



Department of Civil Engineering

Study Material

Unit-III

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.

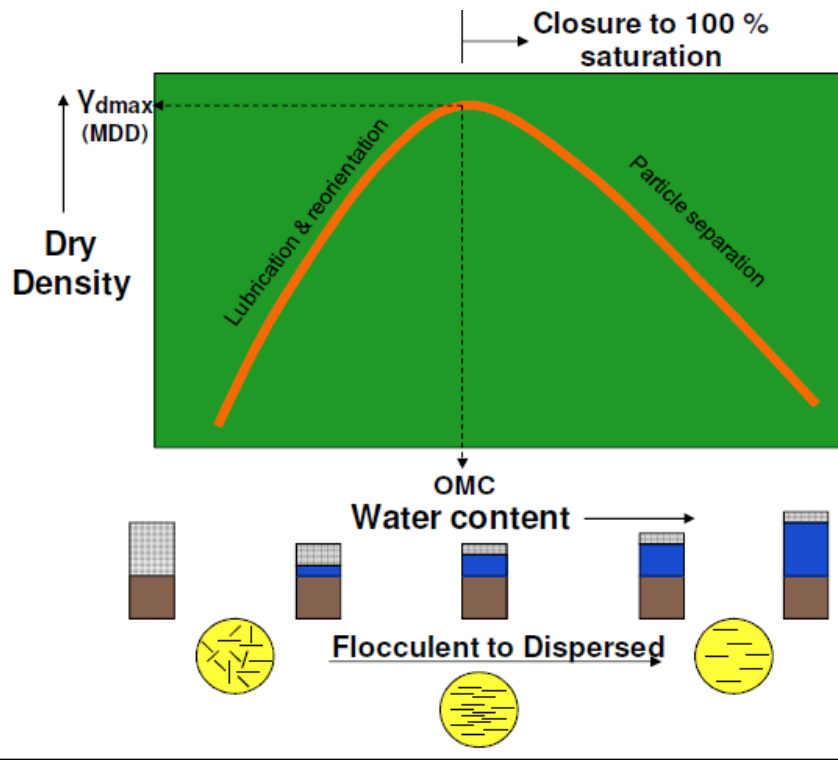
Hence, Compaction

- 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



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Mechanism of Compaction-



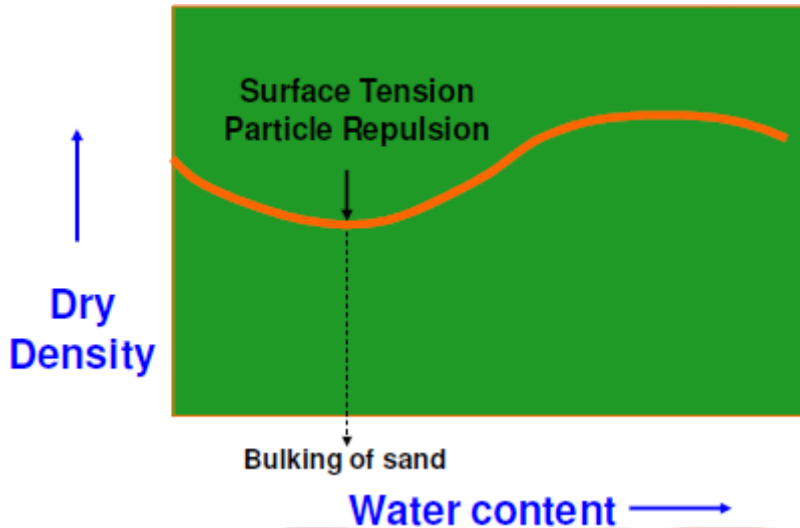
Optimum Moisture Content (OMC) is the moisture content at which the maximum possible dry density is achieved for a particular compaction energy or compaction method. The corresponding dry density is called Maximum Dry Density (MDD). Water is added to lubricate the contact surfaces of soil particles and improve the compressibility of the soil matrix. It should be noted that increase in water content increases the dry density in most 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 downward 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:

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

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Factors affecting Compaction-

