# SOIL MECHANICS

## Compaction of Soil



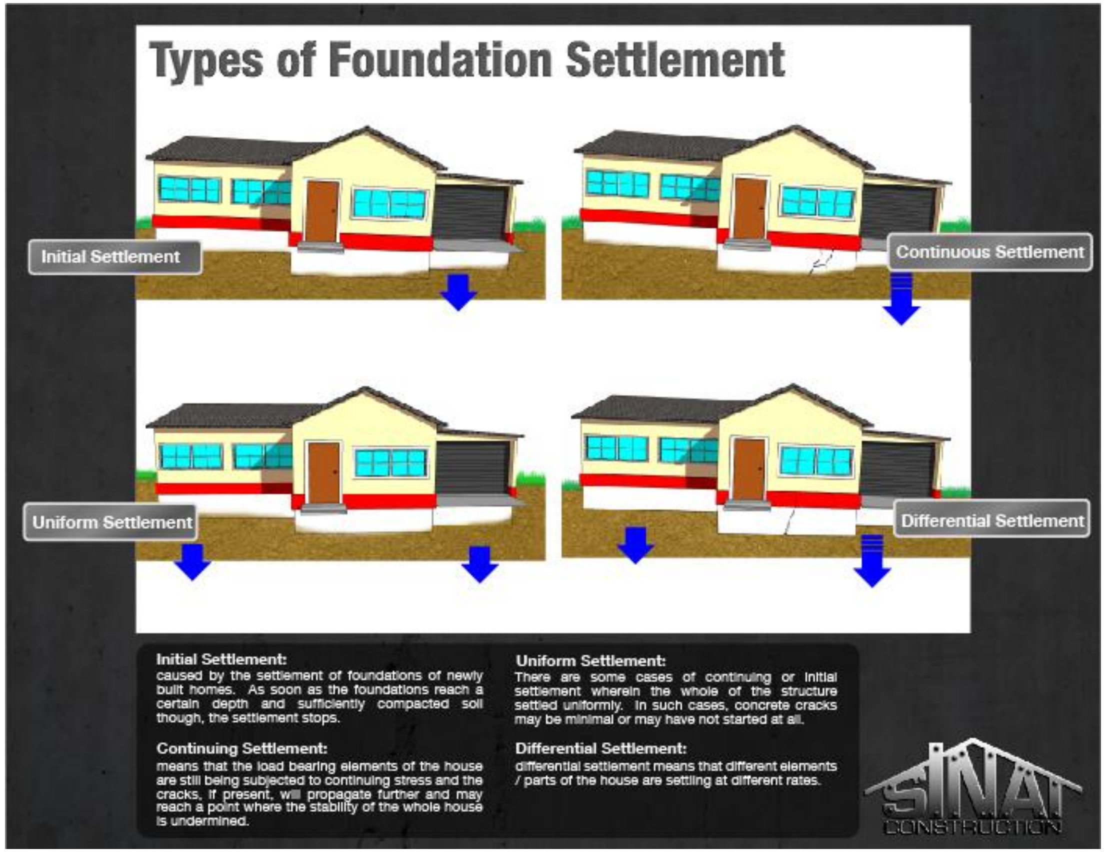
Abhash Acharya

# SOIL COMPACTION

- Compaction is a process of pressing soil particles close to each other by mechanical methods.
- In compaction air is expelled from the void space in soil mass and thus dry density of soil is increased.
- In other words, compaction is the densification of soil by removal of air which requires mechanical energy.


# PURPOSE OF SOIL COMPACTION

- To increase the dry density of soil.
- Soil compaction is done to improve engineering properties such as shear strength, stability and bearing capacity.
- To decrease the undesirable settlement of structures.
- To control undesirable volume changes.

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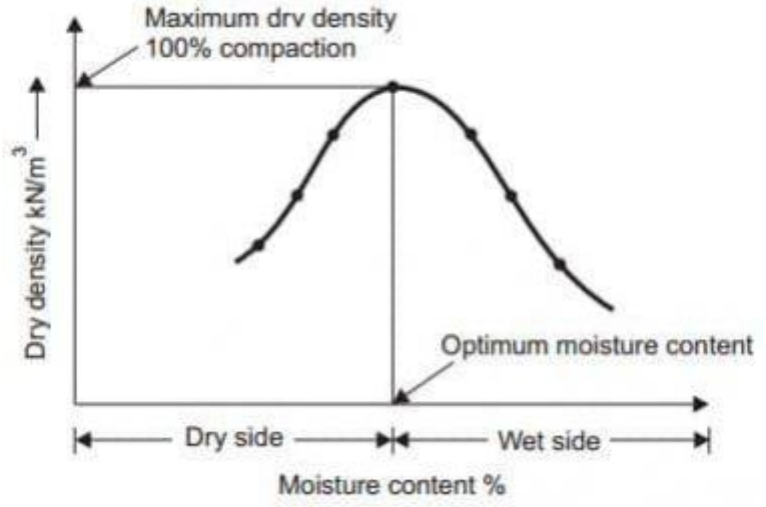
# DRY DENSITY AND WATER CONTENT RELATIONSHIP

- For any soil there exist a definite relationship between the soil water content and dry density to which the soil can be compacted and that for a specific amount of compaction energy or effort applied on the soil there is a particular water content at which the soil attains its maximum dry density.

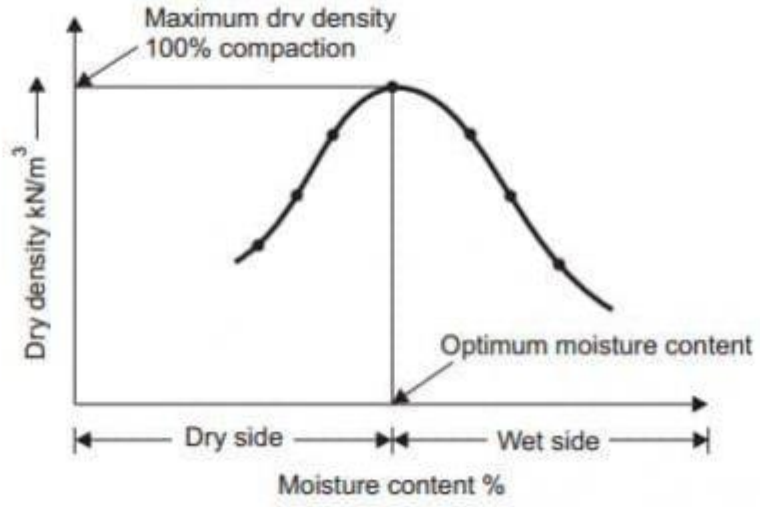
- The water content corresponding to the maximum dry density is known as **Optimum Moisture Content (O.M.C.) or Optimum Water Content (O.W.C.).**



# DRY DENSITY AND WATER CONTENT RELATIONSHIP

- At a water content lower than the optimum, the soil is rather stiff and has lot of void spaces and, therefore the dry density is low.

