UNIT-I

* **Soil :** It is defined as an unconsolidated material, composed of Solid particles, produced by disintegration of rocks and decomposition of organic matter.

* **Soil Mechanics:** It is a branch of Mechanics which deals with the action of forces on Soil and with the flow of water in Soil. The term 'Soil Mechanics' was coined by late Dr. Karl Terzaghi, who is recognized as the father of soil Mechanics.

* **Foundation Engineering or Soil Engineering:**
It is an applied science dealing with the application of principles of Soil Mechanics to practical problems. It includes site investigation, design and Construction of foundations, earth retaining structures and earth structures.

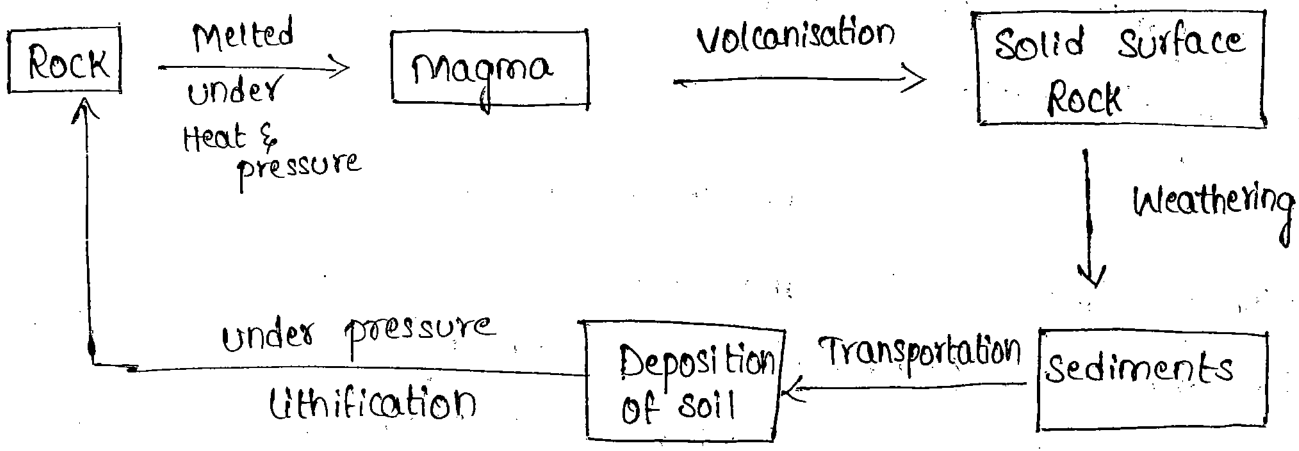
* **Geotechnical Engineering:**
It is a broader term which includes Soil mechanics, foundation engineering, rock mechanics and geology.

* **Origin of Soils:**
Soils are formed by weathering of rocks and decomposition of organic matter. Therefore, Soils may be organic or inorganic.

→ organic Soils are Called 'Cumulose soils'.
→ Examples for organic Soils are peat, Humus, muck etc.
→ All the Solids are derived from disintegration of Rocks. The process of Soil formation is called pedogonesis and it is cyclic process.

The cycle of Soil formation consist of following

Geological cycle :



Types of Weathering :

(a) physical

(b) Chemical

(a) physical weathering :

→ It is due to physical effects like temperature, abrasion, wedging action of ice, penetration of plant roots etc.

→ physical weathering results in no change in chemical composition of particles.

→ It produces coarse grained and non cohesive soils.

Examples : Gravel, Sands

(b) Chemical Weathering :

→ It is due to chemical actions (oxidation, hydration, carbonation, leaching, hydrolysis etc)

→ original rock minerals are transformed into clay minerals, due to chemical weathering.

→ It results in fine grained and cohesive soils.

Ex :- clay

* The important minerals found in Rocks are

1) Feldspar
2) Quartz
3) Ferro magnesium Minerals
4) Iron oxides
5) Calcite
6) Dolomite
7) mica
8) Gypsum

Type of Rocks :

(i) Igneous Rocks (primary Rocks)

These are formed due to solidification of magma (volcanic eruption)

Ex: Granite, Basalt, Diorite, Andesite, Gabbro, Rhyolite.

(ii) Sedimentary Rocks (secondary Rocks)

When igneous Rocks are weathered by physical, chemical (or) Biological means then the particles are pragmented (or) hardened through the process of Lithification.

Ex: Sandstone, clay stone (shale), lime stone, conglomerate, Dolomite and chalk.

(iii) Metamorphic Rocks (Tertiary Rocks)

Igneous Rocks and Sedimentary Rocks may be Subjected to intense treat and pressure inside the earth interior Such condition cause change in mineral composition of rocks. Such Rocks are Called Metamorphic Rocks.

→ This process increases the Strength and hardness of the Rock.

Ex: Marble (derived from limestone)

Quartzite (derived from Sand stone)

Gneisses (derived from Granite)

Schist (derived from mica)

Slate (derived from claystone)

Type of Soils :

The fragmented Rock particles which may be resulted by physical, chemical, biological weathering is called sediment.

If Sediments remain over parent Rock Such soil deposit is Called Residual Soil.

→ If Sediments are transported and deposited at some other place then Such Soil is Called transported soil.

→ Transporting agency may be water, wind, glacier (or) Gravity force.

1) Alluvial soil (Fluvial soil)

→ Large part of north India is Concerned with alluvial deposits.

→ These deposits have alternating layers of Sand, silt and clay.

→ These are found along River banks and in River planes.

→ These have poorely graded (uniformly graded) Sediments deposit.

→ These have high productivity and fertility but these have lower bearing Capacity and more compressibility.

Finer Soils – Size of voids less – High Compressibility – more no. of Voids

Coarser Soils – Size of voids more – low Compressibility – less no. of void

2) Lacustrine Soils :

→ These are deposited in the bed of lakes and Reservoirs by still water.

→ These are either silty (or) clay. Such soils have flocculated structure.

Flocculated Structure – High volume of voids.

3) Marine soils :

→ These are confined along a narrow belt near the coast.

→ These are Sands, clays and silts deposited on sea bed by sea water.

→ These are also compressible and have low shear strength.

→ Such soils also have flocculated Structure and high salt content.

4) Black Cotton Soils :

→ These are expansive soils or (clays of high plasticity) present in large part of Central India and a portion of South India.

→ formed due to Chemical weathering.

→ parent rock is basalt or trap.

→ Exhibits large swelling and shrinkage due to presence of montmorillonite mineral.

5) Desert Soils :

These are wind blown deposits of Sand.

→ Sand dunes are desert Soils.

Boulder deposits:

→ These are large quantities of boulders deposited by rivers flowing in highly terrain near the foot of hills.

Important field names of Soils:

Loam: It is a mixture of sand, silt and clay. Approximately in equal proportions.

Varved clay: It contains alternate thin layers of clay and silt. It is generally a lacustrine deposit.

Loess:

It is a loose deposit of wind-blown deposit (Aeolian soil)

. It has silt sized particles.

> It is weakly cemented by calcium carbonate.

> It is formed in arid and semiarid regions in nearly vertical banks.

Bentonite:

→ It is chemically weathered volcanic ash.

→ It is highly water absorbent and has high shrinkage and swelling.

→ Contains high percentage of clay mineral, montmorillonite.

Marl:

It is a stiff marine calcareous clay of greenish colour.

Caliche:

A soil which contains gravel, sand and silt and the particles are cemented by calcium carbonate.

* Dune Sand :

It is a wind transported soil, containing relatively uniform Size of particles of fine to medium sands.

* Fill :

It is a man made deposit of soil.

* Moorum :

It consists of small pieces of disintegrated rock.

* Drift :

It refers to soil deposit made by glaciers directly or indirectly.

* Till :

It is an unstratified deposit formed by melting of a glacier.

→ It consists of particles of different sizes ranging from boulders to clay. It is also called boulder - clay.

* Talus :

It is a Colluvial deposit of broken rock pieces. It is generally found at the foot of cliffs or steep slopes.

* peat :

It is a highly organic soil, fibrous nature and entirely of vegetative matter in varying states of decomposition.

→ It posses an organic odour.

→ Brown to black in colour.

* Humus :

→ It is an organic amorphous earth of top soil, consisting partly decomposed vegetative matter.

→ It is dark brown.

Muck: It is a mixture of ... and black decomposed organic matter.

It is usually found in conditions of imperfect drainage as in Swamps.

peat and Muck are called cumulose soils.

Source of transportation/ Deposition	Type of Soil
River	Alluvial soils
Lakes	Lacustrine Soils
Sea	Marine Soils
Wind	Aeolian Soils Ex: Sand dunes, loess
Gravitation	Colluvial soils Ex: Talus
Glacier	Glacier deposited soils Ex: Drift, till, outwash

* Soil Structure:-

→ The arrangement of soil particles in a soil mass depends upon the force responsible for formation.

→ the behaviour of soil depends on the soil structure.

* Important types of structures:- Depending upon the particle size and mode of formation the following are important types:

> Single grained
> Flocculated
> Composite structure
> Honey-comb
> Dispersed

* Single grained (or) coarse Grained structure:-

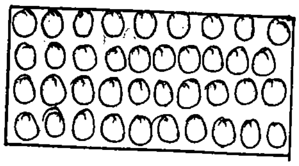
→ It is also called coarse Grained structure.

→ This structure is found mainly in coarse Grained soils having particle size > 0.02mm

Ex:- Sands and Gravels

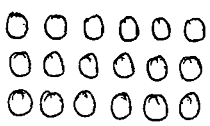
→ In the formation of these soils Gravity force place dominant role where as surface Electric forces are negligible.

Ex:-

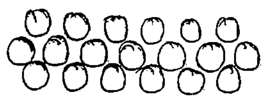


→ Formed by Gravity force
→ particles are in contact with each other.

→ If particles are assumed as spheres, the loosest and densest packaging are shown in the figures.



Loosest packing [cubical array]



Densest packing [Rhombohedral]

→ the void ratio for the loosest state is 0.91, and the void ratio for the densest state is 0.35 when the particles are assumed as perfect spheres.

* Honey combed structure :-

→ It is found in the soils having particle size is in the range of 0.02mm to 0.0002mm

→ In this case Gravity force and surface Electric force both play the role in formation.

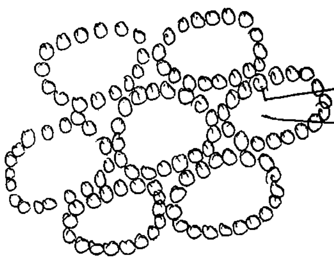
→ These soils May Enclose large volume of voids.

→ the structure of soil is similar to Honey net.

→ when the structure is unbroking, such soils have good bearing capacity and Strength

→ But once the structure is Broken the strength reduces and soils undergo change in volume.

→ This type of structure present in finesands or silts



→ under vibrations and shocks, the structure collapses and large deformation takes place.

* Flocculant and dispersed structures:-

→ these are found in soils having particle size smaller than 0.0002 MM.

→ the fine particles are flaky which are Electrically charged.

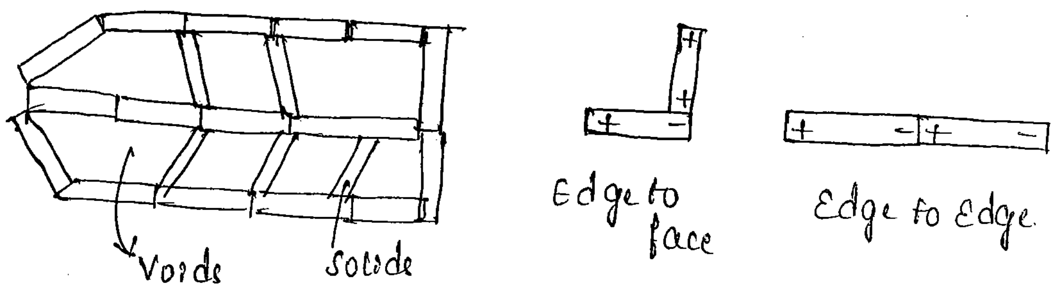
→ Note that coarse particles are rounded (or) subrounded which donot carry surface Electrical forces.