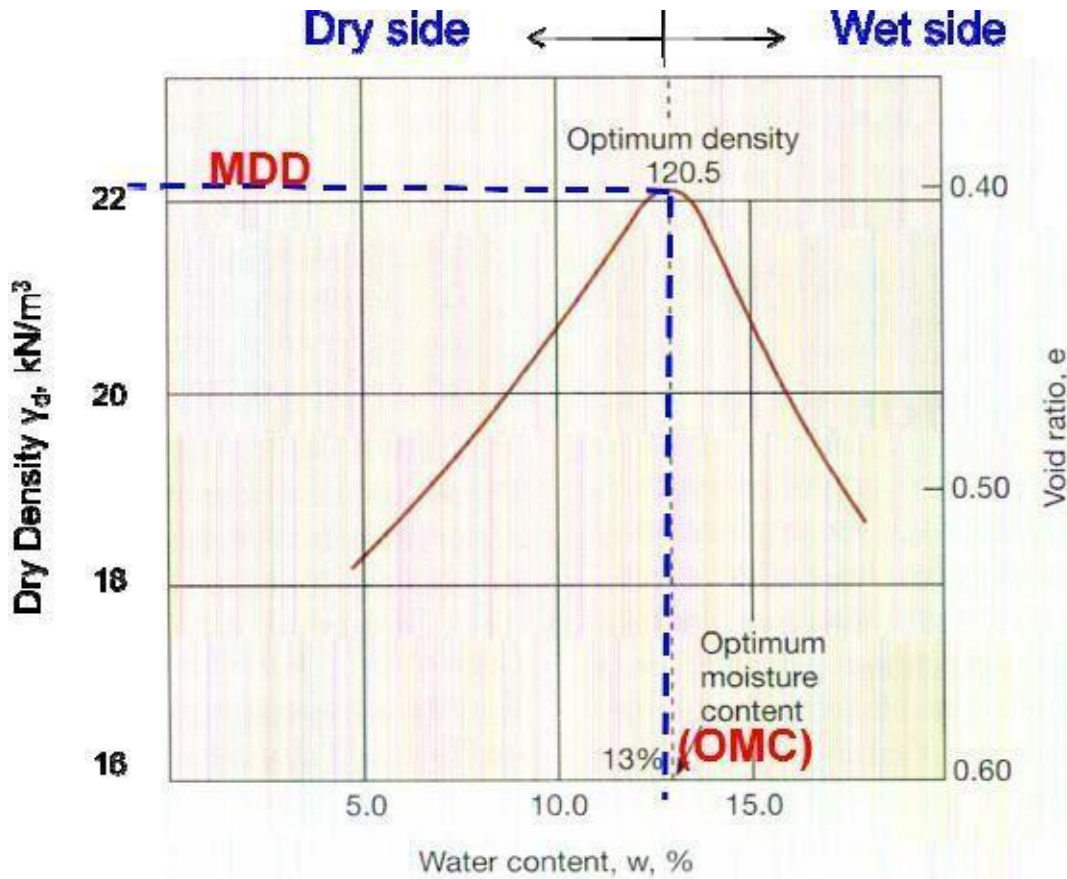
1. Water Content
2. Amount of Compaction
3. Method of Compaction
4. Type of Soil
5. Addition of Admixtures

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.