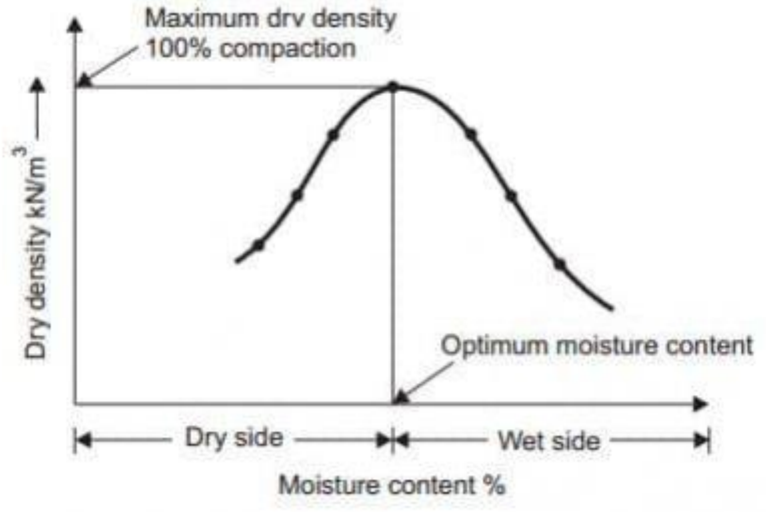
- As the water content is increased, the soil particles get lubricated and slip over each other, and move into densely packed positions and the dry density is increased.



# DRY DENSITY AND WATER CONTENT RELATIONSHIP

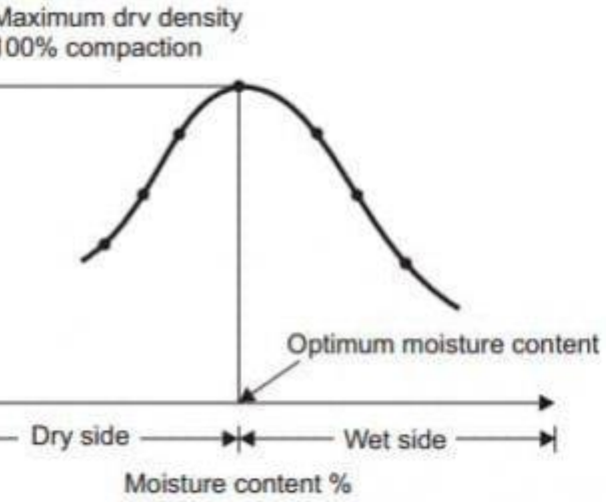
- However, at a water content more than the optimum, the additional water reduces the dry density, as it occupies the space that might have been occupied by solid particles.

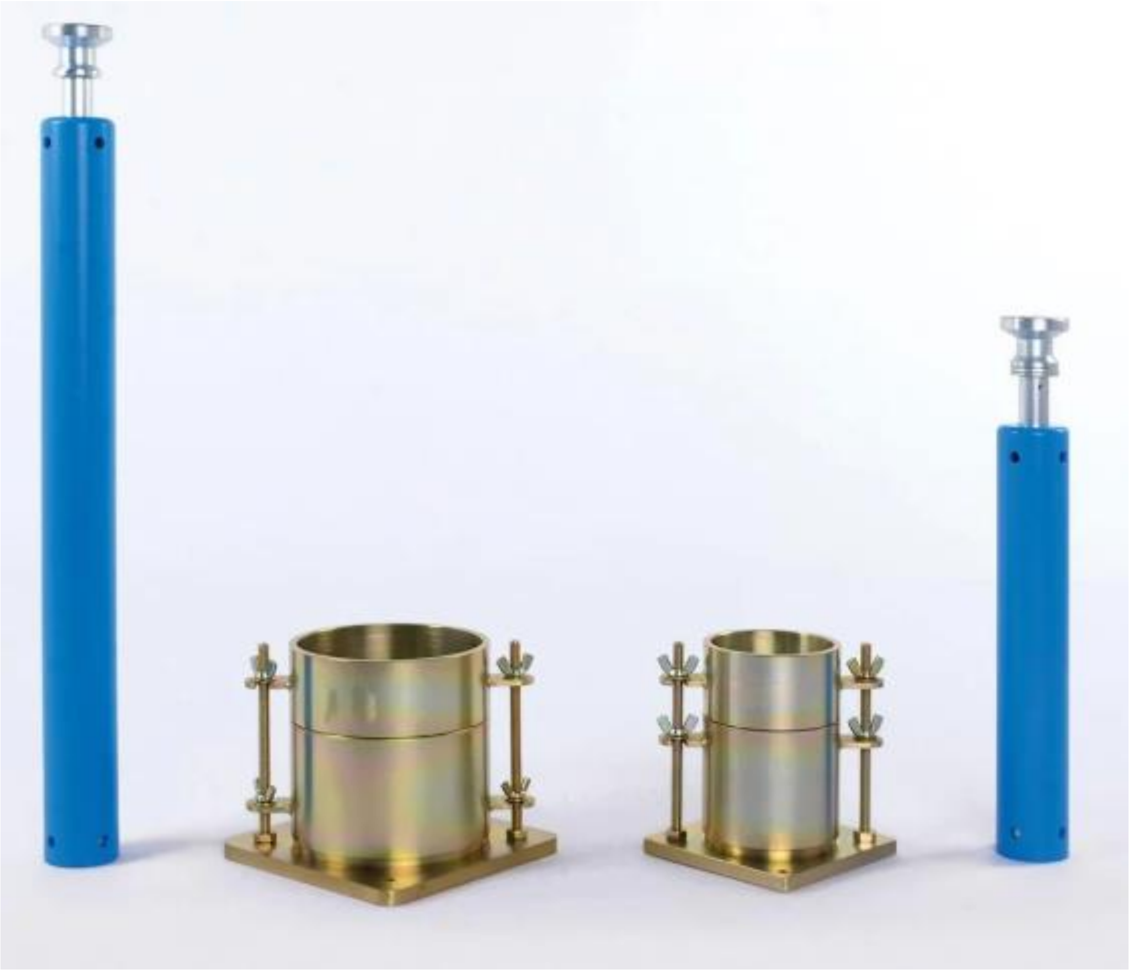
- The curve between water content and dry density is known as the **water content-dry density curve or the moisture content-dry density curve or the compaction curve.**

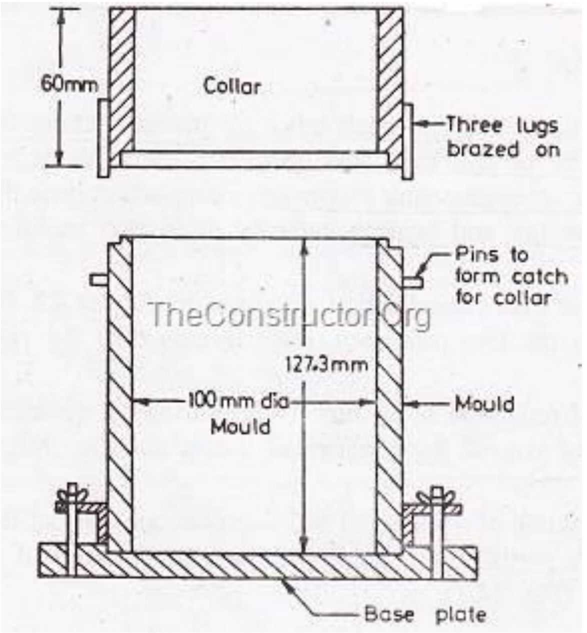


# LABORATORY TEST TO OBTAIN COMPACTION CHARACTERISTICS

- Standard Proctor Test
- Modified Proctor Test



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# STANDARD PROCTOR TEST

**Procedure**

- 2.5 kg of air-dried soil passing through 4.75mm is taken.
- Water is added to soil (4% for coarse grained and 8% for fine grained), such that the water content is less than expected optimum moisture content.

