Compaction

Compaction means pressing of soil mass close to eachother by using mechanical methods.
The air present inside the soil mass expelled out from the void space and the mass density of soil mass will increased.

Defn 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 decrease the porosity (void ratio) of the soil, and thus increase its dry density. The process may be accomplished by rolling, tamping & vibration.

Method or Type of Compaction can cause

1. Impact or dynamic – sharp blow
2. Kneading – rearranging
3. pressure – static weight
4. Vibration – shaking

Objectives :–

- To achieve the required density quickly
- To improve shear strength against erodability
- To improve expansion & shrinkage properties
- To reduce distortion under stress
- To reduce compressibility
- To reduce permeability
- To increase shear strength
- To improve bearing capacity of soil

The engineering properties of a soil are affected by compaction

- Effect on soil in general
- Effect due to variation in moisture content.

Principle of Compaction

Compaction is the densification of soil by removal of air which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles. The soil particles slip over each other and move into a densely packed position.

The dry unit wt. after compaction first increases as the moisture content increases.

At a moisture content $w = 0$ $\gamma = \gamma_d$

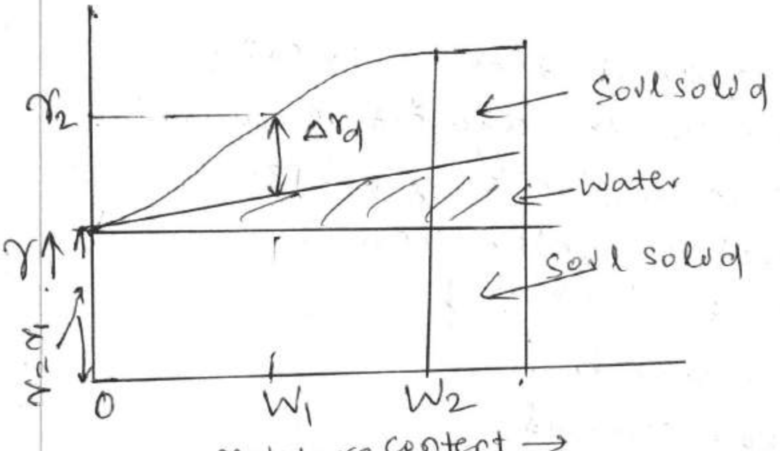
$$\gamma = \gamma_{d(w=0)} = \gamma_1$$

When the moisture content is gradually increased & the same compactive effort is used for compaction, the wt of soil solids in a unit volume gradually increases

at $w = w_1$, $\gamma = \gamma_2$

Dry unit wt. at this moisture content is given by

$$\gamma_d (w = w_1) = \gamma_d (w = 0) + \Delta\gamma_d$$



Beyond a certain moisture content $w = w_2$ any increase in moisture content tends to reduce the dry unit wt. of soil. This phenomenon occurs because the water takes up the spaces that would have been occupied by the solid particles. The moisture content at which maximum dry unit weight is attained is generally referred to as the OMC.

- The compaction of soil is required for the construction of earth dam, embankment, highway, runway etc & many engineering construction works.
- Compaction is a rapid process of reduction of volume by using roller, vibration & tamping. The volume of partially saturated soils decreases because of the expulsion of air without affecting the water content.

Compaction test :- Compaction test is two types

1. Standandard proctor test
2. Modified proctor test

- The test normally provides the relation between the water content and dry density of soil mass.
- The water content at which the dry density of soil is maximum that is called OMC (optimum moisture content) & the dry density is called MDD (Maximum dry density)

Standard proctor Test :

- The test is recommended by IS-2720 (part VII) (1965)

In 1933 R.R. proctor has suggested the compaction test.