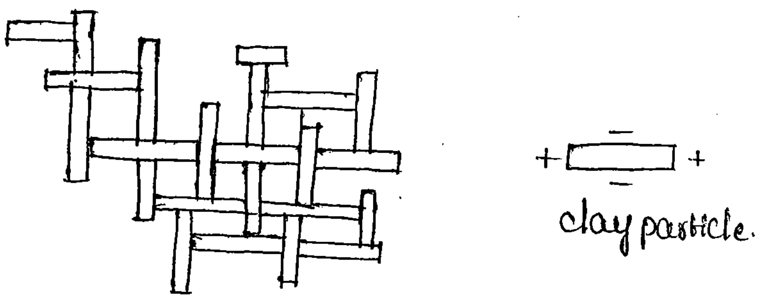
→ Flocculant and dispersed structures are formed due to surface. Electrical forces and Gravitational forces are negligible.

a) Flocculant Structure :-

→ Flocculant structures are formed by attractive forces.

→ these structures Enclose large volume of voids. Molecules are arranged Either Edge to Edge (or) Edge to face.





→ the soil having flocculant structure, high permeability. But shear strength is higher than dispersed structure and compressibility is lower than disperse structure.

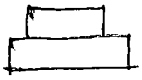
→ It has high shear strength, low compressibility, high permeability.

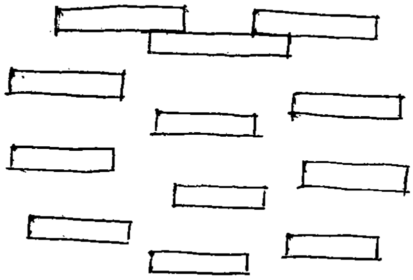
Ex:- Marine clay

Note:- With increase in concentration of dissolved Minerals water has tendency to convert soil into flocculant structure due to surface Electric forces.

b) Dispersed Structure:-

→ Such soils are formed due to repulsive forces in which particles are arranged face to face.


Face to face.



Ex:- Lacustrine clay.

Note:-

→ A flocculant structure on remoulding may convert into dispersed structure

→ It has low shear strength, high compressibility and low permeability.

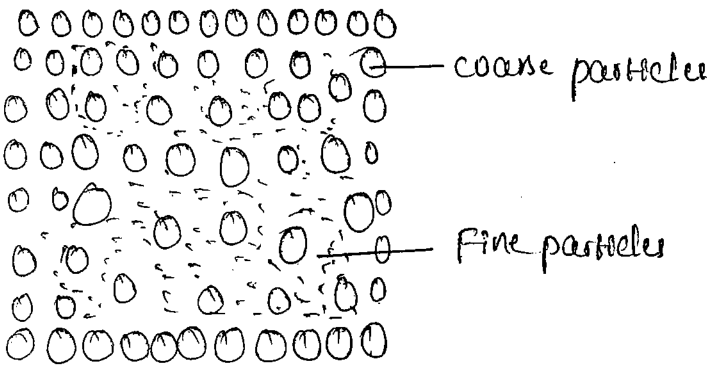
* Structure of composite soil:-

→ when soil contains different type of particles, a 'composite structure' is formed

→ usually composite soil is well graded (or) Gap Graded.

> Coarse Grained Skeleton:- In such soil mass coarse particles are in contact with each other and voids b/w them are filled by fined particles.

- such soils have high bearing capacity and shear strength is high and low compressibility.



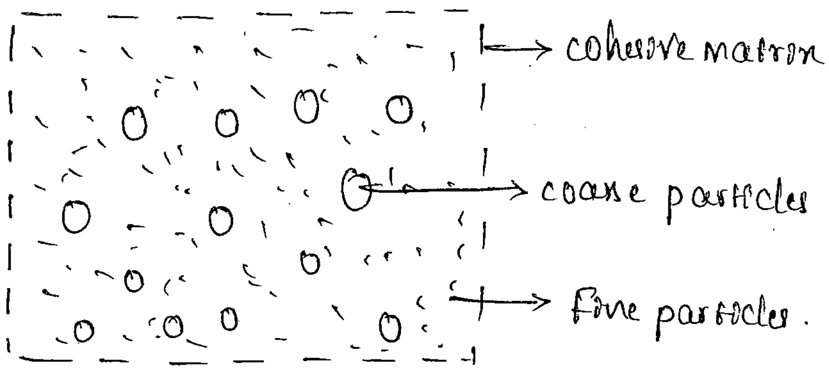
- coarse particles are contact with each other.

> cohesive Matrix:-

→ In this structure proportion of fine grained soils is more.

→ Some coarse grained particles are present which do not touch Each other

→ Such soils are relatively more compressive than single grained skeltons



* Remoulding:-

→ Remoulding causes a loss of shear strength in cohesive soils.

* Thixotrophy:-

→ the phenomenon of regaining of lost strength with the passage of time, with no change in water content, is known as 'thixotrophy'

→ Bentonite clay Exhibits thixotrophy property.

clay Minerals:-

→ the clay Minerals are hydrous aluminium Silicate with other Metallic ions in a sheet like structure.

→ Their particles are Very small in size, Very flaky in shape and they have considerable surface area.

→ These clay Minerals are Evolved Mainly from the chemical Weathering of certain rock Minerals.

* Structure of Clay Minerals:-

→ clay Minerals are composed of two basic structural units.

(i) Tetrahedral unit (ii) Octahedral unit.

(i) Tetrahedral unit:-

→ the tetrahedral unit comprises of a central silicon atom surrounded by four oxygen atoms positioned at the vertices of the tetrahedron.

→ the tetrahedral units are combined with Each other such that Each oxygen atom at the base of tetrahedron lies in same plane and is being shared Between two tetrahedron units.

→ this combination of tetrahedral units is called Silica sheet.

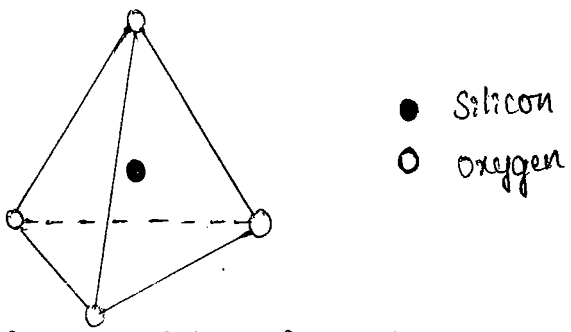


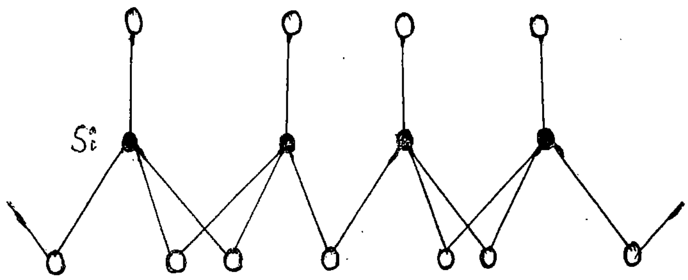
Fig a) SINGLE TETRAHEDRAL UNIT

$4\times(-2)=-8$

$4\times(+4)=+16$

$6\times(-2)=-12$

Net $=-4$



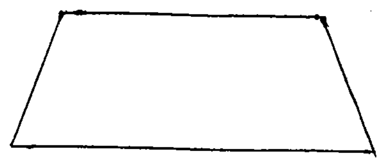


Fig b) SYMBOLIC REPRESENTATION OF SILICA SHEET

→ In above Silica sheet, Each of the oxygen ion at the base is common to two adjacent units.

→ The sharing of charges leaves the three negative charges at the base per tetrahedral unit

→ This, along with the two negative charges at the apex, Makes a total of five negative charges to four positive charges of silicon ion. thus, there is a net charge of −1 per unit.

ii) <u>Octahedral units</u>.

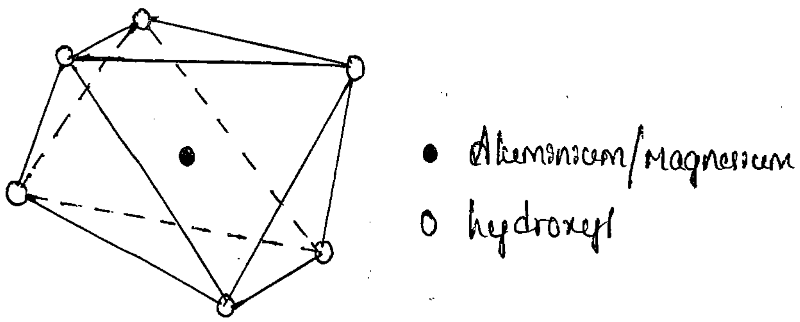
→ the octahedral unit comprises a central ion of Either aluminium, Magnesium or iron Surrounded by six hydroxyl ions

→ the octahedral sheet is a combination of octahedral units. If the atom at the centre is Aluminium, the resulting sheet is called gibbsite sheet.

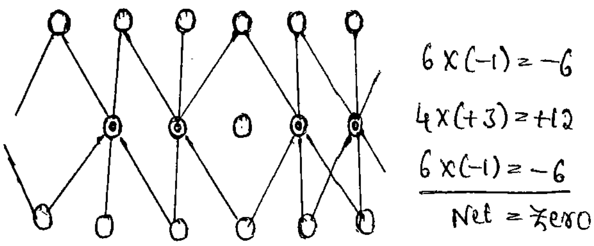
→ If Magnesium is the central atom, the sheet is called the brucite sheet.

→ If iron is the central atom, the sheet is called Fernite sheet

→ Each hydroxyl ion in Gibbsite sheet is being shared between 3 octahedral units. therefore, net charge present over Gibbsite is −1.



Single octahedral unit



Diffused soluble layer.

Isomorphous substitution:-

→ It is possible that one atom in a basic unit may be replaced by another atom. the process is known as isomorphous substitution.

→ For Example, one silicon ion in a tetrahedral unit may be substituted may lead to increase in negative charge on the particle which affect the physical properties of Mineral.

* Types of clay Minerals:-

→ clayey soils are made of three basic minerals

i) Kaolinite Mineral

ii) Montmorillonite Mineral

iii) Illite Mineral

(i) Kaolinite Mineral:-

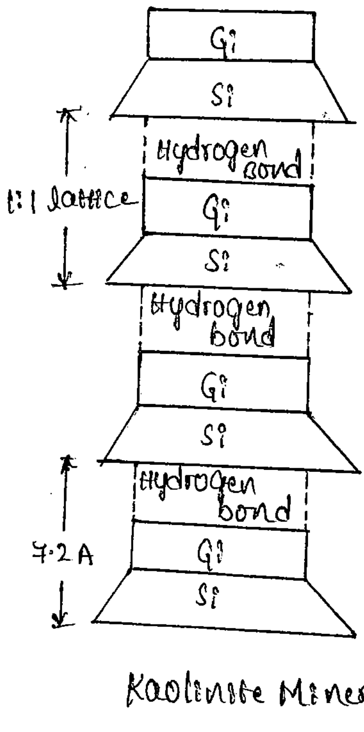
→ Kaolinite Minerals are made of an aluminium sheet (gibbsite sheet, Gi) combined with a silica sheet (Si).

→ the structural units join together by hydrogen bond, which develops between the oxygen of silica sheet and the hydroxyls of Alumina sheet. since hydrogen bond is strongest bond, kaolinite Mineral is quite stable.

→ Thus soils consisting kaolinite Mineral do not show much change in volume due to moisture variation.

→ The most common Example of kaolinite Mineral is china clay.

→ the surface area of the kaolinite particles per unit mass is about $15 m^2/g$. the surface area per unit mass is defined as specific surface



Kaolinite Mineral

(ii) Montmorillonite Minerals:-

→ Montmorillonite Mineral is a three layer sheet Mineral.