| Sand | Sandy Silt or Silty Sand | Silt | Clay |
|---|---|---|---|
| 6 to 10% | 8 to 12% | 12 to 16% | 14 to 20% |

- Take mass of mould with base plate but without collar (M1). The collar is fitted and soil is placed on the mould to about one-third.
- Soil is compacted using 2.5kg of rammer falling through a height of 310mm in 25 blows, evenly distributed over surface.
- Similarly, second and third layer of soil are filled and compacted.
- Collar is removed and soil above mould is trimmed off.
- Then mass of mould with base plate and compacted soil is taken (M2). So, the mass of compacted soil = M2-M1
- Now, Bulk Density (ρ) = (M2-M1)/V

  Where, V = Volume of the mould = $\frac{\pi d^2}{4} * H$

  Dry density ($\rho_d$) = $\frac{\rho}{1+w}$, w = water content obtained from oven drying method.
- Again, add some more water to increase the water content by (2-3) % and test is repeated. Plot $\rho_d$ vs. w curve and determine the OMC and Maximum dry density.

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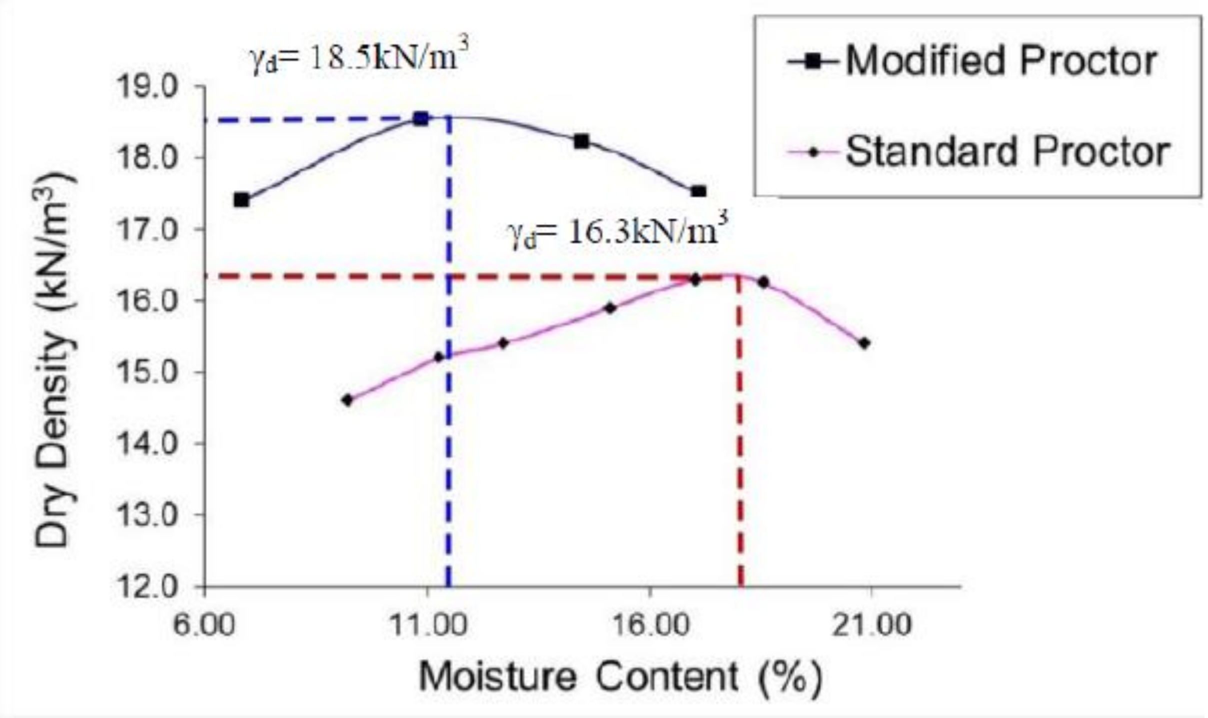
# MODIFIED PROCTOR TEST

- It is the method developed during second world war due to the requirement of higher subgrade resistance of pavements.
- In this method same mould as in standard proctor test is used but the compaction effort is increased by using 4.5kg of rammer falling through a height of 450mm.
- The compaction of soil is done in 5 layers with each layer receiving 25 blows of rammer.




# FACTORS AFFECTING COMPACTION

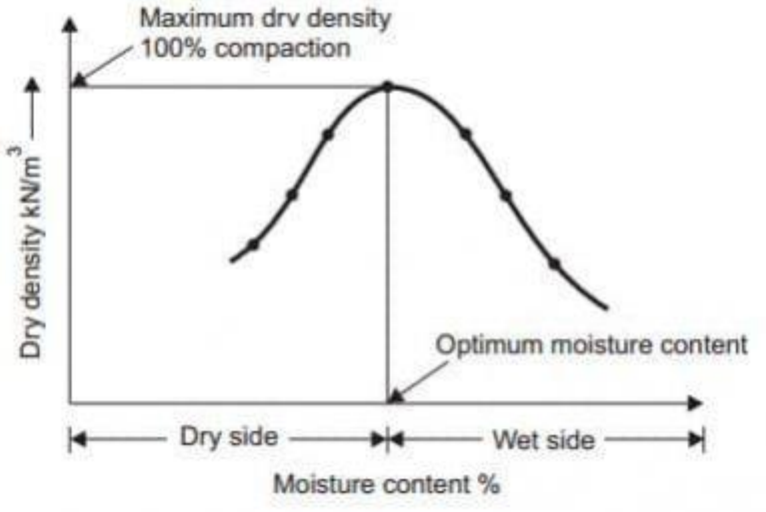
- Water Content
- Amount of Compaction
- Type of Soil
- Method of Compaction
- Admixtures

# FACTORS AFFECTING COMPACTION

- **<u>Water Content</u>**

  - Initially $\rho_d$ increases with increase in water content due to lubricating effect and results ease in compaction.

  - However, at a water content more than the optimum, the additional water reduces the dry density, as it occupies the space that might have been occupied by solid particles.




# FACTORS AFFECTING COMPACTION

- **Amount of Compaction**

  - The effect of increasing the amount of compactive effort is to increase the maximum dry density and to decrease the optimum water content.

  - At a water content less than the optimum, the effect of increased compaction is more predominant.

