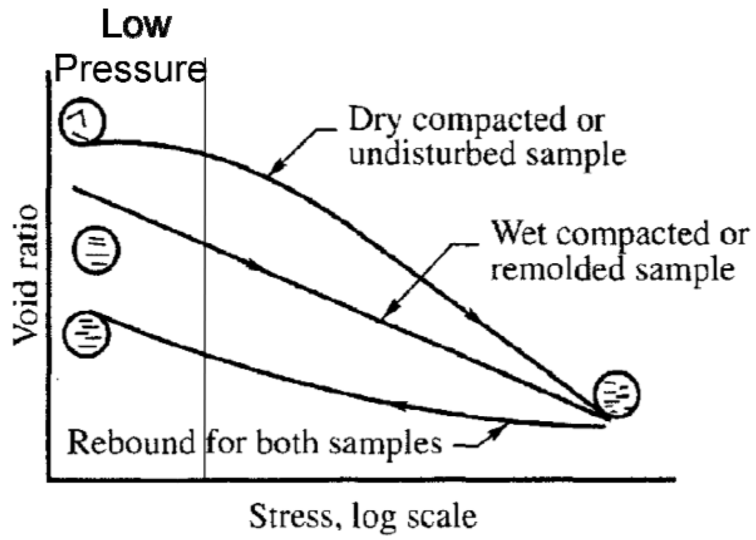
2. This results in reduced settlement.

3. Both elastic settlement and consolidation settlement are reduced.

4. Soil compacted dry of optimum experiences greater compression than that compacted wet of optimum.

Effect on Compressibility

Optimum shows more compressibility than that on dry side. But at higher pressure, behavior is similar.



Effect on Soil Structure

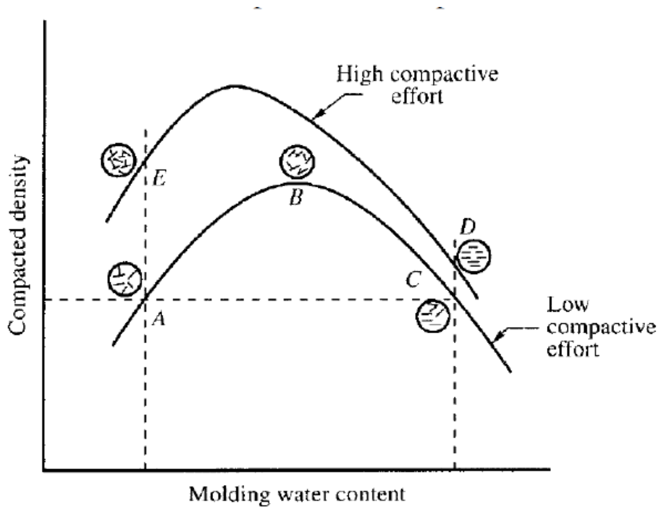
In fine grained soil

1. On dry side of optimum, the structure is flocculated. The particles repel and density is less.

2. Addition of water increases lubrication and transforms the structure into dispersed structure

In coarse grained soil, single grained structure is maintained

In composite soil, behaviour depends on composition.



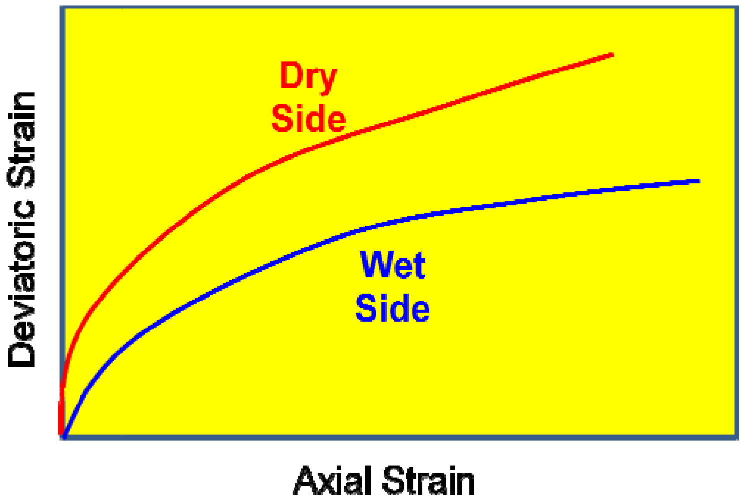
Effect on Pore Pressure

1. Clayey soil compacted dry of optimum develops less pore water pressure than that compacted wet of optimum at the same density at low strains.