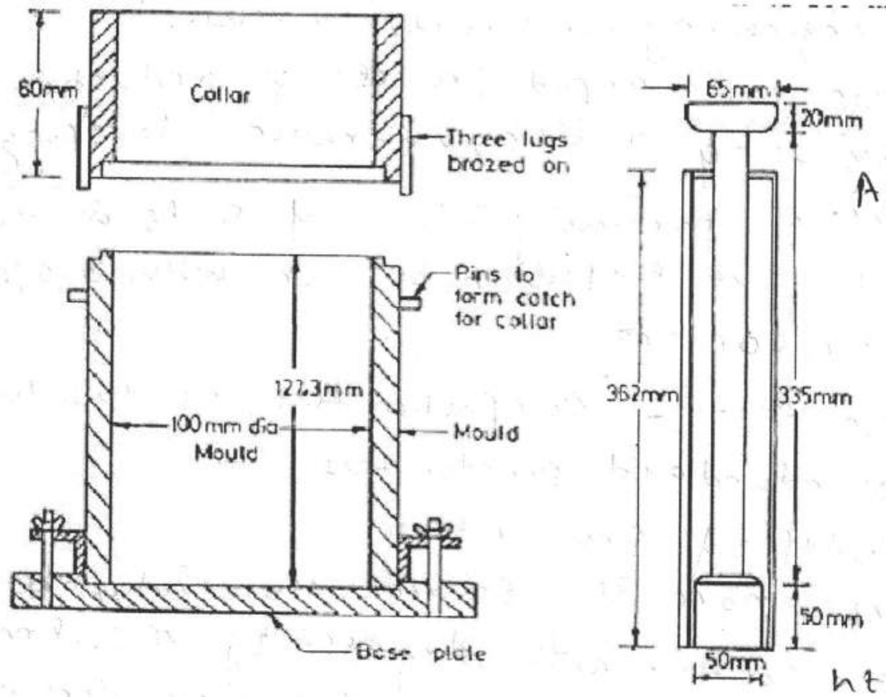
Procedure: About 3kg oven dried soil passing 4.75mm sieve mixed with small quantity of water

For maturing 5 to 30 mins (more time for clayey soil)

Initial water content for coarse grained soil 4%
Start for fine grained ,, 10%.

After that increase 2%.

1/3rd ht. of mould is filled with soil & 25 no. of blows are given. Repeat this process for 3 layers after that level soil surface. Take soil sample from the centre of the compacted specimen for water content determination. Soil is removed from mould broken with hand more water is added to soil to increase water content by 2 to 3%



Apparatus
1. Mould of Capacity 1000ml
2. Collar (ht 60mm)
3. Rammer (2.5kg)
4. Detachable base plate

ht of fall 30.5 Cm

Ranges OMC

Type of soil	O.MC
Sand	6–10%.
Sandy silt to silty sand	8–12%.
Silt	12 to 16%.
Clay	14 to 20%.

Bulk mass density $\rho = M/V$ gm/ml

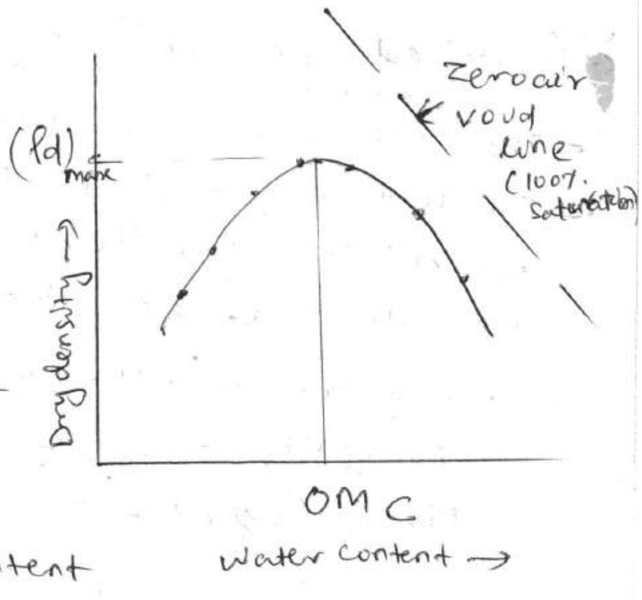
where M = mass of compacted soil

V = volume of mould

Dry density $\rho_d = \frac{\rho}{1+w}$ W = water content

Compaction curve

water content abscissa
dry density as ordinate



It is observed that the dry density initially increases with an increase in water content till the maximum dry density $(\rho_d)_{max}$ is attained.
Further increase in water content the dry density decreases
The water content corresponding to maximum dry density is known as OMC or OWC

$(\rho_d)_{theo\,max}$ / $(\rho_d)_{sat}$ - For a given water content theoretical maximum density is obtained corresponding to the conditions when there are no air voids (Degree of saturation is equal to 100%.)
In this condition the soil becomes saturated by reduction in air voids to zero but with no change in water content

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

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

A line which shows the water content dry density relation for the compacted soil containing a constant percentage air voids is known as air void line & can be given by