  - At a water content more than OMC, the volume of air voids become almost constant and the effect of increased compaction is not significant.

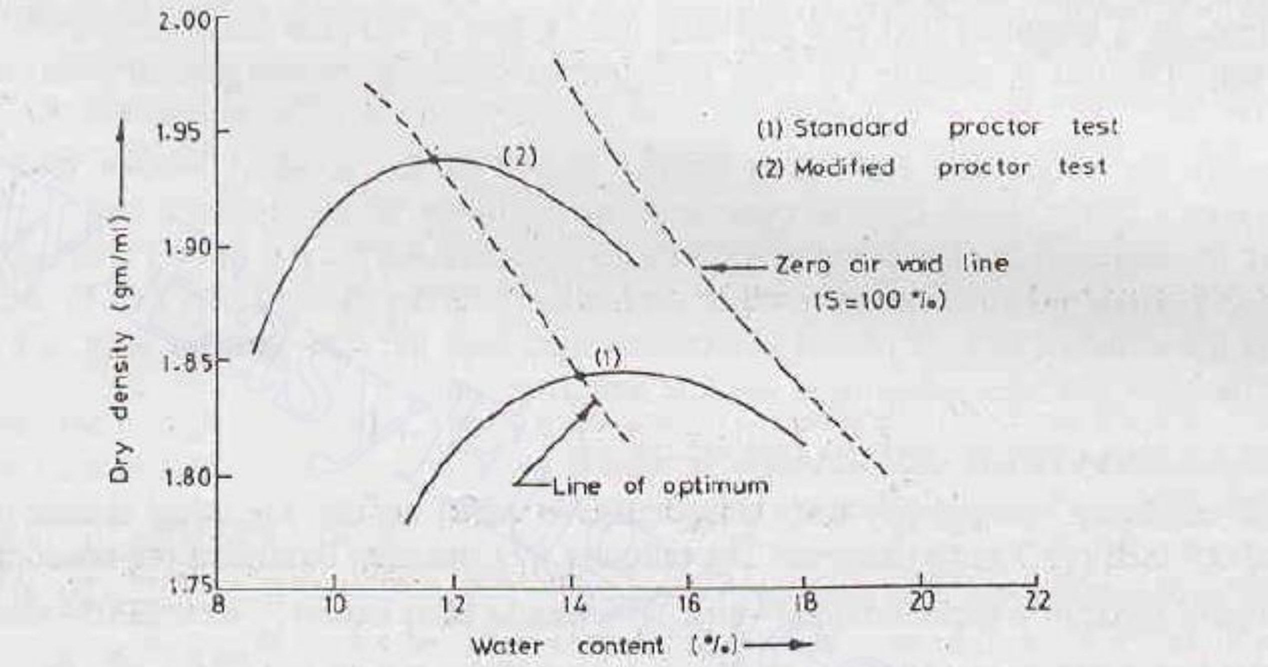


Fig. 14.4. Compaction Crves of Standard Proctor Test and Modified Proctor Test.

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# FACTORS AFFECTING COMPACTION

- **Type of Soil**

  - Coarse-grained soils can be compacted to a higher dry density than fine-grained soils. With the addition of even a small quantity of fines to a coarse-grained soil, the soil attains a much higher dry density for the same compactive effort. But when fines are excessive, the dry density decreases.
  - Well graded sand attains a much higher dry density than a poorly graded soil.
  - Cohesive soils attain a relatively lower maximum dry density as compared to cohesionless soils due to high air voids.
  - Clays of high plasticity have very low dry density and a very high OMC.

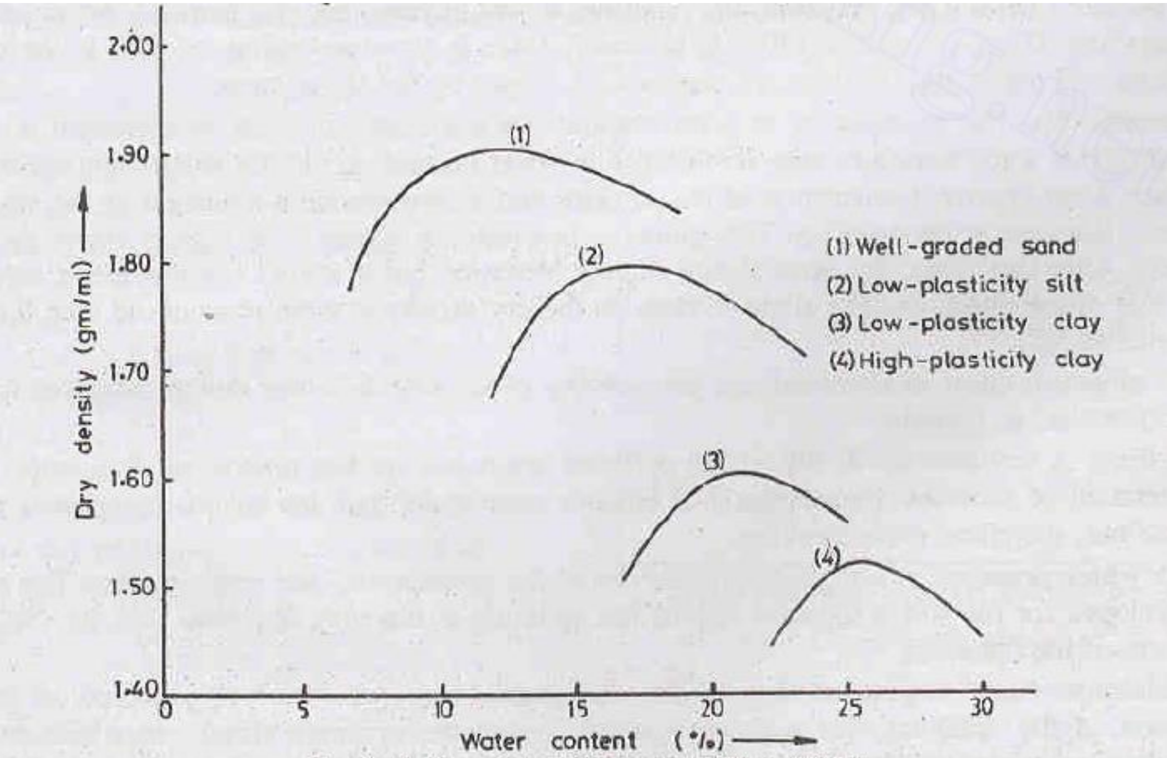


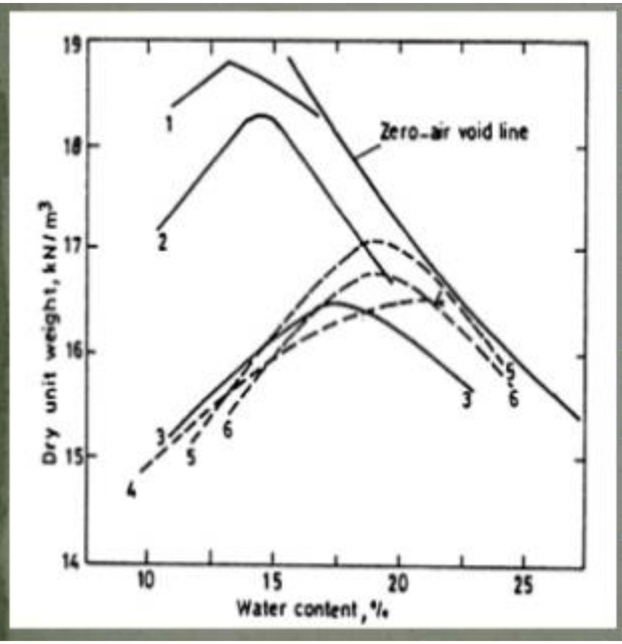
Fig. 14.6. Compaction Curves for Different Soils.