→ Basic three layer sheet units are formed by keeping one silica sheet (Si) on the top and bottom of gibbsite sheet (Gi)

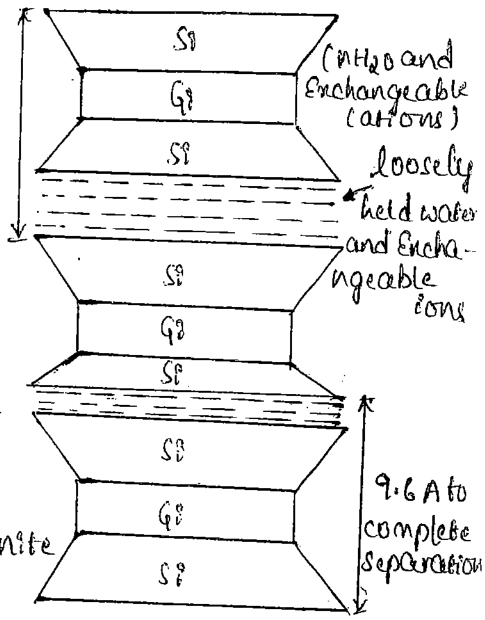
→ Isomorphous substitution of Magnesium (or) iron for the aluminium in the gibbsite sheet is common. It attracts water to form a water layer between two connecting basic units.

→ The bonding between basic units is by water forces and Exchangeable ion linkage.

→ The bonding of these sheet is very weak, and water may enter between the units. These Mineral has significant affinity for water, and results in Expansion and Swelling.

→ Bentonite and Black cotton soils contains Montmorillonite Mineral in large proportion.

→ Specific surface of Montmorillonite is about 200–800 m^2/g.



Montmorillonite Mineral

iii) Illite Minerals:-

→ Illite is also a three-layer sheet Mineral.

→ It consists of basic three layer sheet unit similar to montmorillonite. There is also a substantial amount of isomorphous substitution of silicon by aluminium in silica sheet.

→ Consequently, the Mineral has a larger Negative charge than that in montmorillonite. The basic units are bonded by non-Exchangeable pottasium (K^+) ions, which is stronger than the bond in montmorillonite.

→ These illite swells less than Montmorillonite, However swelling is More than in kaolinite.

The specific surface is 50–100 m^2/g

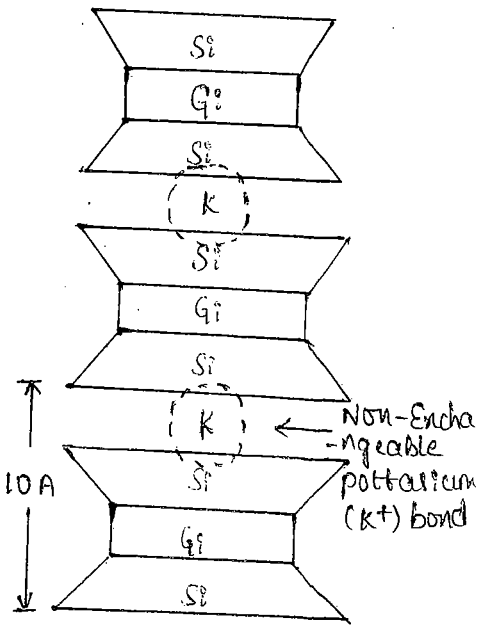


Fig: Illite Mineral

Clay Water Relationship:-

→ Clay soils are Normally associated with water and their properties are Greatly influenced by the presence of water, ~~thus~~. whereas, there is no impact of structural water on Granular Soils Except for reduction in void due to submergence.

→ The Surface of clay particles carry Negative charges.

→ The Edges of a clay particle May have a positive or a negative charge.

→ Because of net negative Surface charges, the clay particles repel Each other, but Edge to surface attraction May occur. Generally clay particles attract cations (positive ions)

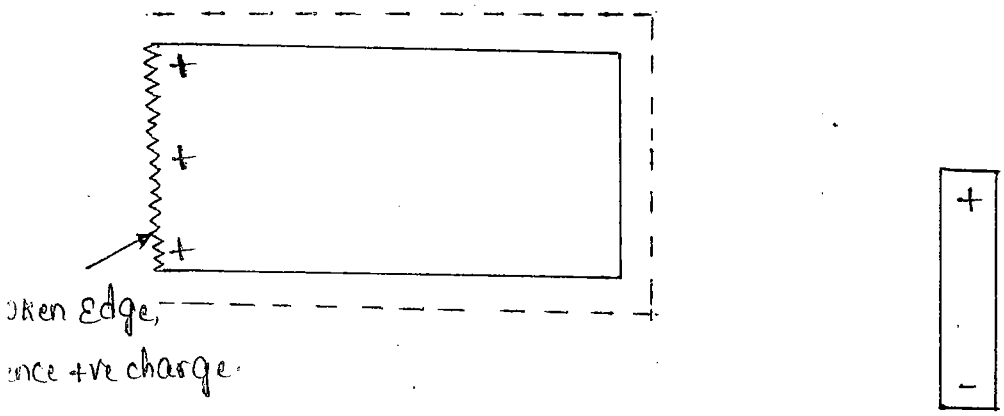


Fig: clay particle.

→ The water immediately surrounding a clay Mineral is a dipolar Molecule. It is also treated as a bar Magnet.

→ Further to balance the negative charge near the surface layer of clay Molecule, cations from water Molecule are attracted.

→ this attraction decreases with distance from the surface. Hence there is not attraction on pore water.

→ the distance from the Surface of the particle to the limit of attraction is termed the diffuse double layer.

→ the water contained between the diffuse layer and adjacent to the surface of clay is termed as Rigid layer.

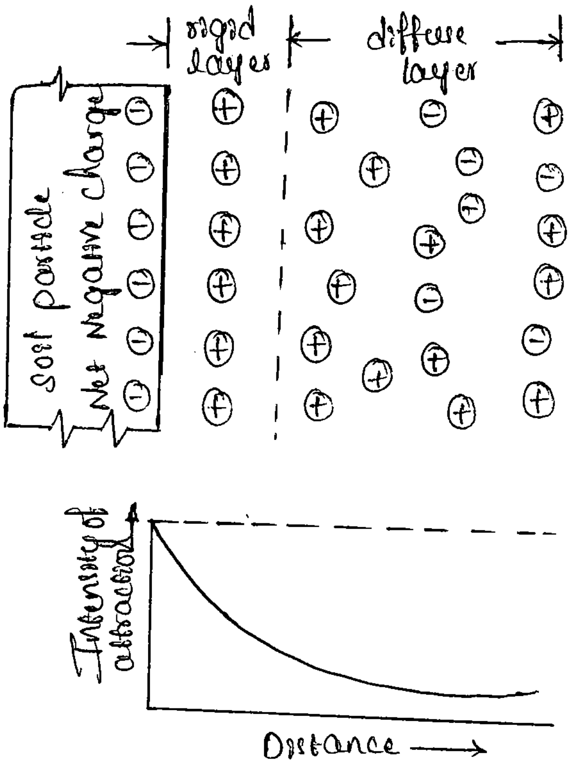


fig: Diffuse Double layer.

Note:- The surface of clay particles carry a negative charge.

→ This results from any one of the combination of the following factors

(i) Isomorphous substitution

(ii) Surface dissociation of OH^-

(iii) Absence of cation in the crystal lattice

(iv) Adsorption of anion

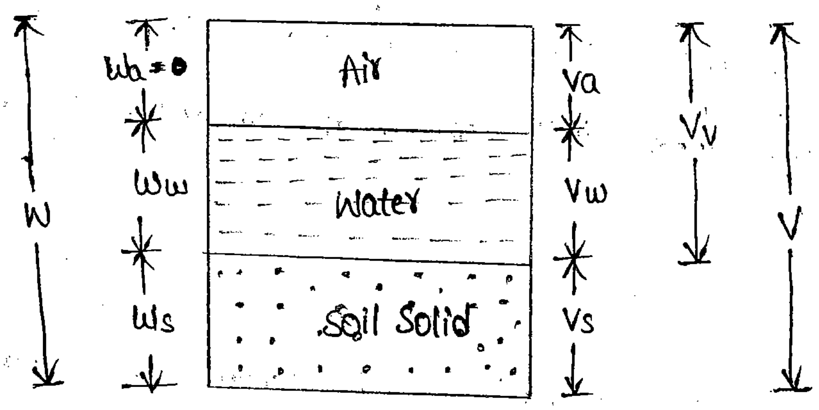
(v) presence of organic matter

* phase Diagram

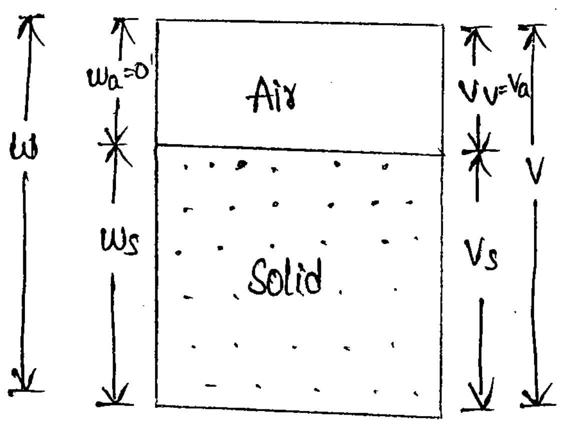
→ Soil mass, in general is a three phase system composed of solid, liquid and gaseous phase.

→ Different phases present in soil mass cannot be separated.

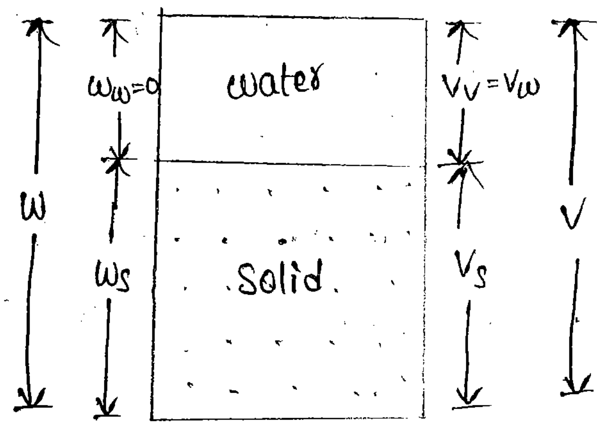
→ The diagrammatic representation of the different phases in a soil mass is called the 'phase diagram', or 'block diagram.'



partially Saturated System



Dry phase System



Saturation phase System

$$V_v = V_a + V_w$$

$$V = V_v + V_s$$

Basic Definitions:

1) Water Content (W)

→ Water content is also called moisture content.

→ It is ratio of weight of water (W_w) to the weight of soil solids (W_s)

$$W = \frac{W_w}{W_s}$$

→ This is represented as a percentage.

→ The water content of a oven dry soil is zero but natural water content for most soils is around 60%.

→ There is no upper limit for water content. It can be greater than 100%.

2) Degree of Saturation (S):

→ It is defined as the ratio of the volume of water to the volume of voids in soil mass.

$$S = \frac{V_w}{V_v} \times 100$$

V_w = volume of water

V_v = volume of voids

→ For dry soil, $S = 0\%$

→ fully saturated soil $S = 100\%$

→ partially saturated soil $0 < S < 100\%$.

3) Void Ratio (e):

→ It is defined as ratio of total volume of voids to the volume of solids.

$$e = \frac{V_v}{V_s}$$

V_v = volume of voids

V_s = volume of soil solids

→ In General $e > 0$, i.e. no upper limit for void ratio.

→ It is expressed in decimal.

4) Porosity (n):

→ It is defined as the ratio of volume of voids to the total volume of soil.

$$n = \frac{V_v}{V} \times 100\,\%$$

V_v = Volume of Voids

V = Total volume of soil

→ The range of porosity is $0 < n < 100\%$

(5) Air content (a_c):

→ It is defined as the ratio of volume of air to the total volume of soil voids.

$$a_c = \frac{V_a}{V_v}$$

V_a = volume of air in voids

V_v = Volume of voids

→ It is expressed in percentage.