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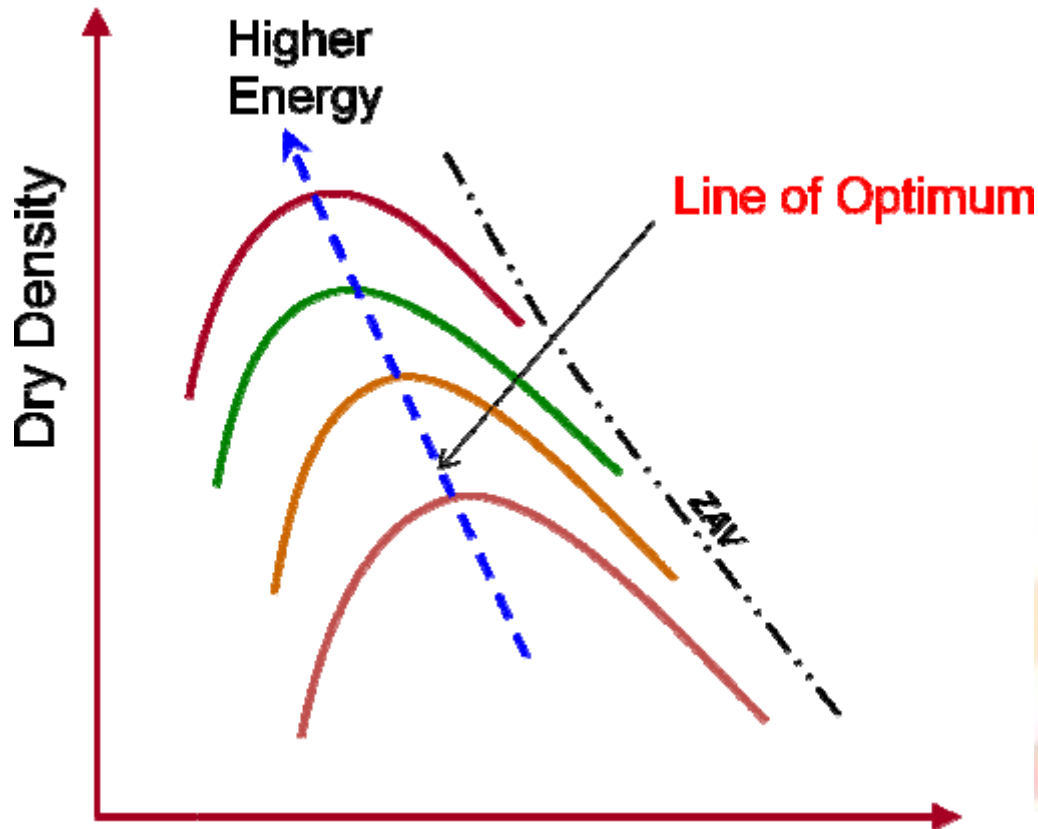


Effect of Amount of Compaction-

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.

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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.

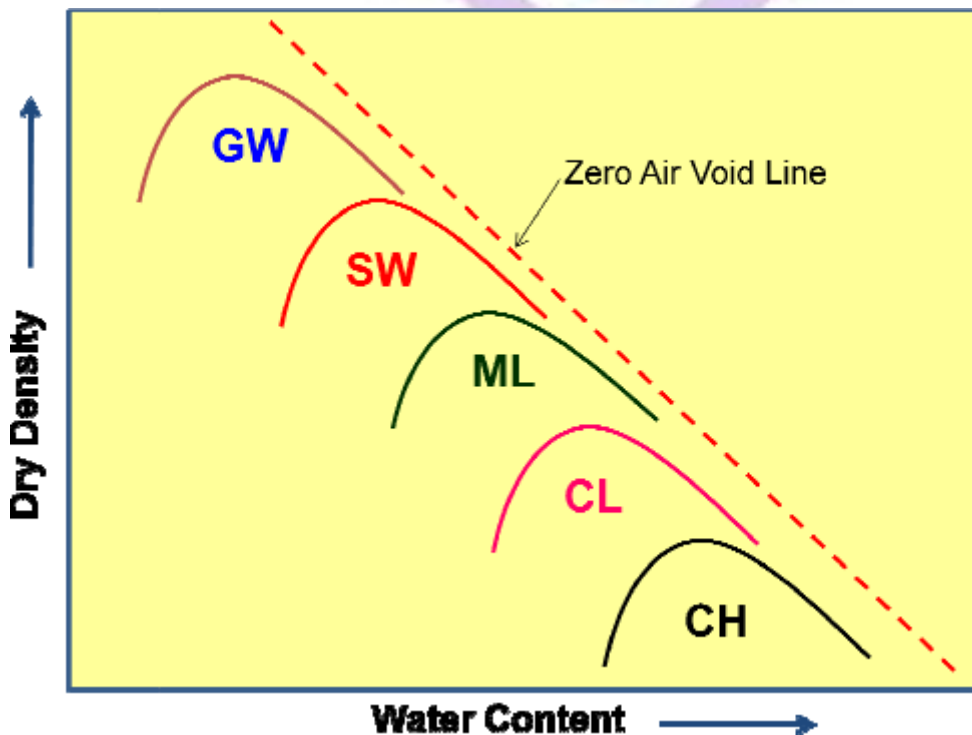
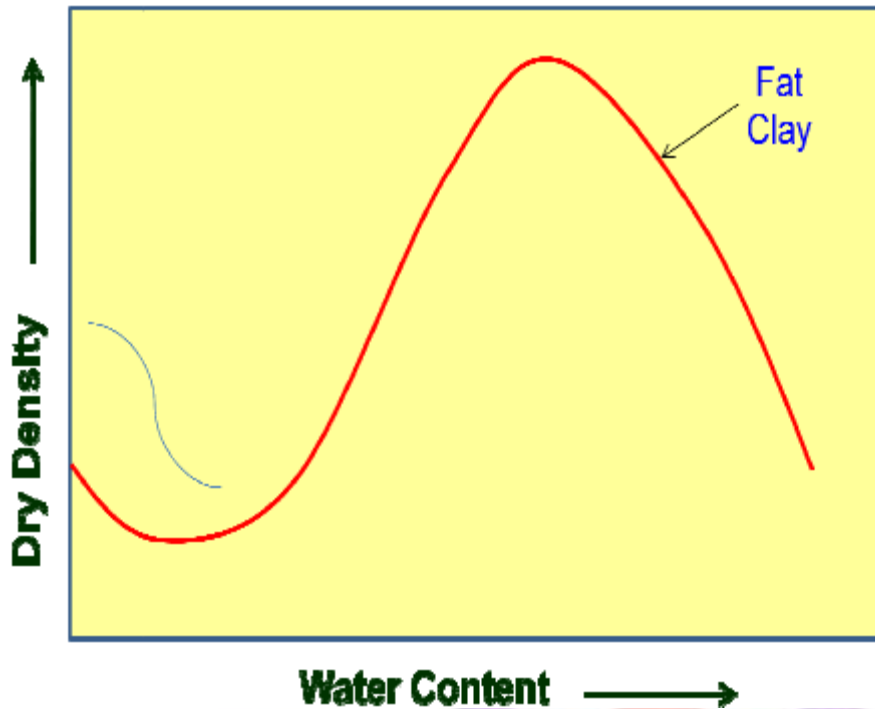
Further, suitability of a particular method depends on type of soil.