# FACTORS AFFECTING COMPACTION

- **<u>Method of Compaction</u>**

  - The dry density achieved depends not only upon the amount of compactive effort but also on the method of compaction.

  - For the same amount of compactive effort, the dry density will depend upon whether the method of compaction utilizes kneading action, dynamic action or static action.




| Compaction curve | Method |
|---|---|
| 1 | Laboratory static compaction at 13790 kPa |
| 2 | Modified AASHTO compaction |
| 3 | Standard proctor compaction |
| 4 | Laboratory static compaction at 1379kPa |
| 5 | Field compaction rubber lyred loaded ,6 passes |
| 6 | Field compaction sheep's foot rollers,6 passes |

# FACTORS AFFECTING COMPACTION

- **Admixtures**

  - The compaction characteristics of the soils are improved by adding other materials, known as admixtures.

  - The most commonly used admixtures are lime, cement and bitumen.

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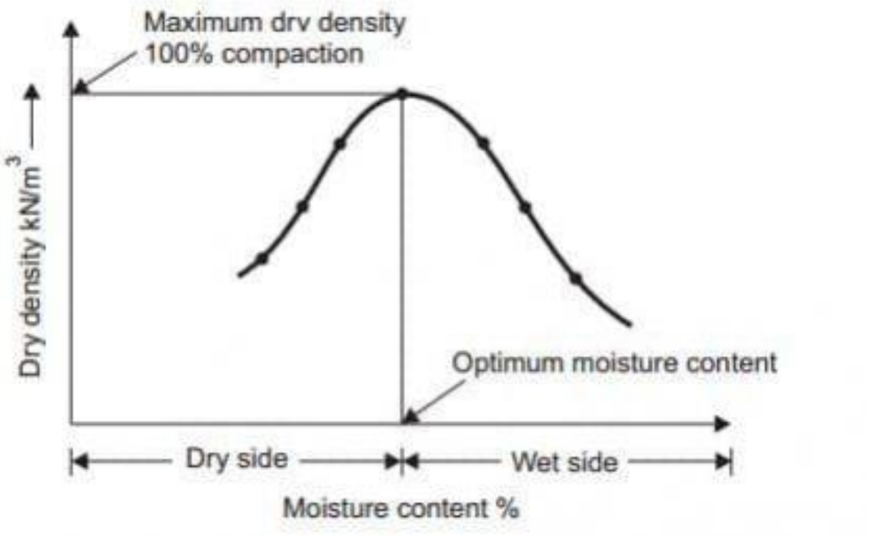
# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

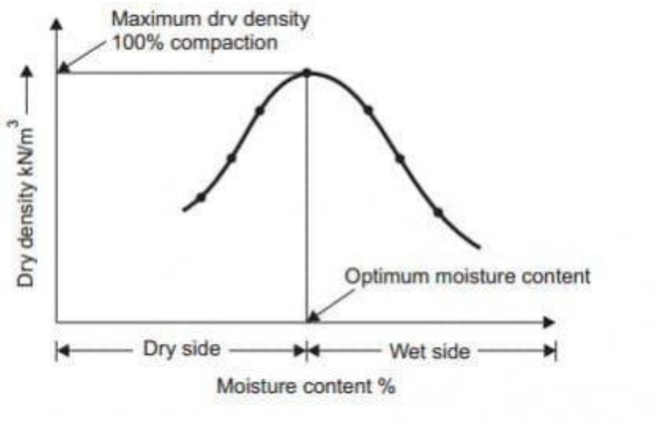
- The water content of a compacted soil is expressed with reference to the OMC. Thus, soils are said to be compacted **dry of optimum** or **wet of optimum** (i.e. on **the dry side** or **wet side** of OMC). The structure of a compacted soil is not similar on both sides even when the dry density is the same, and this difference has a strong influence on the engineering characteristics.
    - Soil Structure
    - Permeability
    - Compressibility
    - Pore Water Pressure
    - Swelling
    - Shrinkage
    - Stress-Strain Relationship

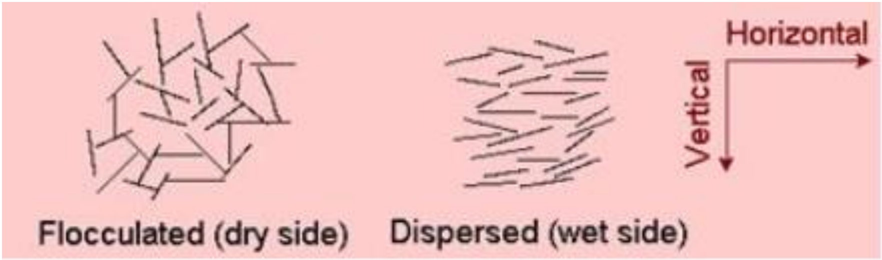



# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Soil Structure**

For a given compactive effort, soils have a flocculated structure on the dry side (i.e. soil particles are oriented randomly), whereas they have a dispersed structure on the wet side (i.e. particles are more oriented in a parallel arrangement perpendicular to the direction of applied stress). This is due to the well-developed adsorbed water layer (water film) surrounding each particle on the wet side.

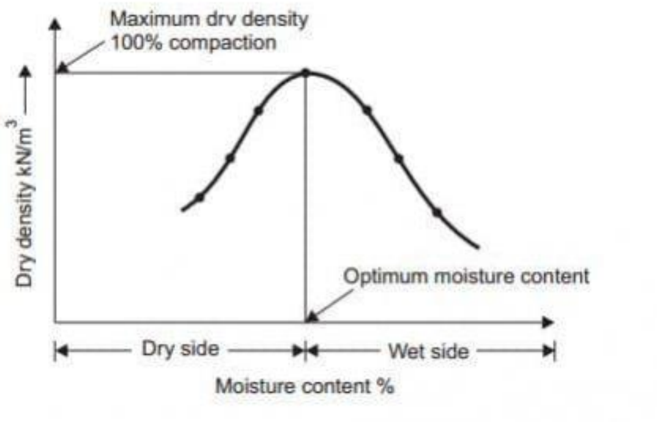


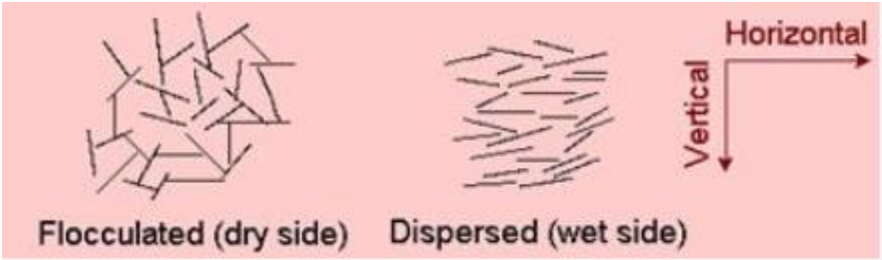



# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Permeability**

The randomly oriented soil in the dry side exhibits the same permeability in all directions, whereas the dispersed soil in the wet side is more permeable along particle orientation than across particle orientation.