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

The line showing dry density as a function of water content for soil containing no air voids is called zero air void line or saturation line and is given by

$$\boxed{\rho_d = \frac{\rho_w G}{1+wG}}$$

Modified Proctor Test

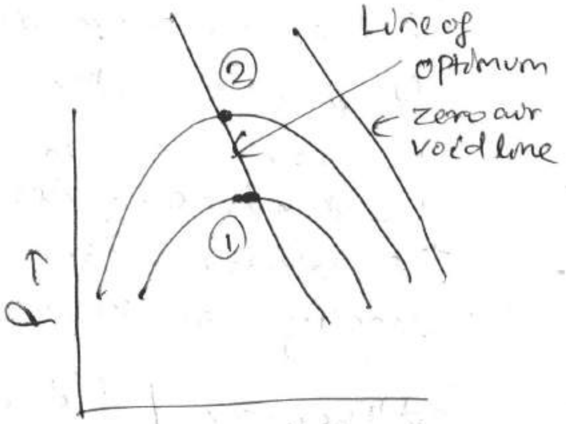
- The test was developed to represent heavier compaction
- The test is used to stimulate the field conditions where heavy rollers are used

procedure same as standard proctor test

wt. of rammer 4.89 kg free fall 450mm

No. of blows - 25

No. of layers - 5



The curve 2 is higher than to standard proctor test

the heavier compaction increases density but decreases OMC.

- The percentage increase of dry density is between 3 to 18 % for most soils
- The percentage increase is more for clayey soil & than for sandy soil.

Maximum dry density attained in the modified proctor test is lower than theoretical max^m dry density by the zero air void line

The line of optimum joins the points indicating max^m dry density. It is roughly ||le to zero air void line

Factors affecting compaction :-

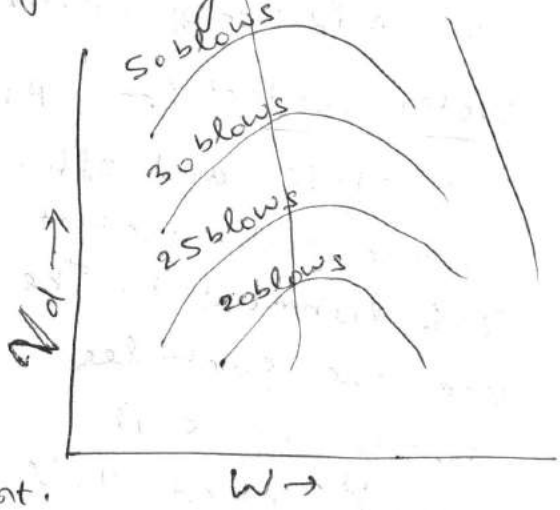
(i) water content.
(ii) Amount & type of compaction
(iii) Method of compaction
(iv) Type of soil
(v) Addition of admixtures.

Water content :- At low water content the soil is stiff and offers more resistance to compaction. As the water content is increased the soil particles gets lubricated. The soil mass becomes more workable and the particles have closer packing. The dry density of soil is increased with an increase in water content till OMC is reached. At this stage the air voids attain approximately at constant volume. with further increase in water content the air voids donot decrease but the total voids increase and dry density decrease.

Thus higher density is achieved upto OMC due to forcing air out from the soil voids.
After OMC is reached & it becomes more difficult to force air out & to further reduce the air voids. This phenomena is more or less is based on the diffuse double layer theory

Amount of compaction :- The effect of increasing the amount of compactive effort is to increase the maximum dry density and to decrease OMC. At water content less than OMC (optimum) the effect of increased compaction is more predominant. At a water content more than optimum the volume of air voids becomes almost constant and the effect of increased compaction is not significant.

The maximum dry density doesnot go on increasing with an increase in the compactive effort. For a certain increase in the compactive effort, the increase in the dry density becomes smaller and smaller. Finally a stage is reached beyond which there is no further increase in dry density with an increase in the compactive effort



- As the compaction effort is increased the maxm dry density is also increased
- As the compaction effort is increased the OMC is decreased to some extent.

This is true for all soils.