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.

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Typical Compaction Curve for Fat Clay



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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-

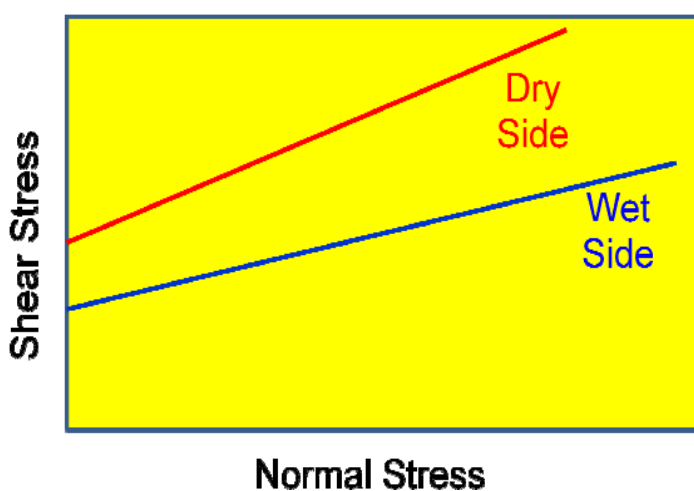
1. Density
2. Shear strength
3. Permeability
4. Bearing Capacity
5. Settlement
6. Soil Structure
7. Pore Pressure
8. Stress Strain characteristics
9. Swelling & Shrinkage