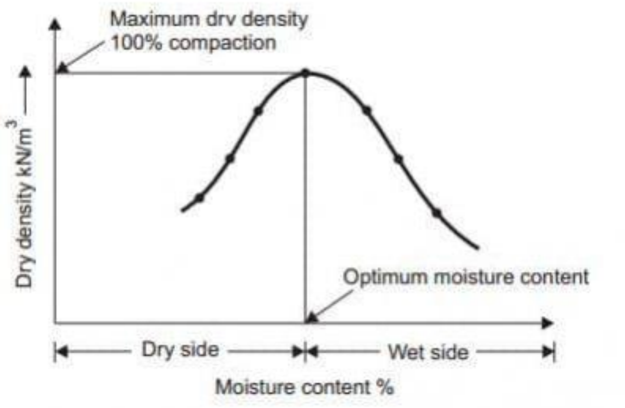


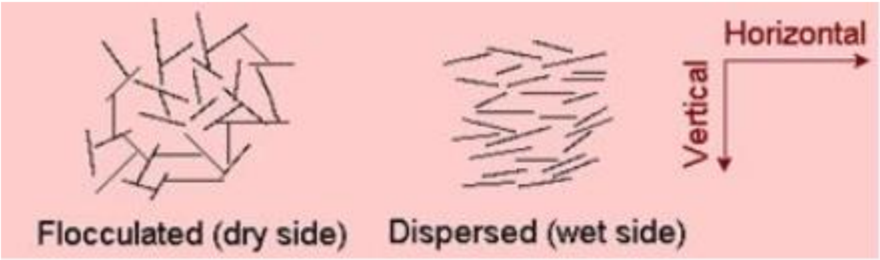



# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Compressibility**

The flocculated structure developed on the dry side of the optimum offers greater resistance to compression than the dispersed structure on the wet side. Thus, the soils on the dry side are less compressible.

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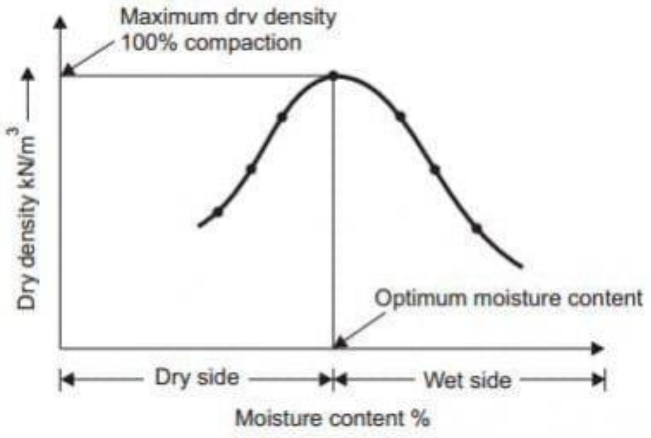
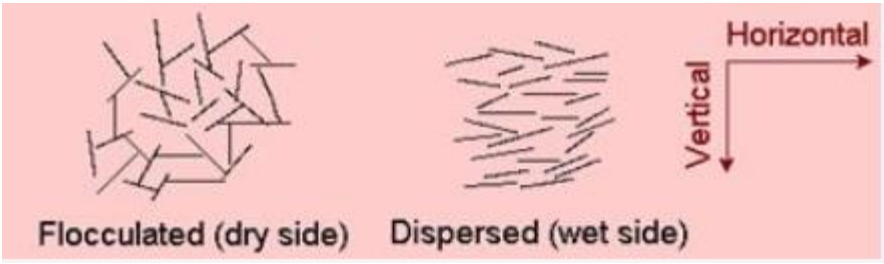
# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Pore Water Pressure**

A sample compacted dry of the optimum has low water content. The pore water pressure for the soil compacted dry of the optimum is therefore less than that for the same soil compacted wet of the optimum.

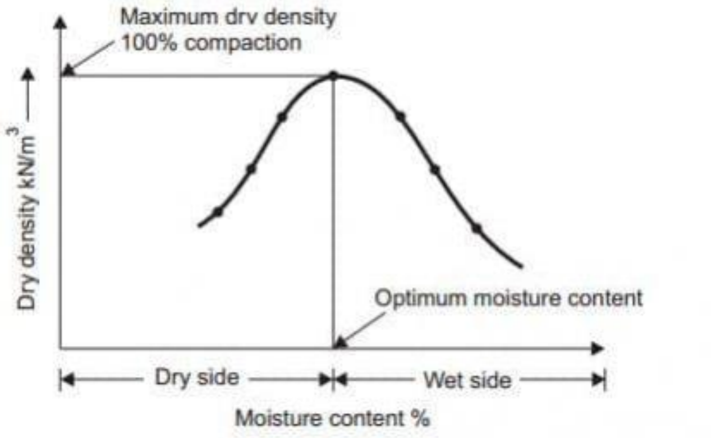


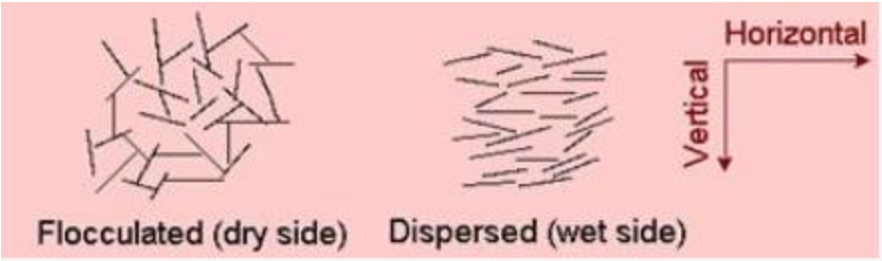



# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Swelling**

Due to a higher water deficiency and partially developed water films in the dry side, when given access to water, the soil will soak in much more water and then swell more.