The degree of compaction is not directly proportional to the compaction effort

Compaction energy per unit volume used for standard proctor test

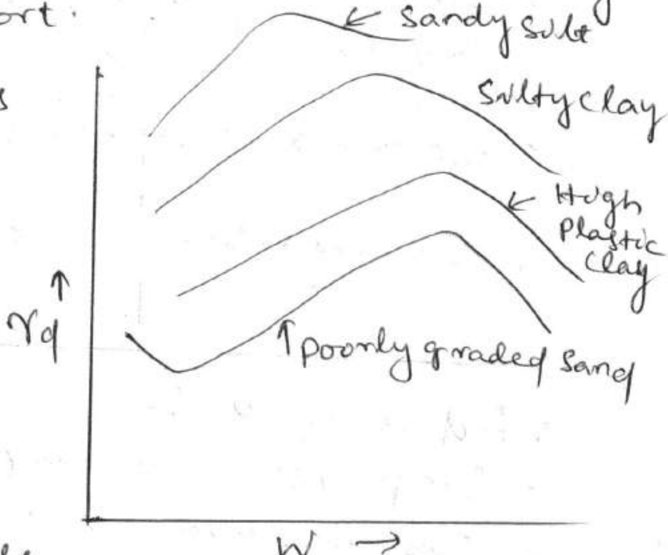
$$E = \frac{\left(\begin{matrix}\text{No. of blows}\\ \text{Per layer}\end{matrix}\right) \times \left(\begin{matrix}\text{No of}\\ \text{layers}\end{matrix}\right) \begin{matrix}\text{Wt. of}\\ \text{Rammer}\end{matrix} \times \begin{matrix}\text{Ht. of}\\ \text{drop of}\\ \text{Rammer}\end{matrix}}{\text{volume of mould}}$$

$$E = \frac{25 \times 3 \times 2.5 \times 9.81 \times 0.305}{1000}$$

$$= 594 \ kNm/m^3$$

Type of soil :-

- The dry density achieved depends upon the type of soil.
- The coarse grained soils can be compacted to higher dry density than fine grained soils. With addition of even a small amount of fines to a coarse grained soil the soil attains a much higher dry density for same compactive effort.



- A well graded sand attains higher dry density than poorly graded sand.

Cohesive soils have high air voids. These soils have lower max^m dry density as compared to cohesionless soils. Such soils require more water & OMC is high.

- Heavy clays of high plasticity have very low dry density & very high OMC

Method of compaction : The dry density achieved depends on the method of compaction.
Table shows the suitability criteria of various methods of compaction

Type of soil	Mode of Compaction
Cohesive soil	Sheep foot Roller, Precompression
Cohesionless soils	Smooth wheel Rollers Vibratory Rollers, Blasting Explosives Vibroflotation
Both cohesive and cohesionless soils	Tampers, pneumatic tyred Rollers

Type of Equipment	Suitability of soil type	Nature of project
Rammers or Tampers	All soils	In confined areas such as fills behind retaining wall, basement wall etc. Trench fill
Smooth wheeled Rollers	Crushed Rocks Gravel & Sand	Road Construction
Pneumatic tyred Roller	Sands, gravel silt, Clayey soil	Base, Sub base & Embankment Compaction for highways airfield, Earth dam
Sheep foot Rollers	Clayey soil	Core of earth dams
Vibratory Rollers	Sands	Embankments for oil storage tanks etc

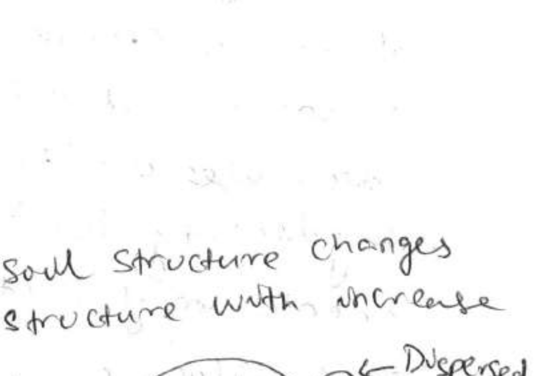
(v) Admixtures :-

- Improves the compaction characteristics of the soil
- The maximum dry density achieved depends upon the type & amount of admixtures
- Commonly used admixtures are lime, cement, & bitumen.

Effect of compaction on properties of soils:-

a. Soil structure
b. permeability
c. Swelling
d. Shrinkage
e. pore water pressure
f. compressibility
g. stress strain relationship
h. shear strength of soil

a. Soil structure:- In general soil structure changes from flocculated to dispersed structure with increase in compacted water content.