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

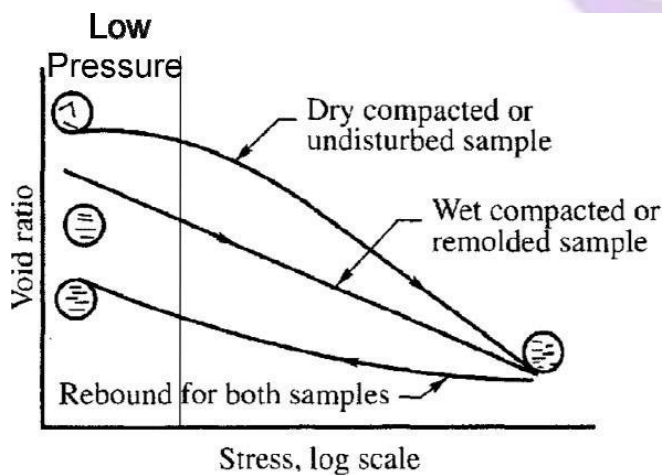
1. Increase in compaction increases the density and number of contacts between soil particles.
2. This results in increased
3. Hence bearing capacity increases which is a function of density and

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.



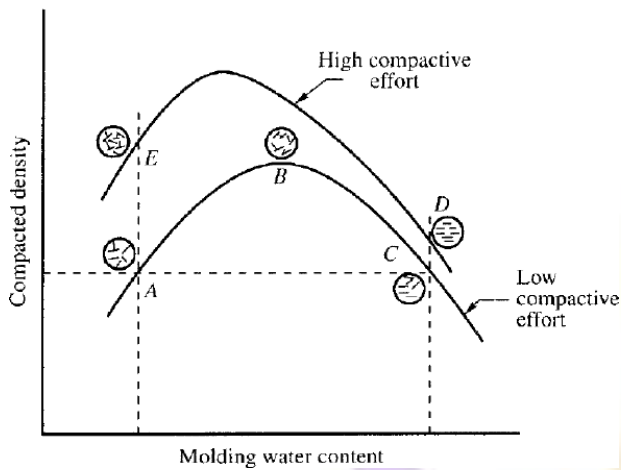
Effect on Soil Structure

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.

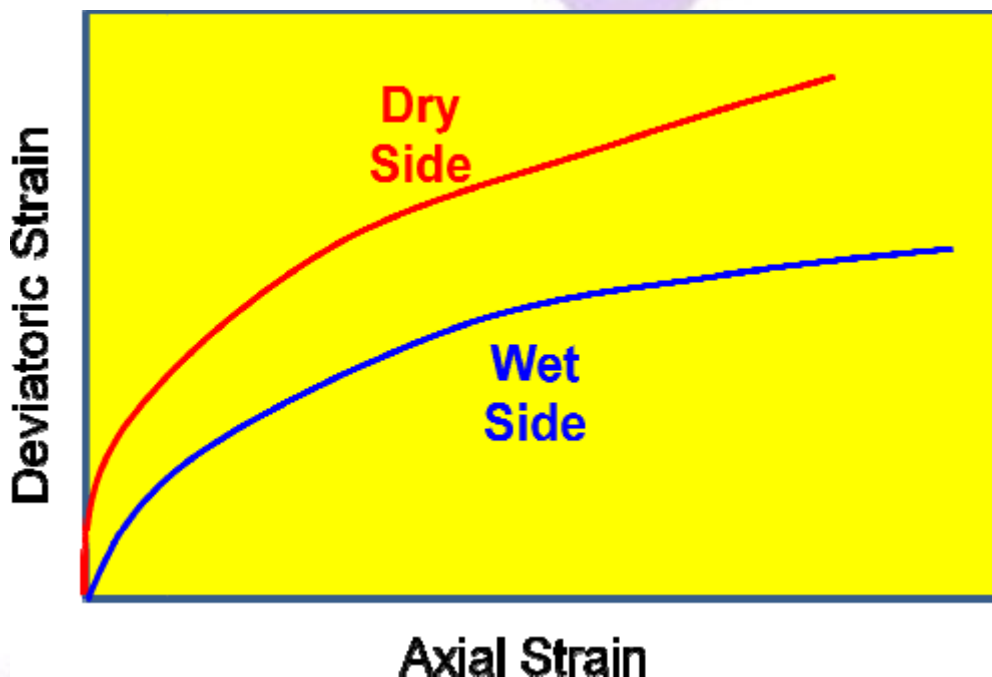


Effect on Pore Pressure

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.



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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.