2. However, at higher strains the effect is the same in both the cases.

Effect on Stress Strain Characteristics:

The strength and modulus of elasticity of soil on the dry side of optimum will always be better than on the wet side for the same density. Soil compacted dry of optimum shows brittle failure and that compacted on wet side experiences increased strain



Effect on Swell Shrink aspect

The effect of compaction is to reduce the void space. Hence the swelling and shrinkage are enormously reduced. Further, soil compacted dry of optimum exhibits greater swell and swell pressure than that compacted on wet side because of random orientation and deficiency in water.

7. Standard Proctor's Compaction Test

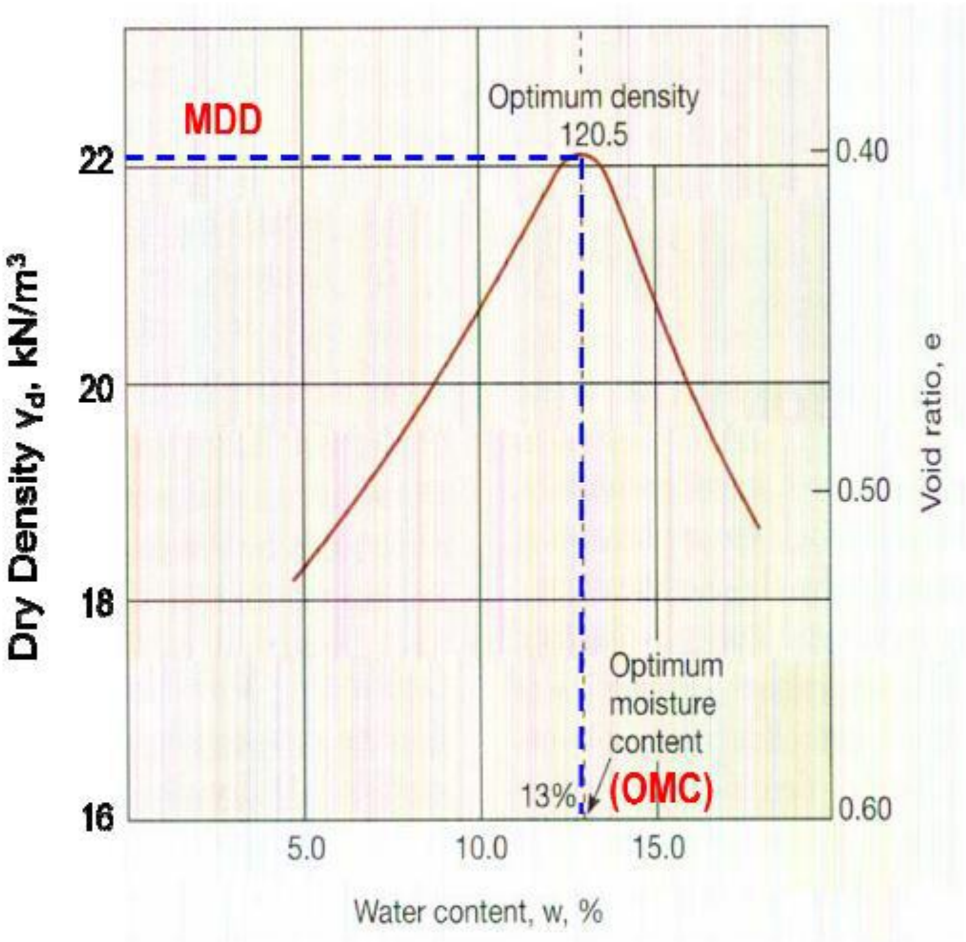
Refer IS 2720 – Part VII – 1987

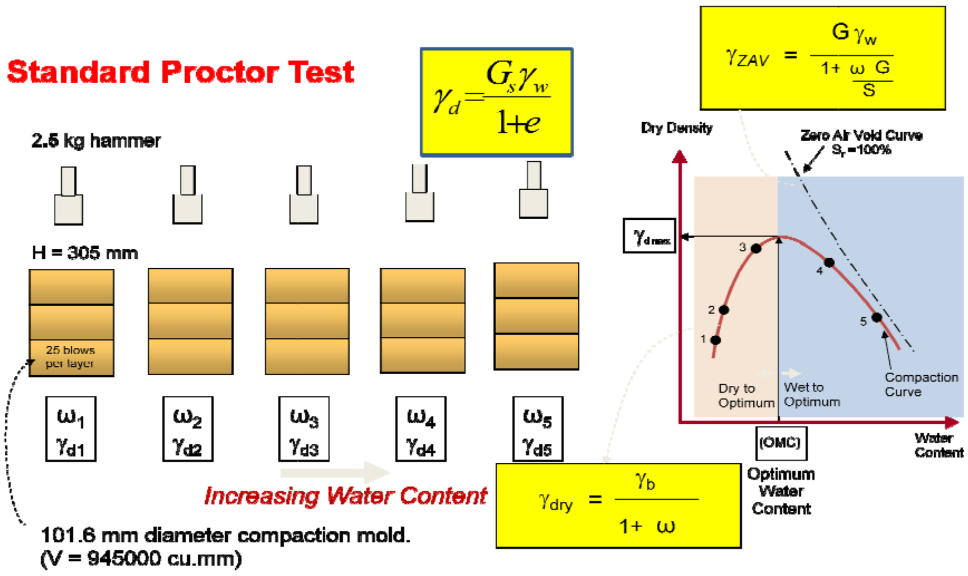
Apparatus

1. Cylindrical metal mould with detachable base plate (having internal diameter 101.6 mm, internal height 116.8 mm and internal volume 945000 mm3)
2. Collar of 50 mm effective height
3. Rammer of weight 2.5 kgf (25 N) with a height of fall of 304.8 mm

Procedure

1. About 3 kg of dry soil, with all lumps pulverized and passing through 4.75 mm sieve is taken.
2. The quantity of water to be added in the first trial is decided. (Less for Corse grained soil and more for Fine grained soil).
3. Mould without base plate & collar is weighed
4. The inner surfaces of mould, base plate and collar are greased.
5. Water and soil are thoroughly mixed.
6. Soil is placed in mould and compacted in three uniform layers, with 25 blows in each layer. Blows are maintained uniform and vertical and height of drop is controlled.
7. After each layer, top surface is scratched to maintain integrity between layers.
8. The height of top layer is so controlled that after compaction, soil slightly protrudes in to collar.
9. Excess soil is scrapped.
10. Mould and soil are weighed (W)
11. A representative sample from the middle is kept for the determination of water content.
12. The procedure is repeated with increasing water content.
13. The number of trials shall be at least 6 with a few after the decreasing trend of bulk density.


MDD
Optimum density
120.5
22
20
18
16
0.40
0.50
0.60
Dry Density γd, kN/m³
Void ratio, e
Optimum
moisture
content
13%
(OMC)
5.0
10.0
15.0
Water content, w, %



8. Modified Compaction Test

In early days, compaction achieved in field was relatively less. With improvement in knowledge and technology, higher compaction became a necessity in field. Hence Modified Compaction Test became relevant. It was developed during World War II by the U.S. Army Corps of Engineering tobetter represent the compaction required for airfield to support heavy aircraft.