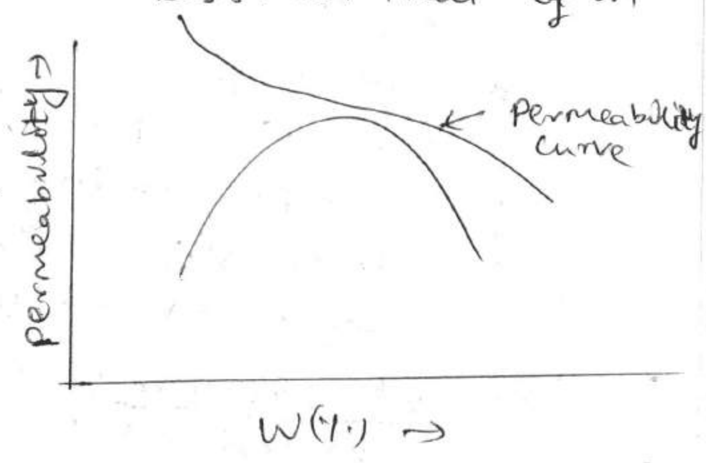
- soils compacted at a water content less than OMC generally have flocculated structure. Soils compacted at a water content more than OMC usually have dispersed structure.

If a point A on the dry side of the optimum the water content is so low that the attractive forces are more predominant than repulsive forces. This results in flocculated structure. As the water content is increased beyon the optimum the repulsive forces increase and the particles get oriented into a dispersed structure. If the compactive effort is increased there is corresponding increase in the orientation of particles. and higher dry densities are obtained as shown by upper curve

(b) permeability: The permeability of a soil depends upon the size of voids. The permeability of soil decreases with an increase in water content on the dry side of OMC. Because of improved orientation of the particles and a corresponding reduction in the

size of voids which cause decrease in permeability.
- The minimum permeability occurs at or slightly above OMC.
- After that stage the permeability slightly increases but it always remains much less than that ~~of~~ on the dry side of optimum.

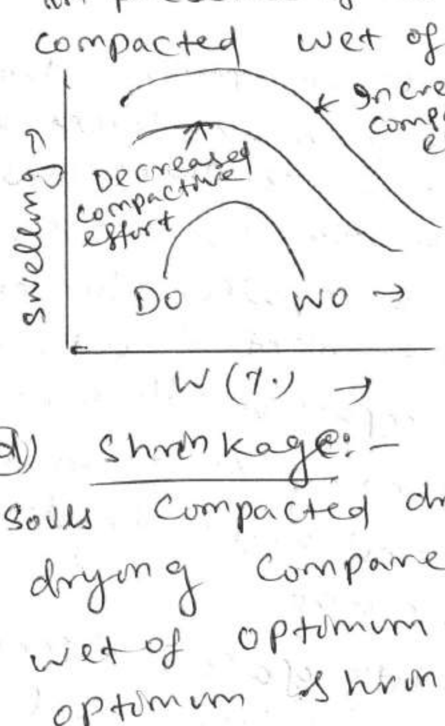
If the compactive effort is increased the permeability decreases due to increased dry density & better orientation of particles.

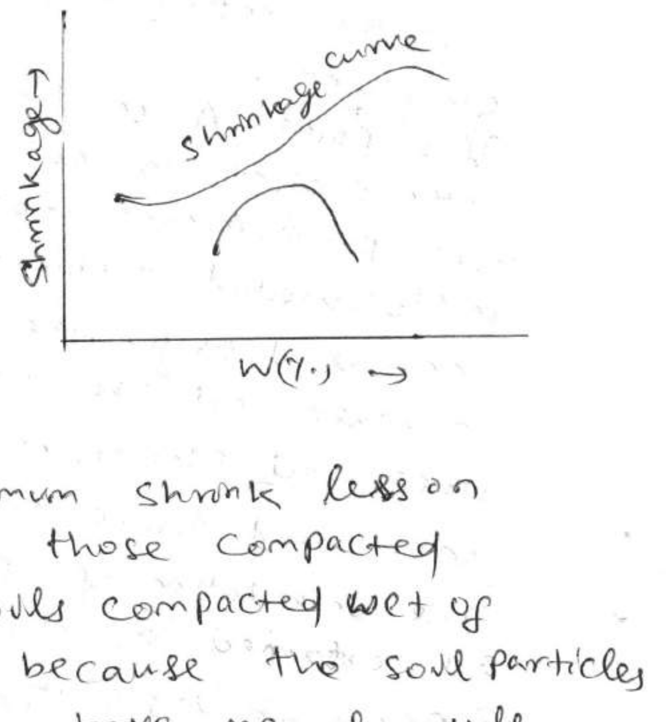


(c) Swelling :-

A soil compacted dry of optimum, water content has high water deficiency and more random orientation of particles

Soil compacted dry of optimum shows more swelling in presence of excess moisture as compared to soil compacted wet of optimum.