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

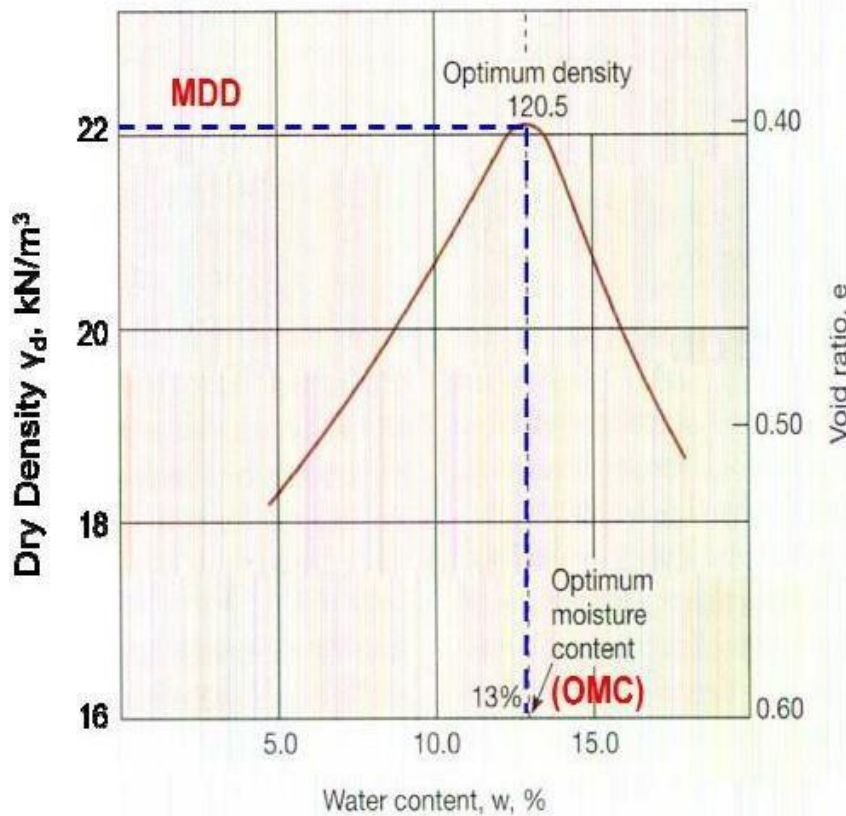


Procedure

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 Coarse 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.

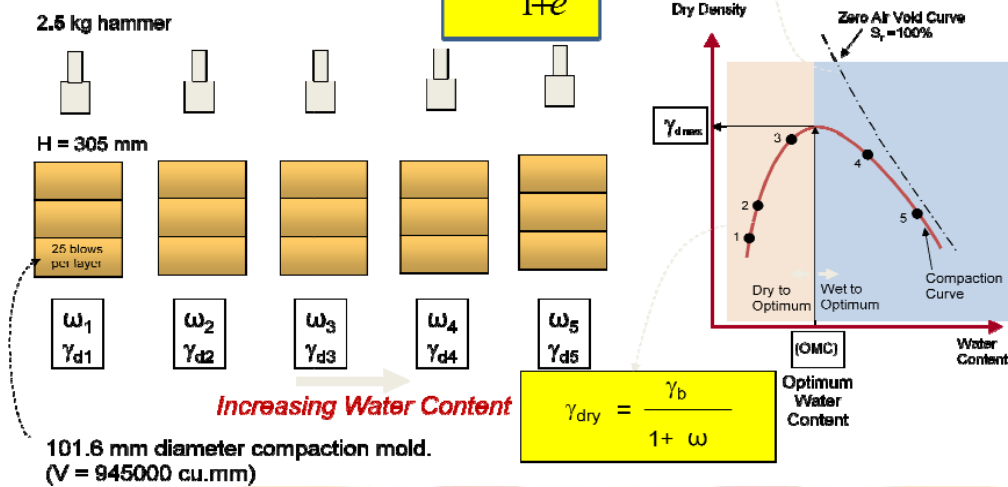


7. After each layer, top surface is scratched to maintain integrity between layers.
8. The height of top layer is so controlled that after compaction, soil slightly protrudes in to collar.
9. Excess soil is scrapped.
10. Mould and soil are weighed (W)
11. A representative sample from the middle is kept 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.