(6) Percentage Air voids (n_a):

→ It is defined as ratio of volume of air to the total volume of soil mass.

$$n_a = \frac{V_a}{V} \times 100$$

V_a = volume of air

V = total volume of soil

→ It is expressed in percentage.

5) Unit weights

(a) Bulk unit weight (γ_t)

→ It is the ratio of total weight of soil to the total volume of soil mass.

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V_a + V_w + V_s}$$

→ It is expressed as $\frac{KN}{m^3}$

Bulk density

→ It is ratio of total soil mass to the total volume.

$$\rho_t = \frac{M}{V} = \frac{M_s + M_w}{V_a + V_w + V_s}$$

→ It is expressed as $\frac{Kg}{m^3}$

(b) Dry unit weight (γ_d)

→ It is ratio of total dry weight of soil to the total volume of soil mass.

$$\gamma_d = \frac{\text{Dry weight of soil}}{\text{Total Volume}} = \frac{W_s}{V}$$

Dry Density

→ It is defined as the ratio of total dry mass to the total volume.

$$\rho_d = \frac{M}{V} = \frac{M_s}{V}$$

c) Saturated unit weight (γ_{sat})

→ It is defined as ratio of total saturated weight of soil to the total volume of soil mass.

$$\gamma_{sat} = \frac{W_{sat}}{V}$$

Saturated Density

→ It is defined as ratio of total saturated soil mass to the total volume of soil mass.

$$\rho_{sat} = \frac{M_{sat}}{V}$$

d) Submerged unit weight or Buoyant unit weight (γ')

→ It is the ratio of buoyant weight of soil to the total volume of soil mass.

$$\gamma' = \frac{W_{sub}}{V}$$

→ When soil is below water i.e in submerged condition, a buoyant force acts on the soil solids which is equal in magnitude to the weight of water displaced by the soil solids. Hence the net weight of soil is reduced and reduced weight is known as buoyant weight or submerged weight.

$$\gamma' = \frac{W_{sub}}{V} = \gamma_{sat} - \gamma_w$$

→ γ' is roughly $\frac{1}{2}$ of saturated unit weight.

Note: Submerged density $\rho' = \rho_{sat} - \rho_w$

e) unit weight of water (γ_w):

→ It is defined as ratio of weight of water to the volume occupied by the water.

$$\gamma_w = \frac{W_w}{V_w}$$

→ It is expressed in $\frac{KN}{m^3}$

→ The unit weight of water is taken to be constant as 9.81 KN/m^3

f) unit weight of solids (γ_s):

→ It is defined as ratio of weight of soil solids to the volume occupied by the soil solids.

$$\gamma_s = \frac{W_s}{V_s}$$

→ It is expressed in $\frac{KN}{m^3}$

8) Specific gravity (G):

→ It is defined as the ratio of weight of a given volume of solids to the weight of an equivalent volume of water at $4^\circ C$.

$$G = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \gamma_w} \qquad \left[\because \gamma_s = \frac{W_s}{V_s}\right]$$

→ For organic soils, it lies in the range of 1.2 to 1.4

→ For Inorganic soils, lies in the range of 2.65 to 2.80.

9) Apparent or Mass specific gravity (G_m):

→ It is defined as ratio of bulk unit weight of soil to unit weight of water.

$$G_m = \frac{W_t}{V \gamma_w} = \frac{\gamma_t}{\gamma_w}$$

→ If soil is in Saturated state,

$$G_m = \frac{\gamma_{sat}}{\gamma_w}$$

→ If soil is in dry state,

$$G_m = \frac{\gamma_d}{\gamma_w}$$

Some Important Relationships

1. Relation between W_s, W_w and W:

$$W = W_s + W_w + W_a^{\nearrow 0}$$

$$W = W_s + W_w$$

$$W = W_s\left(1 + \frac{W_w}{W_s}\right) \qquad \left(\because \text{Water content } w = \frac{W_w}{W_s}\right)$$

$$W = W_s(1 + w)$$

$$\boxed{W_s = \frac{W}{1+w}}$$

2. Relation between e and n :

We know, porosity, $n = \frac{V_v}{V} = \frac{V_v}{V_s + V_v}$

$$= \frac{\left(\frac{V_v}{V_s}\right)}{1 + \left(\frac{V_v}{V_s}\right)} \qquad \left(\because e = \frac{V_v}{V_s}\right)$$

$$\boxed{n = \frac{e}{1+e}}$$

3. Relation between e, s, w and G :

We know,

Void ratio $e = \frac{V_v}{V_s}$

$$= \frac{V_v}{V_w} \times \frac{V_w}{V_s}$$

$$= \frac{V_v}{V_w} \times \frac{W_w / \gamma_w}{W_s / \gamma_s}$$

$$= \frac{V_v}{V_w} \cdot \frac{W_w}{W_s} \cdot \frac{G \gamma_w}{\gamma_w}$$

$$= \frac{1}{S} wG$$

$$e = \frac{wG}{S}$$

$$\boxed{eS = wG}$$

4. Relation between γ_t, G_s, e, w and γ_w :

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{W_s\left(1 + \frac{W_w}{W_s}\right)}{V_s\left(1 + \frac{V_v}{V_s}\right)}$$

But $\frac{W_w}{W_s} = w$ and $\frac{W_s}{V_s} = \gamma_s = G_s \gamma_w$

$$\therefore \gamma_t = \frac{G_s \gamma_w (1 + w)}{1 + e}$$

But $w = \frac{Se}{G_s}$

$$\gamma_t = \left(\frac{G_s + Se}{1+e}\right)\gamma_w$$

Special case (a): If Soil is Saturated, then

$\gamma_t = \gamma_{sat}$ and $S = 1$

Hence
$$\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right)\gamma_w$$

Special case (b): If Soil is dry, then

$\gamma_t = \gamma_d$ and $S = 0$

Hence
$$\gamma_d = \left(\frac{G_s + 0 \times e}{1+e}\right)\gamma_w$$

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

Special case (c): If soil is submerged, then

$$\gamma' = \gamma_{sat} - \gamma_w = \left(\frac{G_s + e}{1+e}\right)\gamma_w - \gamma_w$$

$$\gamma' = \left(\frac{G_s - 1}{1+e}\right)\gamma_w$$

5. Relation between γ_t, γ_d, w:

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V}$$

$$\gamma_t = \frac{W_s(1 + W_w/W_s)}{V}$$

$$\gamma_d = \frac{\gamma_t}{1+w} \qquad \left(\because \gamma_d = \frac{W_s}{V}\right)$$

6. Relation between γ_d, G_s, w and n_a:

$$V = V_s + V_w + V_a$$

$$1 = \frac{V_s}{V} + \frac{V_w}{V} + \frac{V_a}{V} = \frac{V_s}{V} + \frac{V_w}{V} + n_a$$

$$1-n_a = \frac{V_s}{V} + \frac{V_w}{V} = \frac{W_s/G_s\gamma_w}{V} + \frac{wW_s/\gamma_w}{V} \qquad \left(\because V_w = \frac{wW_s}{\gamma_w}\right)$$

$$= \frac{\gamma_d}{G_s\gamma_w} + \frac{wW_s/\gamma_w}{V}$$

$$= \frac{\gamma_d}{G_s\gamma_w} + \frac{w\gamma_d}{\gamma_w} = \frac{\gamma_d}{\gamma_w}\left(w + \frac{1}{G_s}\right)$$

$$\boxed{\gamma_d = \frac{(1-n_a)G_s\gamma_w}{1+wG}}$$

Special case When $n_a = 0$, then soil become fully saturated at a given water content

Hence
$$\boxed{\gamma_d = \frac{G_s\gamma_w}{1+wG}}$$

or
$$\gamma_{sat} = \left(\frac{G_s+e}{1+e}\right)\gamma_w$$

7. Relation between S, w, G_s, γ_t and γ_w :

$$\gamma_t = \left(\frac{G_s+Se}{1+e}\right)\gamma_w$$

$$\frac{\gamma_t}{\gamma_w} = \left(\frac{G_s+Se}{1+e}\right) = \left(\frac{G_s+wG_s}{1+\frac{wG_s}{S}}\right)$$

$$\left(1+\frac{wG_s}{S}\right) = \frac{G_s\gamma_w}{\gamma_t}(1+w)$$

$$\frac{1}{G_s}\left(1+\frac{wG_s}{S}\right) = \frac{\gamma_w}{\gamma_t}(1+w)$$

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

$$\boxed{S = \frac{w}{\frac{\gamma_w}{\gamma_t}(1+w) - \frac{1}{G_s}}}$$

Note: Generally Specific gravity is represented either at 27°C or 20°C. If test temperature is different than the Standard temperature then Correction has to be done as follows

$$\varphi = \frac{}{\gamma_w}$$

$$\varphi \times \gamma_w = \text{constant}$$

$$\varphi_{27^\circ C} \times \gamma_{w\,27^\circ C} = \varphi_{T^\circ C} \times \gamma_{w\,T^\circ C}$$

$$\boxed{\varphi_{27^\circ C} = \frac{\varphi_{T^\circ C} \times \gamma_{w\,T^\circ C}}{\gamma_{w\,27^\circ C}}}$$

* Formulae :

* $e_s = w\varphi$

* $w_s = \dfrac{w}{1+w}$

* $\gamma_t = \left(\dfrac{\varphi+se}{1+e}\right)\gamma_w$

* $\gamma_d = \left(\dfrac{\varphi\gamma_w}{1+e}\right)$

* $\gamma_{sat} = \left(\dfrac{\varphi+e}{1+e}\right)\gamma_w$

* $\gamma_d = \dfrac{\gamma_t}{1+w}$

* $s = \dfrac{w}{\dfrac{\gamma_w}{\gamma_t}(1+w) - \dfrac{1}{\varphi}}$

* $n_a = 1 - \left(\dfrac{V_w+V_s}{V}\right)$

* $\gamma_d = \dfrac{(1-n_a)\,\varphi\,\gamma_w}{1+es}$

* $\gamma' = \left(\dfrac{\varphi-1}{1+e}\right)\gamma_w$.

* $e = \dfrac{n}{1-n}$ & $n = \dfrac{e}{1+e}$

problems :

① A Soil Sampler of volume $1000\ cm^3$ is used to Collect Soil Samples. It was found that Sampler contain 2kg soil with dry unit of weight $1800\ Kg/m^3$. Now 300g water is mixed to the soil, the water content of the Sample will be

Sol:- $\because \gamma_d = 1800\ Kg/m^3$

$$W_s = V \times \gamma_d = 1000 \times 10^{-6} \times 1800 = 1.8\ Kg$$

But actual weight of sample, $W = 2Kg$

$\therefore$ Weight of water before mixing additional water,

$$W_{w_1} = W - W_s = 2 - 1.8 = 0.2\ Kg$$

After mixing 300g of water, the total weight of water Should be $W_{w_2} = 0.2 + 0.3 = 0.5\ Kg$

Thus water content, $\omega = \frac{W_{w_2}}{W_s} \times 100 = \frac{0.5}{1.8} \times 100 = 27.8\%$

② An oven dry soil has mass specific gravity of 1.5 g/cc. If bulk density of Soil in its natural State is 2 g/cc, then the water content of soil in natural state will be
(a) 50% (b) 25% (c) 100% (d) 33.33%

Sol:- For oven dry Soil,

Mass Specific gravity, $G_m = \frac{\gamma_d}{\gamma_\omega} = 1.5\ g/cc$

$\therefore \gamma_d = 1.5\ g/cc$

Given, bulk density, $\gamma_t = 2 g/cc$

using, $\gamma_d = \frac{\gamma_t}{1+\omega}$

$$1.5 = \frac{2}{1+\omega}$$

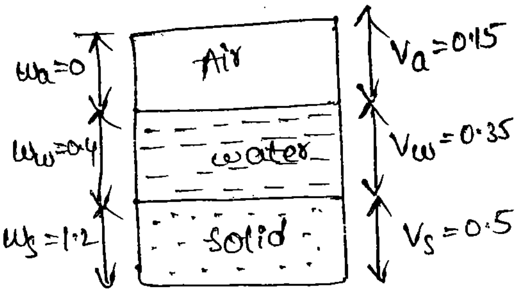
$$\omega = \frac{2}{1.5} - 1 = 33.33\%$$

Hence option (d) is Correct.