(d) Shrinkage:-

Soils compacted dry of optimum shrink less on drying compared with those compacted wet of optimum. The soils compacted wet of optimum shrink more because the soil particles in the dispersed structure have nearly ll le orientation of particles and can pack more efficiently

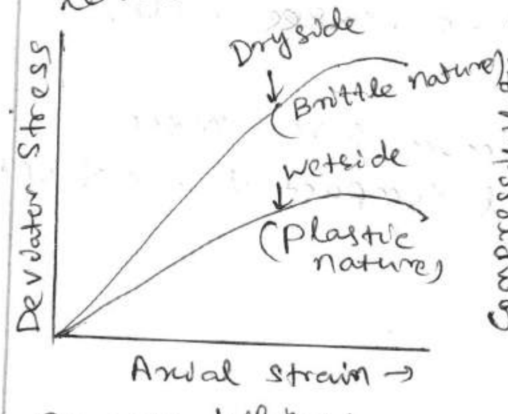
Pore water pressure:- A sample compacted dry of optimum has low water content. The pore water pressure developed for the soil compacted dry of optimum is less than that for the same soil compacted wet of optimum.

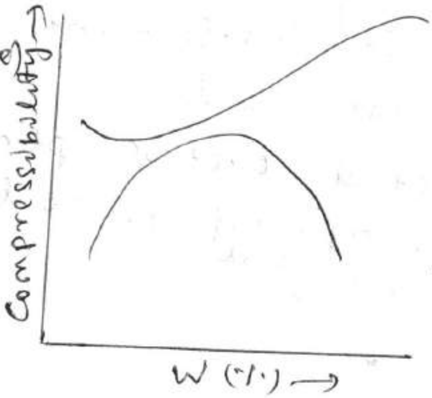
Compressibility :

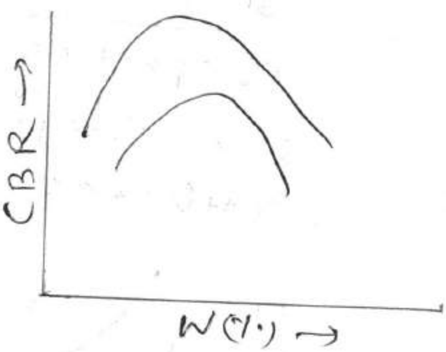
- Compressibility of soil is minimized on compaction. Soil compacted dry of optimum are less compressible compared to these compacted wet of optimum.
- It increases with an increase in degree of saturation.

Stress strain relationship

- The soil is compacted dry of optimum have a steeper stress strain curve with peaks at low strains than those on the wetside.
The modulus of elasticity for the soils compacted dry of optimum is high. Such soils have brittle failure like dense sands or over consolidated clay.
- The soil compacted wet of optimum have relatively flatter stress strain curve and lower modulus of elasticity.







Permeability:-

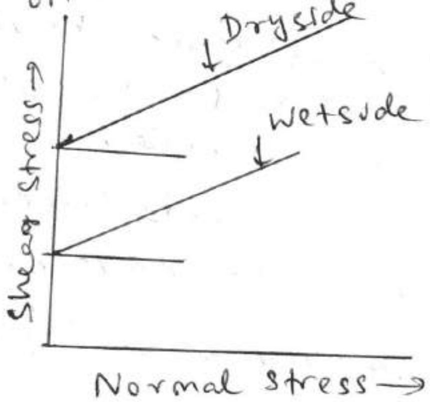
In case of fine grained soils for the same dry density soil compacted wet of optimum will be less permeable than that compacted dry of optimum.