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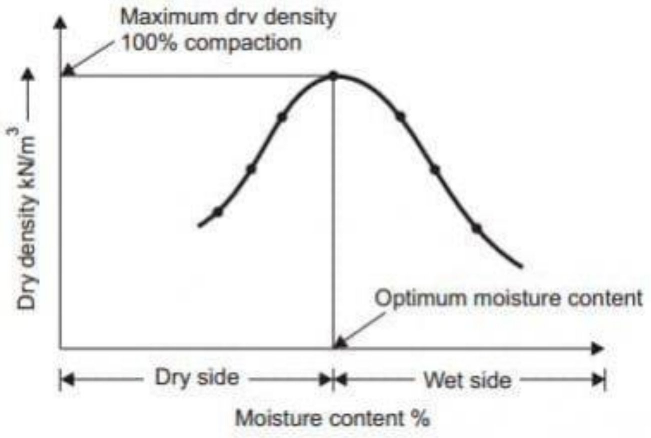
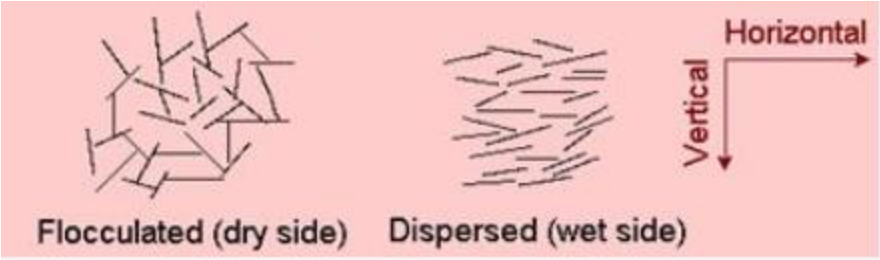
# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Shrinkage**

During drying, soils compacted in the wet side tend to show more shrinkage than those compacted in the dry side. In the wet side, the more orderly orientation of particles allows them to pack more efficiently.

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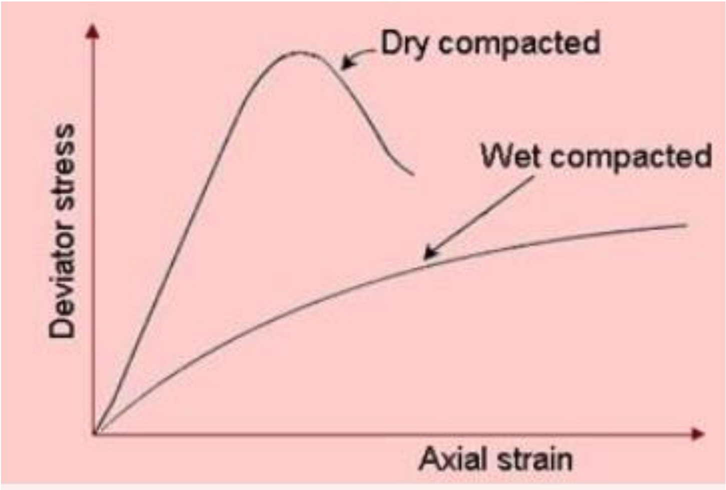
# EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

- **Stress-Strain Relationship**

The soils compacted dry of optimum have steeper stress-strain curve than those on the wet side. The modulus of elasticity for the soils compacted dry of the optimum is therefore high. Such soils have brittle failure.

The soils compacted on the wet of the optimum have relatively flatter stress-strain curve and a corresponding lower value of modulus of elasticity. The failure in this case occurs at a large strain and is of plastic type.




# METHOD OF COMPACTION

Compaction methods in field depends upon soil types, maximum dry density required and economic considerations. Commonly used compaction methods are:

- Tampers
- Rollers
  - Smooth Wheeled Rollers
  - Pneumatic tyred Rollers
  - Sheep-footed Rollers
  - Grid Rollers
- Vibrating Plates

The compaction achieved will depend on the thickness of lift (or layer), the type of roller, the no. of passes of the roller, and the intensity of pressure on the soil.

# METHOD OF COMPACTION

| Equipment | Most suitable soils | Least suitable soils |
| --- | --- | --- |
| Smooth steel drum rollers (static or vibratory) | Well-graded sand-gravel, crushed rock, asphalt | Uniform sands, silty sands, soft clays |
| Pneumatic tyred rollers | Most coarse and fine soils | Very soft clays |
| Sheepsfoot rollers | Fine grained soils, sands and gravels with > 20% fines | Uniform gravels, very coarse soils |
| Grid rollers | Weathered rock, well-graded coarse soils | Uniform materials, silty clays, clays |
| Vibrating plates | Coarse soils with 4 to 8% fines | |
| Tampers and rammers | All soil types | |

# METHOD OF COMPACTION

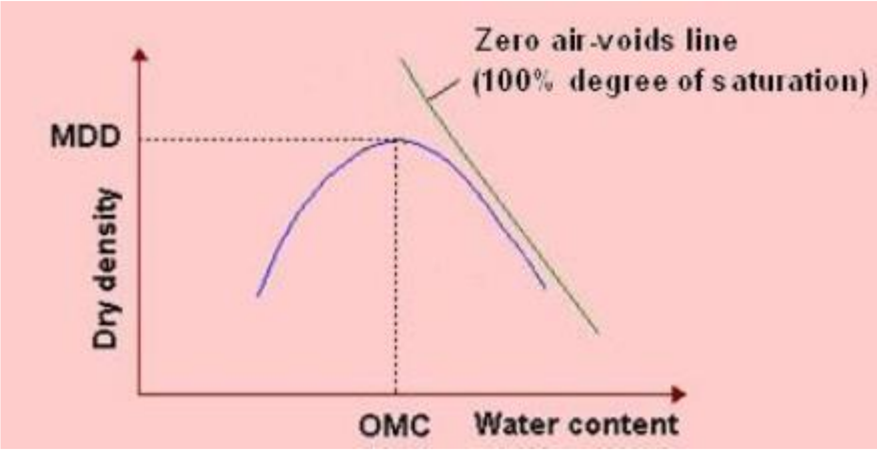

# ZERO-AIR-VOID LINE (ZAV LINE)

Dry density can be related to water content and degree of saturation (S) as

$$\gamma_d = \frac{G_s.\gamma_w}{1+e} = \frac{G_s.\gamma_w}{1+\frac{w.G_s}{S}}$$

Thus, it can be visualized that an increase of dry density means a decrease of voids ratio and a more compact soil. Similarly, dry density can be related to percentage air voids ($n_a$) as

$$\gamma_d = \frac{(1-n_a)G_s.\gamma_w}{1+wG_s}$$




The relation between moisture content and dry unit weight for a saturated soil is the **zero air-voids line.** It is not feasible to expel air completely by compaction, no matter how much compactive effort is used and in whatever manner.

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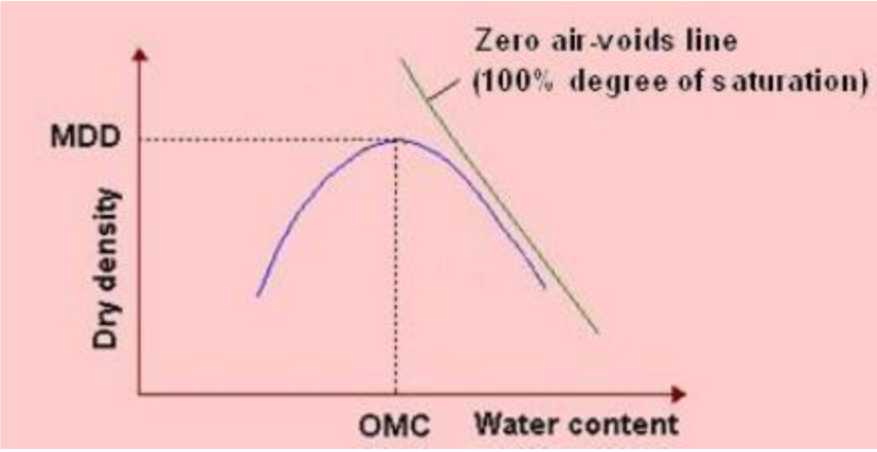
# COMPACTION CONTROL AT FIELD

- The laboratory compaction tests give the optimum water content and the maximum dry density.