(3) Figure shows a block diagram for a soil sample, having volumes and weights in cc and g respectively.

Consider the following statements

1. Soil is partially saturated with degree of saturation greater than 60 %.
2. Void ratio = 100 %.
3. Water content = 40 %.
4. Saturated unit weight = 2 g/cc



Which of the above statements are true

(a) 1, 2 and 3 (b) 1, 2, 3 and 4 (c) 1, 2 and 4 (d) 2 and 3

Sol:- 1. Degree of Saturation $S = \frac{V_w}{V_v} \times 100 = \frac{0.35}{(0.15+0.35)} \times 100 = 70\%$

2. Void ratio, $e = \frac{V_v}{V_s} = \frac{0.15+0.35}{0.5} \times 100 = 100\%$

3. Water content, $w = \frac{W_w}{W_s} \times 100 = \frac{0.4}{1.2} \times 100 = 33.33\%$

4. Saturated unit weight, $\gamma_{sat} = \left(\frac{G+se}{1+e}\right)\gamma_w$

using $se = Gw$

$$G = \frac{se}{w} = \frac{1\times1}{0.333} = 3$$

$$\gamma_{sat} = \left(\frac{3+1\times1}{1+1}\right)\times1 = 2\ g/cc$$

Hence option (c) is correct.

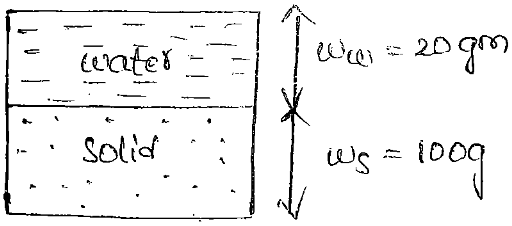
Consider the phase diagram of the soil given below;

The soil is completely saturated

The specific gravity of soil solids is 2.6 (take density of water as 10 kN/m³)

Match List-I (physical properties of soil) with List II (corresponding values) and select the correct answer using the codes given below.

List-I List-II



	List-I		List-II
1.	water content	A.	0.34
2.	Void ratio	B.	0.52
3.	porosity	C.	20.53
4.	Saturated density	D.	20%.

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

Sol:- 1. water content, $\omega = \frac{W_w}{W_s} \times 100 = \frac{20}{100} \times 100 = 20\%$

2. Void ratio, $e = \frac{\omega G}{S} = \frac{0.2 \times 2.6}{1} = 0.52$

3. porosity, $n = \frac{e}{1+e} = \frac{0.52}{1+0.52} = 0.34$

4. Saturated density $\gamma_{sat} = \left(\frac{G + 1 \times e}{1+e}\right)\gamma_\omega = \left(\frac{2.6+0.52}{1+0.52}\right) \times 10$

$= 20.53 \ KN/m^3$

Hence option (d) is correct.

5) Soil Sample A and B have void ratio of 0.5 and 0.7 respectively. If $1.5 \ m^3$ of soil sample A and $1.7 \ m^3$ of Sample B are mixed to form Sample C having a volume of $3.2 \ m^3$, which one of the following correctly represents the porosity of Sample C?

(a) 50%. (b) 37.5%. (c) 100%. (d) 33.33%.

Sol:-

Soil A(1)	Soil B(2)	Soil C(3)
$e_1 = 0.5$	$e_2 = 0.7$	$V_3 = 3.2 \ m^3$
$V_1 = 1.5 \ m^3$	$V_2 = 1.7 \ m^3$	

Even after mixing, Volume of Solids of each Soil will be Same in mixed Sample

The solids in soil A, $V_{s_1} = \frac{V_1}{1+e_1}$

$= \frac{1.5}{1+0.5}$

$= 1\,m^3$

The Solids in soil B, $V_{s_2} = \frac{V_2}{1+e_2} = \frac{1.7}{1+0.7} = 1\,m^3$

Total volume of solids in soil C, $V_{s_3} = V_{s_1} + V_{s_2} = 2m^3$

∴ volume of void in soil C, $V_v = V_3 - V_{s_3} = 3.2 - 2 = 1.2m^3$

∴ porosity, $n = \frac{V_v}{V_3} = \frac{1.2}{3.2} = 0.375$

Hence, Option (b) is correct.

i) Which one of the following is the water content of the mixed Soil made from 1 Kg of soil (say A) with water content of 100% and 1 kg of soil (say B) with water content of 50% ?

(a) 66% (b) 71% (c) 75% (d) 82%

Sol:

Soil A (1)	Soil B(2)	Soil C (3)
$W_1 = 1kg$	$W_2 = 1kg$	$W_3 = W_1 + W_2$
$\omega_1 = 100\%$	$\omega_2 = 50\%$	ω_3

Water content, $\omega = \frac{W_\omega}{W_s} \times 100 \Rightarrow \frac{\omega}{100} = \frac{W_\omega}{W_s}$

$\frac{\omega}{100} + 1 = \frac{W_\omega + W_s}{W_s} \Rightarrow W = \left(\frac{\omega}{100} + 1\right) W_s$

Weight of solids in soil A,

$W_{s_A} = \frac{1000}{1+1} = 500g$

$W_{\omega A} = 1000 - 500 = 500g$

weight of solids in soil B,

$W_{s_B} = \frac{1000}{0.5+1} = 666.7g$

$W_{\omega B} = 1000 - 666.7 = 333.3g$

$W_{s,mix} = W_{sA} + W_{sB} = 500 + 666.7$

$= 1166.7 g$

$W_{w,mix} = W_{wA} + W_{wB} = 500 + 333.3 g$

$= 833.3 g$

$$w = \frac{W_{w,mix}}{W_{s,mix}}$$

$$= \frac{833.3}{1166.7} \times 100$$

$$= 71\%$$

Ans. (b)

7) A soil sample has void ratio of 35%. The specific gravity of solids is 2.7. Calculate the
(i) porosity (ii) Dry density (iii) unit weight if the soil is 75% saturated (iv) unit weight if the soil is submerged.

Sol:- Given void ratio, $e = 35\%$, $G_s = 2.7$

(i) We know porosity, $n = \frac{e}{1+e}$

$$= \frac{0.35}{1+0.35}$$

$$= 0.259$$

(ii) we know, $\gamma_t = \left(\frac{G_s + se}{1+e}\right)\gamma_w$

For dry density, $s = 0$

$$\therefore \gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{2.7 \times 9.81}{1+0.35}$$

$$\gamma_d = 19.62 \ KN/m^3$$

(iii) when soil is 75% saturated i.e $S = 0.75$

$$\therefore \gamma = \left(\frac{G_s + se}{1+e}\right)\gamma_w = \left(\frac{2.7 + 0.75 \times 0.35}{1+0.35}\right) \times 9.81$$

$$= 21.53 \ KN/m^3$$

(iv) we know, $\gamma_{sub} = \gamma_{sat} - \gamma_w$

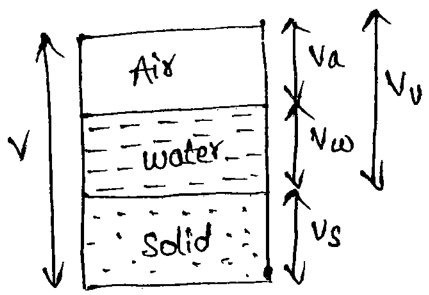
$$= \left(\frac{G_s + se}{1+e}\right)\gamma_w - \gamma_w$$

$$= \left(\frac{G_s - 1}{1+e}\right)\gamma_w$$

$$= \left(\frac{2.7-1}{1+0.35}\right) \times 9.81$$

$$= 12.35 \text{ KN/m}^3$$

3. A Sampler with a volume of 60 cm³ is filled with Saturated Soil Sample. The Specific gravity of Soil solids is 2.65. When the oven dry soil is poured into a graduated cylinder filled with water, it displace 40 cm³ of water, What is the natural moisture content and dry unit weight of Soil?



Sol:- Volume of Soil Sample = Volume of sampler

$$V = 60 \text{ cm}^3$$

When soil sample is poured into graduated cylinder, it displace 40 cm³ of water

∴ Volume of Soil solids, $V_s = 40 \text{ cm}^3$

∵ Total volume, $V = V_v + V_s$

$$\Rightarrow V_v = V - V_s = 60 - 40 = 20 \text{ cm}^3$$

∴ Void ratio, $e = \frac{V_v}{V_s} = \frac{20}{40} = 0.5$

Now we have, $e = 0.5$, $s = 1$ and $G_s = 2.65$

Using $se = wG_s$

Moisture content $w = \frac{se}{G_s} = \frac{1 \times 0.5}{2.65} = 18.86\%$

we know, $\gamma_d = \frac{\gamma_t}{1+w}$

γ_t = bulk unit weight

$$\gamma_t = \left(\frac{G+se}{1+e}\right)\gamma_w = \left(\frac{2.65+1\times0.5}{1+0.5}\right)\times 1 = 2.1 \text{ g/cc}$$

Hence $\gamma_d = \frac{2.1}{1+0.1886} = 1.76$ g/cc

9. The void ratio and specific gravity of a sample of clay are 0.73 and 2.7 respectively. The voids are 92% saturated. Find the bulk density, the dry density and the water content. What would be the water content for complete saturation, the void ratio remaining the same?

Sol:- Given $e = 0.73$, $G = 2.7$ and $S = 92\%$ [$\because \rho_w = 1$ g/cc]

Bulk density, $\rho_t = \left(\frac{G+se}{1+e}\right)\rho_w = \left(\frac{2.7+0.92\times0.73}{1+0.73}\right)\times 1$

$$\rho_t = 1.948 \text{ g/cc}$$

Dry density $\rho_d = \frac{\rho_t}{1+w}$

using $se = wG$

$$w = \frac{se}{G} = \frac{0.92\times0.73}{2.7} = 0.2487 \text{ or } 24.87\%$$

Substituting w value in ρ_d

$$\rho_d = \frac{1.948}{1+0.2487} = 1.560 \text{ g/cc}$$

Let, water content is w for full saturation at given void ratio

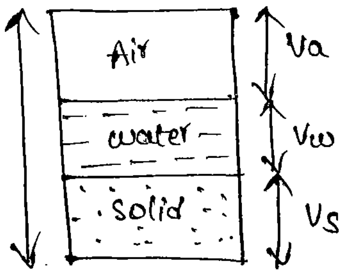
Now, $S = 100\%$, $e = 0.73$

we know $se = wG$

$$w = \frac{se}{G} = \frac{1\times0.73}{2.7} = 0.2703 \text{ or } 27.03\%$$

ii) A compacted cylindrical specimen of 50 mm diameter and 100 mm long is to be prepared from dry soil. If the specimen is required to have a water content of 15% and the percentage of air void is 20%, calculate the weight of soil and water required in the preparation of the soil whose specific gravity is 2.69.

Volume of soil sample = Volume of cylinder



$$V = \frac{\pi}{4} D^2 H = \frac{\pi}{4} \times (5)^2 \times 10 = 196.35\ cc$$

water content, $\omega = \frac{W_\omega}{W_s} = \frac{V_\omega \times \gamma_\omega}{V_s \times \gamma_s} = \frac{V_\omega}{V_s G}$

$$0.15 = \frac{V_\omega}{V_s G}$$

$$V_\omega = 0.15 V_s \times G$$

$$= 0.15 \times V_s \times 2.69$$

$$= 0.40 V_s$$

Also,

% Air void, $n_a = \frac{V_a}{V} = 0.2$

$$V_a = 0.2V$$

$$V = V_s + V_\omega + V_a$$

$$V = V_s + 0.4 V_s + 0.2V$$

$$0.8V = 1.4 V_s$$

$$V_s = \frac{0.8V}{1.4}$$

$$= \frac{0.8 \times 196.35}{1.4}$$

$$= 112.11\ cc$$

Let W_s be the weight of soil solids to prepare soil whose specific gravity is 2.69.