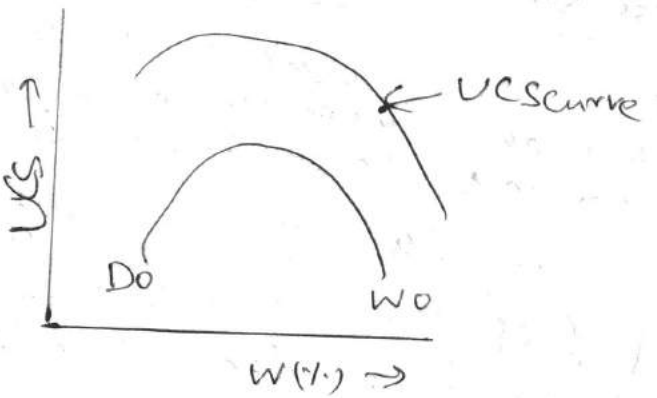
Unconfined compressive Strength :-

- At a given water content shear strength of soil increases with an increase in compactive effort till a critical degree of saturation is reached. After that shear strength decreases

- For same compactive effort the variation of UCS with placement moisture content is similar to (Similar) MDD variation.

- The soil compacted dry of optimum have higher shear strength at low strains (flocculate structure) on the wet side the shear strength is reduced. (Disperse St.)

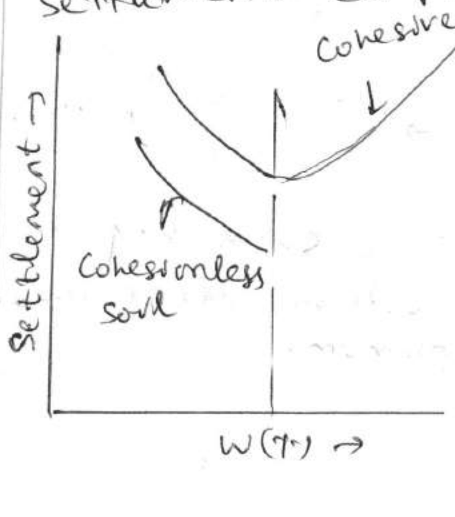




CBR :- CBR value attains its maximum on the dry side of optimum. Thereafter it decreases with the increasing moisture content.

Settlement :- Settlement decreases after compacting the soil.

Soil compacted wet of optimum gives more settlement compared to soil compacted dry of optimum.



Relative compaction :- or Percent compaction

The ratio of the dry density in the field to the maximum dry density as per specified standard is known as Relative compaction

$$\text{Relative compaction} = \frac{\rho_d \text{ in the field}}{(\rho_d)_{max} \text{ in the laboratory}} \times 100$$

- For cohesive soils the dry density of the order of 95% of the maxm dry density of the standard proctor test. Can be achieved using a sheep foot roller or pneumatic tyred roller
- For cohesionless soils the dry density of the order of 100% or more of thod modified proctor test can be achieved by using pneumatic tyred roller or vibratory roller

Field Compaction methods :-

3 methods of compaction - rolling
- ramming
- Vibration

3 categories of compaction equipment namely rollers, rammers and vibrators

Rollers are 3 type.

a. smooth wheel rollers
b. sheep foot rollers
c. pneumatic tyred rollers

Smooth wheel rollers are 3 types

1. Conventional 3 wheel type with two large smooth faced steel wheels in the rear and one smaller smooth faced drum in the front weighing 20 to 150kN
2. tanden rollers weighing 10 to 140 kN
3. three axle tandem rollers weighing 120 to 180 kN

Smooth wheel rollers of the self propelled type are equipped with a clutch type reversing gear so that they can be operated back & forth without turning

Sheep foot rollers - It consists of hollow cylindrical steel drum on which a series of projecting feet are mounted. The wt. of the drum can be varied by filling it partly or fully with water, or sand.

The loaded wt per drum ranges from about 15 to 130 kN

foot pressure range from about 800 to 3500 kN/m^2

Pneumatic tyred Rollers :- smaller wobble wheel rollers to heavy rollers

- The tyre pr. in small rollers are 250 kN/m^2 & tyre load are about 7.5 kN per tyre.
- In case of heavy rollers tyre pr. ranges from 400 to 1050 kN/m^2 & tyre load vary from 100 kN to 500 kN per tyre

Rammers :-

The mechanically operated type comprise of pneumatic and internal combustion type weighing from 300 to 1500 N.

Internal Combustion type jumping rammers known as frog rammers weigh up to 10 kN.