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Standard Proctor Test



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 to better represent the compaction required for airfield to support heavy aircraft.

6.4 Distinction between Standard & Modified Compaction

<u>Standard Proctor Test</u>	<u>Modified Proctor Test</u>
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

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



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Types of field Compaction Equipment:

1. Smooth Wheeled Steel Drum Rollers
2. Pneumatic Tyred Rollers
3. Sheepsfoot Rollers
4. Impact Rollers
5. Vibrating Rollers
6. Hand Operated vibrating plate & rammer compactors

Smooth wheeled steel drum rollers

1. Capacity 20 kN to 200 kN
2. Self propelled or towed
3. Suitable for well graded sand, gravel, silt of low plasticity
4. Unsuitable for uniform sand, silty sand and soft clay



Pneumatic Tyred Rollers

1. Usually two axles carrying rubber tyred wheels for full width of track.
2. Dead load (water) is added to give a weight of 100 to 400 kN.
3. Suitable for most coarse & fine soils
4. Unsuitable for very soft clay and highly variable soil.



Sheepsfoot Roller

1. Self propelled or towed
2. Drum fitted with projecting club shaped feet to provide kneading action.
3. Weight of 50 to 80 kN
4. Suitable for fine grained soil, sand & gravel with considerable fines.



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Impact Roller

1. Compaction by static pressure combined with impact of pentagonal roller.
2. Higher impact energy breaks soil lump and provides kneading action



Vibrating Drum

1. Roller drum fitted with vibratory motion.
2. Levels and smoothens ruts



Plate & Rammer Compactor:

It is used for backfilling trenches, smaller constructions and less accessible locations

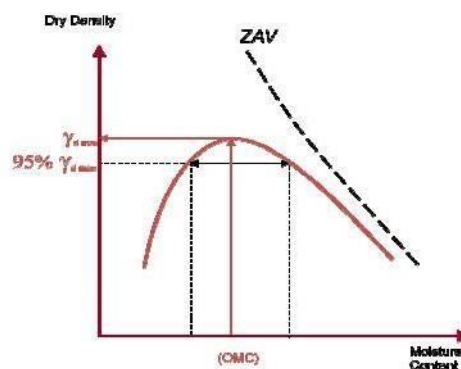


Field Compaction Control-

It is extremely important to understand the factors affecting compaction in the field and to estimate the correlation between laboratory and field compaction. Field compaction control depends on

- (i) Placement water content,
 - (ii) Type of equipment for compaction
 - (iii) Lift thickness
 - (iv) Number of passes based on soil type & degree of compaction desired
- Placement water content is the water content at which the ground is compacted in the field. It is desirable to compact at or close to optimum moisture content achieved in laboratory so as to increase the efficiency of compaction. However, in certain jobs the compaction is done at lower than or higher than OMC (by about 1– 2 %) depending on the desired function as detailed .

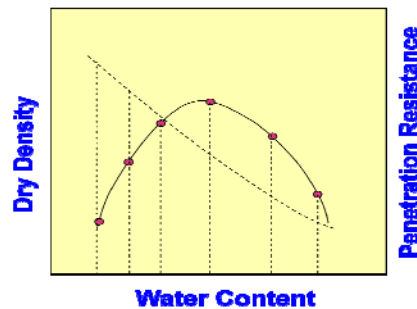
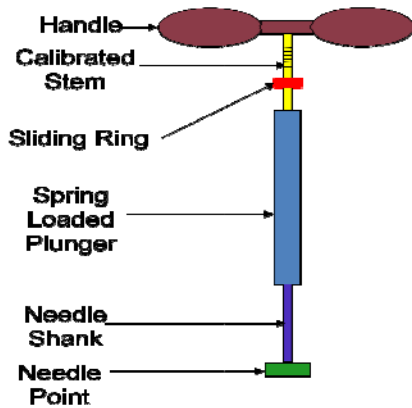
Comparison between field & laboratory compaction methods





Proctor's Needle

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 is 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.

Compaction control in field

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

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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

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 $R.C. \geq 95\%$

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UGC AUTONOMOUS INSTITUTION

Maisammaguda (V), Kompally - 500100, Secunderabad, Telangana State, India

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