We know, $G = \frac{W_s}{V_s \times \gamma_\omega}$

$$W_s = G \times V_s \times \gamma_\omega = 2.69 \times 112.11 \times 1$$

$$= 301.6\ g$$

Weight of dry soil = Weight of Solids

$= 301.6g$

Let W_w be the weight of water to prepare soil whose Specific gravity is 2.69.

$$W_w = w \times W_s = 0.15 \times 301.6 = 45.24g$$

11). A soil sample of Saturated clay has a diameter of 50 mm and the height of 100 mm. The mass of Saturated Sample is 220g and its mass when oven dried is 150g. Find

(i) water content of the clay

(ii) Void ratio

(iii) Dry density of solid

Assume Specific gravity of solid as 2.7.

Sol:- Mass of Saturated soil Sample, $M_{sat} = 220g$

Mass of oven dry soil sample, $M_s = 150g$

$\therefore$ Mass of water in soil, $M_w = 220 - 150 = 70g$

(i) water content of Sample, $w = \frac{W_w}{W_s} \times 100 = \frac{M_w}{M_s} \times 100$

$$= \frac{70}{150} \times 100$$

$$= 46.67\%$$

(ii) Volume of Sample, $V = \frac{\pi}{4} D^2 L$

$$= \frac{\pi}{4} (5)^2 \times 10$$

$$= 196.35 \text{ cc}$$

and $V_w = \frac{M_w}{\rho_w} = \frac{70g}{1g/cc} = 70 \text{ cc}$

For a Saturated soil Sample,

$$V_v = V_w = 70 \text{ cc}$$

$$V_s = V - V_w = 196.35 - 70 = 126.35 \text{ cc}$$

$\therefore$ void ratio, $e = \frac{V_v}{V_s} = \frac{70}{126.35} = 0.55$

(iii) Dry density, $\rho_d = \frac{\rho_t}{1+\omega}$

where, $\rho_t = \rho_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_\omega$

$$\rho_t = \left(\frac{2.7+0.55}{1+0.55}\right)\times 1 = 2.09 \text{ g/cc}$$

Hence $\rho_d = \frac{2.09}{1+0.4667} = 1.425 \text{ g/cc}$

2) A clayey soil with specific gravity of 2.70 has natural moisture content of 16% at 70% degree of saturation. What will be its water content if, after soaking, degree of saturation becomes 90%.

Sol:- In the first case,

Given, $G = 2.7$, $\omega = 16\%$ and $S = 70\%$

we know, $e = \frac{\omega G}{S} = \frac{0.16 \times 2.7}{0.7} = 0.617$

In the second case,

Since degree of saturation is within 100%, void ratio (e) will be same as the previous case

$$Se = \omega G$$

$$\omega = \frac{Se}{G} = \frac{0.9 \times 0.617}{2.7}$$

$$= 0.2057 \text{ or } 20.57\%$$

13) A soil sample has wet density of 20 KN/m^3 and dry density of 18 KN/m^3. If the specific gravity of soil is 2.67. calculate the void ratio, porosity, moisture content and degree of saturation. Assume unit wt of water = 10 KN/m^3.

Sol:- Given, $\gamma_{wet} = \gamma_t = 20\ KN/m^3$, $\gamma_d = 18\ KN/m^3$ and $G = 2.67$

we know, $$\gamma_d = \frac{G\gamma_w}{1+e}$$

$$18 = \frac{2.67 \times 10}{1+e}$$

$$1+e = \frac{2.67 \times 10}{18}$$

$$= 1.483$$

$$e = 0.483$$

We know that,

$$\text{porosity},\ n = \frac{e}{1+e} = \frac{0.483}{1+0.483} = 0.326$$

we have,

$$\text{Dry density},\ \gamma_d = \frac{\gamma_t}{1+w}$$

$$18 = \frac{20}{1+w}$$

$$1+w = \frac{20}{18} = 1.111$$

$$w = 0.111 \text{ or } 11.11\%$$

Using, $$Se = wG$$

$$S = \frac{wG}{e} = \frac{0.111 \times 2.67}{0.483}$$

$$= 0.614 \text{ or } 61.4\%$$

problems of Borrow pit and Fill :-

14) An embankment is to be constructed. The soil is to be compacted at maximum dry density of $18\ KN/m^3$ at optimum moisture content = 15%. The in-situ bulk density and water content in borrow pit are $17\ KN/m^3$ and 8% respectively.

How much excavation should be carried out in the barrow pit for each cubic meter of embankment? Assume $G = 2.7$ and $\gamma_w = 10\ KN/m^3$.

Sol:-

Borrow pit (1)

$\gamma_1 = 17\ KN/m^3$

$w_1 = 0.08$

$G = 2.7$

Embankment (2)

$\gamma_{d2} = 18\ KN/m^3$

$w_2 = 0.15$

$\gamma_w = 10\ KN/m^3$

For fill, $\gamma_{d2} = \dfrac{\gamma_2}{1+w_2} \Rightarrow \gamma_2 = \dfrac{\gamma_{d2}}{1+w_2} = \dfrac{18}{1+0.15}$

$\gamma_2 = 20.7\ KN/m^3$

Void Ratios:

Borrow pit (1)

$$\gamma_1 = \frac{G(1+w_1)}{1+e_1}\gamma_w$$

$$17 = \frac{2.7(1+0.08)\times 10}{1+e_1}$$

$e_1 = 0.7153$

Embankment (2)

$$\gamma_2 = \frac{G(1+w_2)}{1+e_2}\gamma_w$$

$$20.7 = \frac{2.7(1+0.15)\times 10}{1+e_2}$$

$e_2 = 0.5$

Volume of solids (V_s) will remain same in both borrow pit and fill

$$\therefore \quad V_s = \frac{V_1}{1+e_1} = \frac{V_2}{1+e_2}$$

$$\Rightarrow V_1 = \left(\frac{1+e_1}{1+e_2}\right)V_2$$

$$V_1 = \left(\frac{1+0.7153}{1+0.5}\right)\times 1 \text{ cum}$$

$V_1 = 1.143$ cum

Hence, the volume of excavation from borrow pit is $1.143\ m^3$ for each cubic meter of embankment.

15) The soil in a borrow pit has a void ratio of 0.9. A fill of volume 20000 m^3 has to be constructed with an in place dry density of 19.2 KN/m^3. If the owner of borrow pit to be compensated at rate 2.5 Rs per cubic metre of excavation, determine the cost of compensation. Take $G = 2.68$, $\gamma_w = 9.81$ KN/m^3.

Sol:-

Borrow pit (1)

$e_1 = 0.9$

$G = 2.68$

$\gamma_w = 9.81$

The fill (2)

$\gamma_2 = 18$ KN/m^3

$\gamma_{d_2} = 19.2$ KN/m^3

For fill,

$$\gamma_{d_2} = \frac{G\gamma_w}{1+e_2}$$

$$1+e_2 = \frac{G\gamma_w}{\gamma_{d_2}}$$

$$= \frac{2.68 \times 9.81}{19.2}$$

$$= 1.37$$

$$e_2 = 0.37$$

Volume of soil solid (V_s) will remain same in both borrow pit and fill.

$$V_s = \frac{V_1}{1+e_1} = \frac{V_2}{1+e_2}$$

$$V_1 = \left(\frac{1+e_1}{1+e_2}\right) V_2$$

$$V_1 = \left(\frac{1+0.9}{1+0.37}\right) \times 20000$$

$$V_1 = 27737.3\ m^3$$

Cost of compensation to be given to the owner of borrow pit $= 2.50$ $Rs/m^3 \times 27737.3$ m^3

$= 69343.25$ RS

6) Soil is to be excavated from a borrow pit which has a density of 1.75 gm/cc and water content of 12%. The specific gravity of soil particles is 2.7. The soil is compacted so that water content is 18% and dry density is 1.65 gm/cc. For 1000 m^3 of soil in fill, estimate (i) quantity of soil to be excavated from the pit in m^3, (ii) amount of water to be added. Also, determine the void ratios of the soil in borrow pit and fill.

Sol:-

Borrow pit (1)

$\rho_1 = 1.75$ g/cc

$w_1 = 12\%$

$G = 2.7$

The fill (2)

$V_2 = 1000\ m^3$

$w_2 = 18\%$

$\rho_{d_2} = 1.65$ g/cc

(i) $$\rho_{d_1} = \frac{\rho_1}{1+w_1} = \frac{G\rho_w}{1+e_1}$$

$$\frac{1.75}{1+0.12} = \frac{2.7\times1}{1+e_1}$$

$$e_1 = 0.728$$

and $$\rho_{d_2} = \frac{G\rho_w}{1+e_2}$$

$$1.65 = \frac{2.7\times1}{1+e_2}$$

$$e_2 = 0.636$$

We know that volume of solids in borrow pit and fill is same

$$V_s = \frac{V_1}{1+e_1} = \frac{V_2}{1+e_2}$$

$$V_1 = \left(\frac{1+e_1}{1+e_2}\right)V_2$$

$$V_1 = \left(\frac{1+0.728}{1+0.636}\right)\times1000$$

$$V_1 = 1056.23\ m^3$$

Hence, 1056.23 m^3 of soil is to be excavated from the borrow pit.

(ii) We know that, $V_{s_2} = \frac{V_2}{1+e_2}$

$= \frac{1000}{1+0.636}$

$= 611.25\ m^3$

weight of solids $= W_s = V_s \gamma_s$

$W_s = V_s G \gamma_w$

$W_s = 611.25 \times 2.7 \times 9.81$

$W_s = 16190.18$ KN

Now, moisture content, $w_1 = \frac{W_{w_1}}{W_s}$

$\Rightarrow W_{w_1}$ (weight of water in pit) $= w_1 \times W_s = 0.12 \times 16190.18$

$= 1942.8$

and W_{w_2} (weight of water in fill) $= 0.18 \times 16190.18$

$= 2914.23$ KN

$\therefore$ amount of water added $= W_{w_1} - W_{w_2}$

$= 2914.23 - 1942.8$

$= 971.43$ KN

(or)

$= \frac{971.43}{9.81}$ Kg

$= 99.02 \times 10^3$ Kg

Relative Density (I_D or D_r):

→ Relative density is also called degree of density or density index.

→ It is the index which quantifies the degree of packing between the loosest and densest packing of coarse grained soil.

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \quad \text{or} \quad \frac{\frac{1}{\gamma_{min}} - \frac{1}{\gamma}}{\frac{1}{\gamma_{min}} - \frac{1}{\gamma_{max}}} \times 100$$

where e_{max} = void ratio in loosest state

e_{min} = Void ratio in densest state

e = Void ratio in natural state

→ It is the most important property of a coarse grained soil.

→ Coarse grained soil can be classified on the basic of relative density as given below.

I_D (%)	0-15	15-35	35-65	65-85	85-100
Classification	Very loose	Loose	Medium	Dense	Very loose

Note: It is better indicator of denseness of solid than void ratio and dry unit weight, as it represents the relative compactness in absolute terms.

→ Soils having similar shape and grain size distribution exhibit different properties if their relative density differs.

→ This term is not used for cohesive soils as uncertainties are involved in computation of void ratio of cohesive soils in their loosest state in the laboratory.

problems

1. A Saturated Sand deposit have natural moisture content of 30%. It was noticed that the maximum and minimum void ratios are 0.95 and 0.40 respectively. Assume Specific gravity of Sand Solid as 2.7. The Sand deposit would be classified as

(a) medium (b) dense (c) loose (d) very dense.

Sol:- Given $\omega = 0.30$, $S = 1$, $G = 2.7$

$$e = \frac{\omega G}{S} = \frac{0.3 \times 2.7}{1} = 0.81$$

$e = 0.81$, $e_{max} = 0.95$, $e_{min} = 0.40$

$$\text{Relative density, } I_D = \frac{0.95 - 0.81}{0.95 - 0.40} \times 100 = 25.45\%$$

Hence, Sand deposit would be classified as loose.