Types of field Compaction Equipment :-

1. Smooth wheeled Steel Drum Rollers
2. Pneumatic Tyred Rollers
3. Sheepfoot Rollers
4. Impact rollers
5. Vibrating Rollers
6. Hand operated Vibrating plate& rammer compactors

Smooth wheeled steel drum rollers:-

1. Capacity 20kN to 200 kN
2. Self propelled or towed
3. Suitable for well graded sand, gravel, silt of lowplasticity
4. Unsuitable for uniform sand, silt 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 400kN
3. Suitable for most coarse & fine soils.
4. Unsuitable for very soft clay and highly variable soil.

Sheepfoot 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.

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 smoothen 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 & to estimate the correlation between laboratory & 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 grand is compacted in the field. It is desirable to compact at or close to OMC achieved in laboratory so as to increase the efficiency of compaction.

Comparison between field and Laboratory compaction method :

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 in 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.

Distinction between Standard & Modified Compaction :

	Standard Proctor Test	Modified Proctor Test
1.	305mm ht. of drop	450 mm height of drop
2.	25 N hammer	45 N hammer
3.	25 no. of blows per layer	25 blows / layer
4.	3 layer	5 layers
5.	Mould size 945ml	Mould size 945ml
130 6.	Energy 605160 N-mm per m^3	Energy 2726000 N-mm per m3

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

8. At low water content, grains are held together by suction.

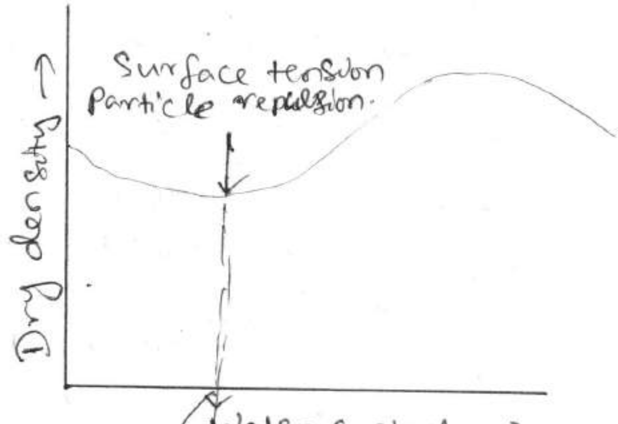
9. This prevents compaction

10. Laboratory tests for MDD on sand requires fully saturated sample & involves vibration.

In the case of pure sand without fines, there is no well defined OMC & the curve is shown.

For the above soils the compaction curve is not useful.

Relative density is used to indicate the level of compaction achieved.



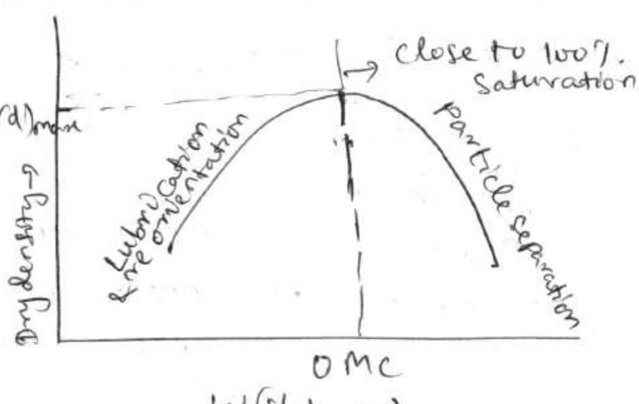
Bulking of Sand

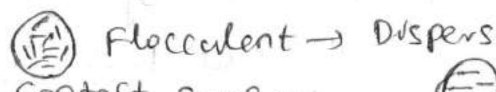
Dry of Optimum	Wet of optimum
- flocculent structure	- dispersed structure
- more shear strength	less shearing strength
- more swelling type	- less swelling type

* To avoid swelling of soil (below the floors, pavement, core of earthen dam) soil is compacted wet of optimum.
* To have more strength (road embankments & casing of earthen dams) the soil is compacted dry of optimum.

Mechanism of Compaction :-

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 upto one stage (dry side). water acts as lubrication. Byond this level any further increase in water (wet side) will only add more void space, there by reducing dry density. Hence OMC indicates the boundary between dry side & wet side. Hence the compaction curve indicates initial upward trend upto OMC & downard 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 air further increase increase in water content results in reduced dry density
5. MDD & OMC depend on the compaction energy & are not unique soil properties.
6. For sand suction at low water contents also prevents compaction.