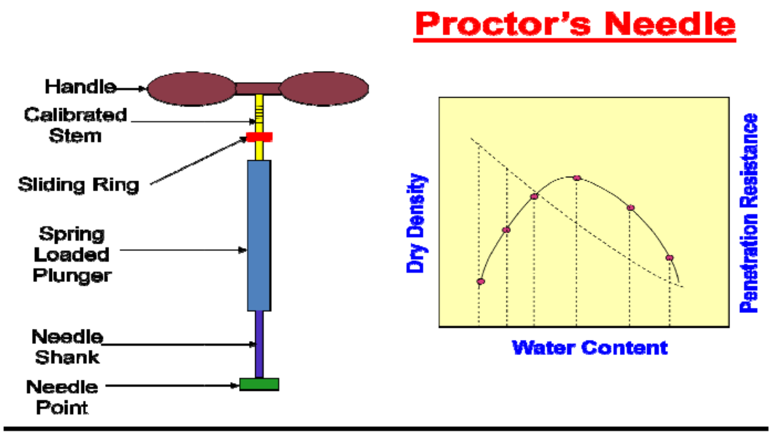
6.4 Distinction between Standard & Modified Compaction

Standard Proctor Test	Modified Proctor Test
305 mm height of drop	450 mm height of drop
25 N hammer	45 N hammer
25 blows/layer	25 blows/layer
3 layers	5 layers
Mould size: 945 ml	Mould size: 945 ml
Energy 605160 N-mm per m^3	Energy 2726000 N-mm per m^3

Compactive energy

$$\frac{\text{No. of blows per layer} \times \text{Number of layers} \times \text{Weight of hammer} \times \text{Height of drop of hammer}}{\text{Volume of mould}}$$

9. Proctor's Needle



1. Used for rapid determination of water content of soil in field.
2. Rapid moisture meter is used as an alternative.
3. Proctor's needle consists of a point, attached to graduated needle shank and spring loaded plunger.
4. Varying cross sections of needle points are available.
5. The penetration force is read on stem at top.
6. To use the needle in field Calibration in done on the specific soil in lab and calibration curve is prepared and the curve is used in the field to determine placement water content.

10. Compaction control in field

There are many variables which control the vibratory compaction or densification of soils

Characteristics of the compactor:

(1) Mass, size

(2) Operating frequency and frequency range

Characteristics of the soil:

(1) Initial density

(2) Grain size and shape

(3) Water content

Construction procedures:

(1) Number of passes of the roller

(2) Lift thickness

(3) Frequency of operation vibrator

(4) Towing speed

11. Degree of Compaction

Relative compaction or degree of compaction

$$R.C. = \frac{\gamma_{d-field}}{\gamma_{d\max-laboratory}} \times 100\%$$

Correlation between relative compaction & relative density $R.C. = 80 + 0.2D_r$

It is a statistical result based on 47 soil samples.
Typical required R.C. >= 95%

12. ASSIGNMENT

1. Explain the laboratory tests to determine the compaction of soils?
2. Difference between standard and modified proctors method of compaction?
3. List and explain the compaction instruments?
4. Briefly explain the compaction control in fields?

13. OUTCOMES

1. Will acquire an understanding of the procedures to determine index properties of any type of soil, classify the soil based on its indexproperties
2. Will be able to determine compaction characteristics of soil and apply that knowledge

to assess field compaction procedures

3. Will be able to determine permeability property of soils and acquires conceptual knowledge about stresses due to seepage and effective stress; Also acquire ability to estimate seepage losses across hydraulic structure
4. Will be able to estimate shear strength parameters of different types of soils using the data of different shear tests and comprehend Mohr-Coulomb failure theory.
5. Ability to solve practical problems related to estimation of consolidation settlement of soil deposits also time required for the same.

14. FURTHER READINGS

http://geotech.fce.vutbr.cz/studium/mech_zemin/soil_mechanics.pdf