The natural void ratio of a Saturated Sand Sample is 0.6 and its density index is 60%. If void ratio in loosest state is 0.9, then the water content Corresponding to densest State will be

(a) 15% (b) 20% (c) 30% (d) 50%

Sol:- Given, $e = 0.6$, $I_D = 60\%$, $e_{max} = 0.9$

$$\% I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$0.60 = \frac{0.9 - 0.6}{0.9 - e_{min}}$$

$$e_{min} = 0.4$$

Assume $G = 2.7$

$$\omega = \frac{S e_{min}}{G} = \frac{1 \times 0.4}{2.7} = 15\%$$

Hence option (a) is Correct.

③ A relative density test was conducted on a Sandy Soil. The following results were obtained:

$e_{max} = 0.95$, $e_{min} = 0.40$, $I_D = 45\%$ and $G = 2.7$

Calculate the dry density of soil. If a 5m thickness of this stratum is densified to a $I_D = 70\%$, how much will be stratum reduce in thickness?

Sol:-

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$45 = \frac{0.952 - e}{0.95 - 0.40} \times 100$$

$$0.95 - e = 0.2475$$

$$e = 0.70$$

We know, $\gamma_t = \left(\frac{G + se}{1+e}\right)\gamma_w$

For dry density, $S = 0$

$$\gamma_d = \frac{G\gamma_w}{1+e} = 1.588 \text{ g/cc}$$

Considering unit Surface area of sample stratum,

$$e = \frac{V_v}{V_s} = \frac{V_1 - V_s}{V_s} \qquad [\because V_1 = 5 \times 1 \times 1 = 5m^3]$$

$$0.70 = \frac{5 - V_s}{V_s}$$

$$V_s = 2.94 \, m^3$$

If soil stratum is densified to 70% relative density

$$70 = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$0.70 = \frac{0.95 - e}{0.95 - 0.40}$$

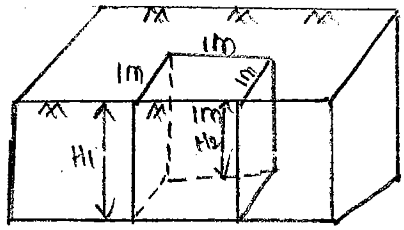
$$e = 0.565$$

Also, $e = \frac{V_v}{V_s} = \frac{V_2 - V_s}{2.94}$

$$0.565 = \frac{V_2 - 2.94}{2.94}$$

$$1.661 = V_2 - 2.94$$

$$V_2 = 4.601\, m^3$$



∴ , The reduction in thickness is given by

$$H_1 - H_2 = \Delta H = \left(\frac{V_1 - V_2}{A}\right) = \left(\frac{5 - 4.601}{1}\right) = 0.399\, m \simeq 0.4\, m.$$

4) The unit weight of a Sand backfill was determined by field measurements to be 1746 kg/m³. The water content at the time of test was 8.6 percent and the unit weight of the Solid constituents was 2.6 g/cm³. In the laboratory the valid ratios in the loosest and densest states was found to be 0.642 and 0.462 respectively. what was the relative density of the fill?

Given, $\gamma = 1746\, kg/m^3$, $w = 0.086$, $\gamma_s = 2.6\, g/cc$

$e_{max} = 0.642$, $e_{min} = 0.462$

$$G = \frac{\gamma_s}{\gamma_w} = \frac{2.6}{1} = 2.6$$

Void ratio of soil in natural state may be obtained by using,

$$\gamma = \frac{G(1+w)}{1+e} \gamma_w$$

$$1746 = \frac{2.6(1+0.086)}{1+e} \times 1000$$

$$e = 1.617 - 1 = 0.617$$

Relative density, $I_D = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{0.642 - 0.617}{0.642 - 0.462} \times 100$

$$= 13.89\%$$

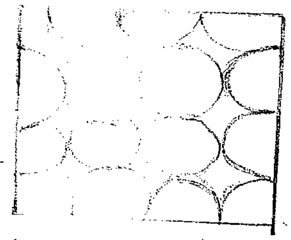
5) Compute the void ratio of uniformly graded coarse grained soil in

(i) loosest possible state

(ii) densest possible state

Assuming the soil particles made up of equal diameter spherical shape.

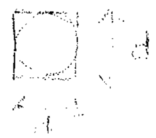
Sol: (i) In loosest packing, each sphere makes contact with six adjacent sphere - four from side, one from bottom and one from top. Assume each sphere is fitted within a cube of side d as shown in figure.



(a) Simple ... of spheres

Volume of void V_v = Volume of cube - volume of sphere

$$= d^3 - \frac{\pi d^3}{6}$$

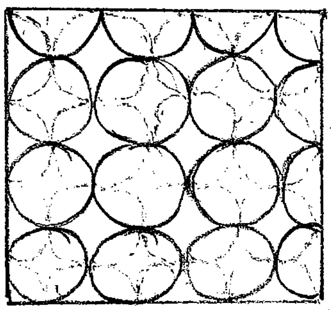


(b) ... element fr... packing

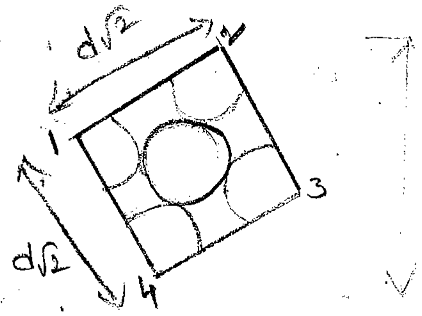
Void ratio, $e = \frac{V_v}{V_s} = \frac{d^3 - \frac{\pi d^3}{6}}{\frac{\pi d^3}{6}} = \frac{1-\frac{\pi}{6}}{\frac{\pi}{6}} = 0.91$

Thus, the void ratio in loosest state of packing is 0.91.

(ii) For densest packing, particles are packed as shown in figure.



(a) Face centered cubic packing of spheres



(b) Cubic element ... face centered cub...

Volume of void, V_v = volume of cube − volume of sphere within cube

$$V_v = (\sqrt{2}d)^3 - \left[4 \times \frac{\pi d^3}{6}\right]$$

$$= 2\sqrt{2}d^3 - \frac{2}{3}\pi d^3$$

The void ratio, $e = \frac{V_v}{V_s} = \frac{\left[2\sqrt{2}d^3 - \frac{2}{3}\pi d^3\right]}{\frac{2}{3}\pi d^3}$

$$= \frac{2\sqrt{2} - \frac{2}{3}\pi}{\frac{2}{3}\pi}$$

$$= 0.35$$

Thus, the void ratio in densest state is 0.35.

Methods for Determination of water Content

1. Oven Drying method

→ This is the Simplest and most accurate method.

→ For inorganic soils, temperature is controlled between 105 − 110°c.

→ For soil containing organic compounds, temperature is maintained about 60°c and if Gypsum is present, then temperature should be maintained at 80°c.

→ Usually 4-6 hrs are enough for sands to dry but 16−20 hrs are required for clay. usually 24 hrs are provided for dying in the oven.

→ If temperature is uncontrolled and more than 110°c, there is a danger of loss of structural water.

→ water content is calculated as follows

let W_1 = weight of empty eq container

W_2 = weight of container + moist soil

W_3 = weight of container + dry soil

W_w (weight of water) = $W_2 - W_3$

$$W_s = W_3 - W_1$$

$$w = \frac{W_w}{W_s} \times 100$$

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

∴ This method is accurate but time taking.

2. Pycnometer Method:

→ This is a quick method but it is less accurate than oven drying method.

→ This method is used only when specific gravity of soil solids is known.

→ A small weight, say 200g to 400g of soil is placed in a clean pycnometer whose capacity is 900 ml.

→ let W_1 = weight of empty pycnometer bottle

W_2 = weight of pycnometer + soil

W_3 = weight of pycnometer + soil + water

W_4 = weight of pycnometer + water

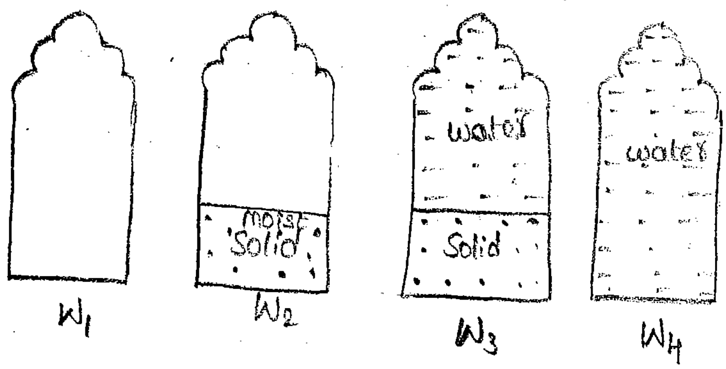


Fig: pycnometer method

Let G be specific gravity of soil solids,

Now, water content, $w = \frac{W_w}{W_s} \times 100$

weight of water $= (W_2 - W_1) - W_s$ —— (1)

If from W_3, the weight of solids W_s could be removed and replaced by the weight of an equivalent volume of water, the weight W_4 will be

$$W_4 = W_3 - W_s + \frac{W_s}{G\gamma_w} \cdot \gamma_w$$

$$W_s = (W_3 - W_4)\frac{G}{G-1} \quad \text{—— (2)} \quad \left[\because V_s = \frac{W_s}{\gamma_s} \text{ and } G = \frac{\gamma_s}{\gamma_w}\right]$$

from (1) and (2)

$$w = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)}\left(\frac{G-1}{G}\right) - 1\right] \times 100$$

Note: In view of the difficulty in removing entrapped air from the soil sample, this method is more suited for cohesionless soil where this can be achieved easily.

→ pycnometer method is suitable for coarse grained soil. But if it is used for fine grained soil, then instead of water kerosine should be used because kerosine has good wetting properties.

Determination of Specific Gravity of soil solids :

pycnometer method :

→ This method is similar to pycnometer method for water content determination, but here oven dry soil is taken instead of moist soil.

Let W_1 = weight of empty pycnometer

W_2 = weight of pycnometer + soil sample (oven dry)

W_3 = weight of pycnometer + soil solids + water

W_4 = weight of pycnometer + water

Weight of solid, $W_s = W_2 - W_1$

weight of equivalent volume of water

$$= (W_4 - W_1) - (W_3 - W_2)$$

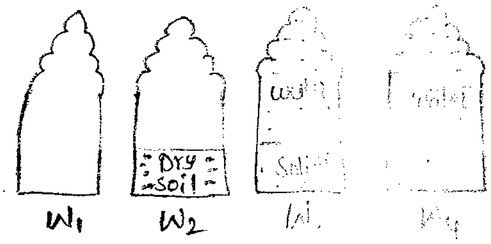


Fig: pycnometer method for determining specific gravity

$$G_s = \frac{\text{weight of solid } (W_s)}{\text{weight of equivalent volume of water}}$$

$$G_s = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_4)}$$

Note :

→ Specific gravity values are generally reported at 27°c (in India)

→ If T°c is the test temperature, then G at 27°c is given by

$$G_{27°c} = G_{T°c} \times \frac{\text{unit weight of water at } T°c}{\text{unit weight of water at } 27°c}$$

→ If kerosene (better wetting agent) is used instead of water then,

$$G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_4)} \times K$$

where K = specific gravity of kerosene

→ G can also be determined indirectly by using shrinkage limit.

Ex: A pycnometer test for the determination of water content of Soil Sample having Specific gravity of soil solids as 2.70 yielded following data:

weight of moist soil = 800 gm

weight of pycnometer with soil and filled with water = 1875 gm

weight of pycnometer filled with water only = 1545 gm

Calculate the water content of the soil.