- In the field, during the compaction of the soils, it is essential to check the dry density and the water content in order to effect proper quality control.

- Compaction control is done by measuring the **dry density** and the **water content** of the compacted soil in the field.




# COMPACTION CONTROL AT FIELD

- **Dry Density**
  - **Sand Replacement Method** (Suitable for cohesionless, firm, gravelly soil)
  - **Core-cutter Method** (Suitable for loose cohesive soil)

# COMPACTION CONTROL AT FIELD

- **Water Content**

- The oven-drying method of the determination of the water content takes 24 hours.
- The water content can be determined indirectly using a Proctor needle also known as plasticity needle.
- The proctor needle consists of a rod attached to a spring-loaded plunger. The stem of the plunger is marked to read the resistance in Newton.
- The needle-shank has graduations to indicate the depth of penetration.
- For cohesive soil, the needle points of larger cross-sectional areas are required and for cohesionless soil, those of smaller cross-sectional areas are used.
- After the soil has been compacted at a given water content in the compaction test in laboratory, the rod with a suitable needle point is forced into the soil mass by 7.5cm at the rate of 1.25cm/sec.
- The maximum force used to penetrate the needle is read out of the scale. This force when divided by the needle (tip) area, will give the penetration resistance.
- A number of such measurements area made in the lab during compaction test, and a calibration curve is obtained between the penetration resistance (R) and the water content.
- To determine the water content of the compacted soil in the field, the soil is compacted in the standard compaction mould in the field. The penetration resistance of the compacted soil is measured.
- The moisture content is then obtained from the calibration curve.

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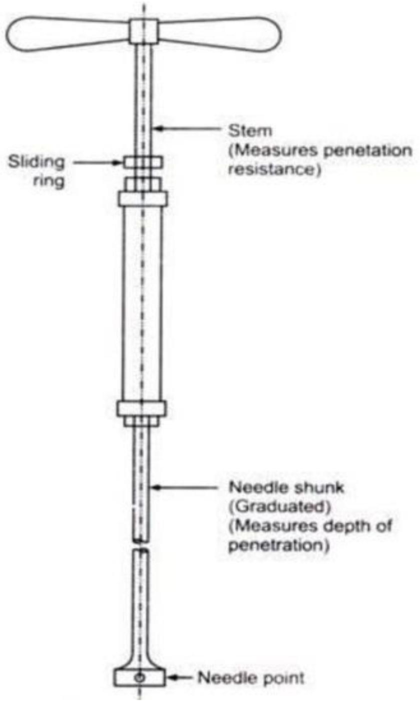
# COMPACTION CONTROL AT FIELD



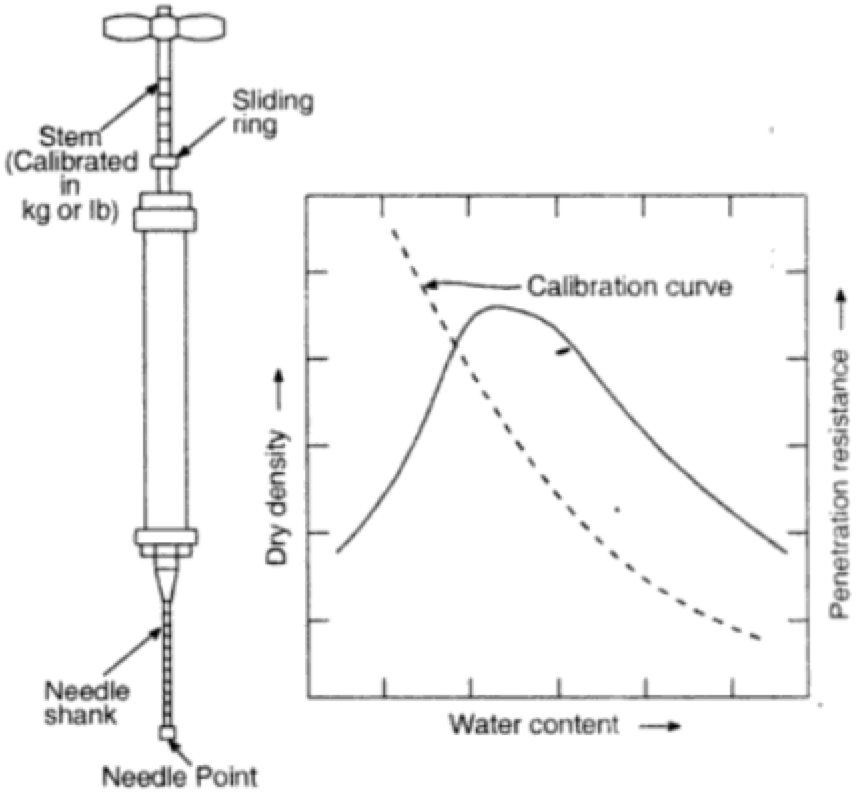




FIG. 17.6. PROCTOR NEEDLE AND CALIBRATION CURVE.

# RELATIVE COMPACTION / PERCENT COMPACTION

- The dry density achieved in the field is compared with the maximum dry density obtained in the standard proctor test or that in the modified proctor test. The ratio of the dry density in the field to maximum dry density in the laboratory is known as the relative compaction or percent compaction.
- For cohesive soils, the dry density of the order of 95% of the maximum dry density of the standard proctor test can be achieved using a sheep-foot roller or a pneumatic-tyred roller.
- For moderately cohesive soils, the dry density of the order of 95% of that in modified proctor test can be achieved using pneumatic tyred roller with an inflation pressure of 600KN/m$^2$.
- For very heavy clay, sheep-foot rollers are effective.
- For cohesionless soils, the dry density of the order of 100% or even more of that in the modified proctor test can be obtained using pneumatic-tyred rollers, vibratory rollers and other vibratory equipment.

# COMPACTION SPECIFICATION

- **End-Product Specification**

    Relative compaction or percentage compaction is specified.

- **Method Specification**
    - Type and weight of roller.
    - The number of passes.
    - Suitable for large projects only.

# COMPACTION AND CONSOLIDATION

| Compaction | Consolidation |
|---|---|
| **Volume reduces for partially saturated soil due to expulsion of air without altering water content.** | Reduction in volume of soil (saturated) by squeezing of water. |
| **It is a rapid process by mechanical means such as rolling, tamping, vibrations.** | Gradual process under sustained static loading. |
| **It is an artificial process.** | It is a natural process. |