Sol:- Given, $W_2 - W_1$ = weight of moist soil = 800 gm

W_3 = weight of pycnometer + soil + water = 1875 gm

we Know,

$$w = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)} \left(\frac{G-1}{G} \right) - 1 \right] \times 100$$

$$= \left[\frac{\text{weight of moist Sample}}{(W_3 - W_4)} \left(\frac{G-1}{G} \right) - 1 \right] \times 100$$

$$= \left[\frac{800}{(1875-1545)} \times \left(\frac{2.70-1}{2.70} \right) - 1 \right] \times 100$$

$$= [1.526 - 1] \times 100$$

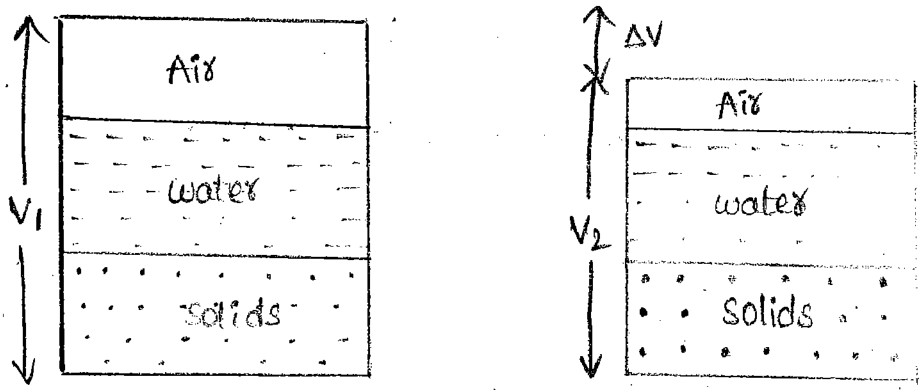
$$w = 52.63\ \%$$

Soil 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.

* principles of Compaction :

→ 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 on soil fill.



(a) Before Compaction (b) After compaction

→ 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.

Note: Compaction is Somewhat different from Consolidation. In Consolidation volume reduction takes place due to expulsion of pore water from Saturated voids.

Difference between Compaction and consolidation

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.

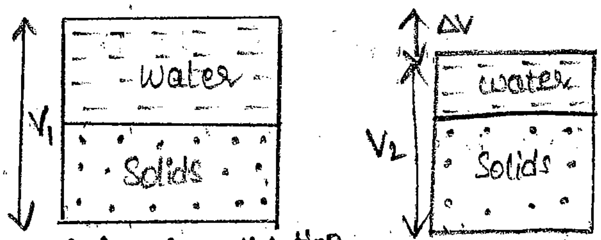
Consolidation

→ 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

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.

* Laboratory Compaction :

→ These tests are designed to estimate the dry density of soils.

→ These tests are based on any one of the following methods or type of compaction; dynamic or impact, kneading, static and vibration.

→ The tests are performed by compacting a wet soil sample in a mould in a specified number of layers.

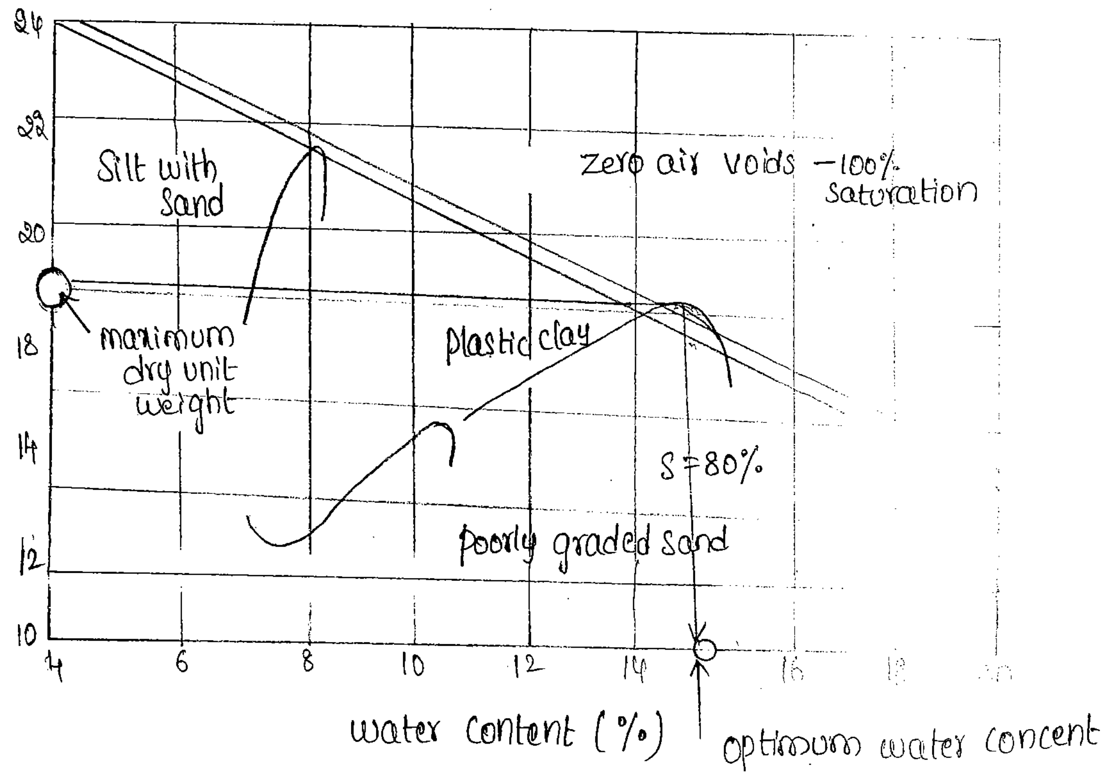
→ Each layer is compacted at specified number of blows.

→ After compaction of final layer, the bulk density of soil and corresponding moisture content are determined.

→ Test are repeated on fresh samples with changed moisture content.

$$\text{Dry density } \boxed{\rho_d = \frac{\rho_t}{1+\omega}}$$

Graph — dry density vs moisture content



* 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 unit weight $\gamma_d = \frac{\gamma}{1+w}$

γ = bulk unit weight = $\frac{\text{weight of compacted soil}}{\text{Volume of mould}}$

w = water content

→ Test is repeated at different water contents.

→ Compaction Curve is plotted between moisture content and dry unit weight.

→ The moisture content corresponding to $\gamma_{d(max)}$ is known as optimum moisture content (OMC) at a given compactive effort.

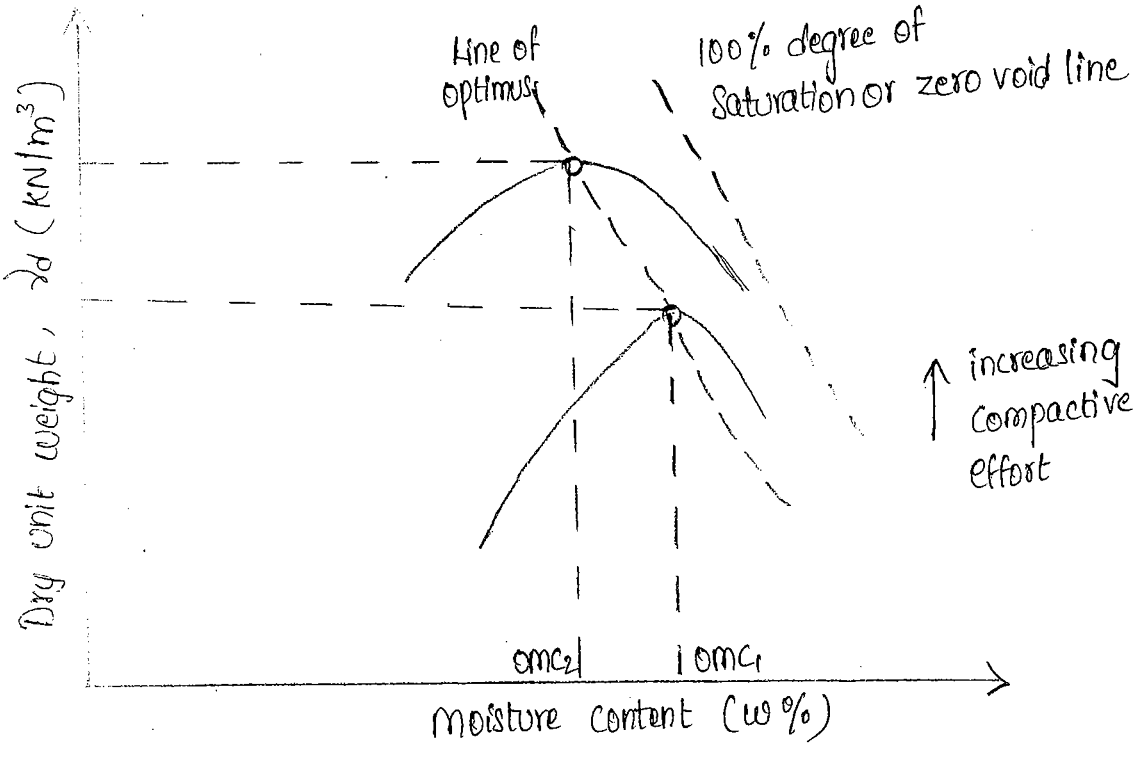


Fig: Compaction Curve

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%.

* 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.

* 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.

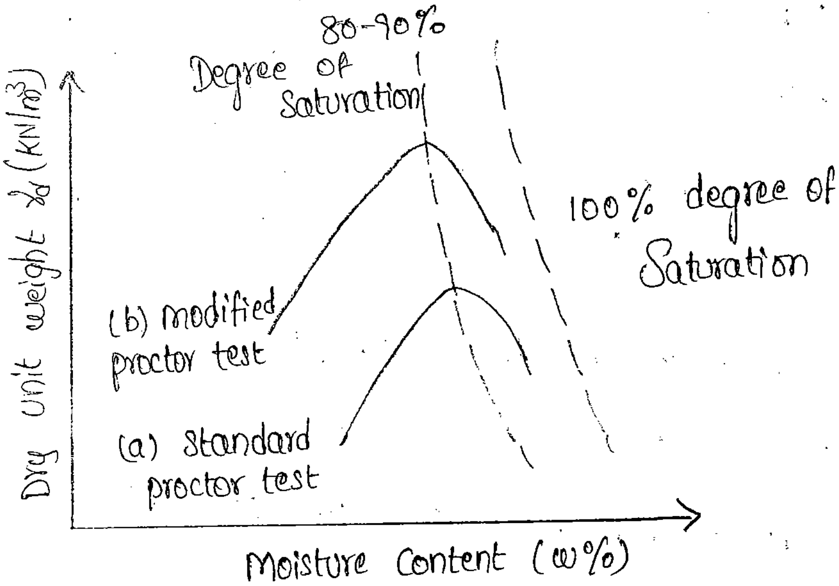
* Indian Standard Equivalent of Modified proctor test (Heavy compaction)

→ 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.

* Comparision of Standard and Modified proctor test:



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

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

where,
- n = number of layers
- 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

$$E = \frac{3 \times 25 \times 2.495 \times 304.8 \times 9.81}{944 \times 10^{-6}} = 592.71 \ KJ/m^3$$

→ Compactive energy per unit Volume in Modified proctor test

$$E = \frac{5 \times 25 \times 4.54 \times 457.2 \times 9.81}{944 \times 10^{-6}} = 2696.30 \ KJ/m^3$$

→ Compactive energy per unit Volume in light Compaction test

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

→ compactive energy per unit volume in Heavy Compaction test

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

problem: The compaction of a floor area is carried out in 250mm thick layers. The hammer used for compaction has the foot area of $0.05\ m^2$. The energy developed per drop of the rammer is 50 kg-m. Assuming 40% more energy in each pass over the compacted area due to overlap, Calculate the number of passes required to develop compactive energy equivalent to IS heavy compaction for each layer.

Sol:- Compactive energy as per IS heavy compaction test

$$= \frac{4.9\,(kgF) \times 0.45\,(m) \times 5\,(layers) \times 25\,(blows/layer)}{10^3 \times 10^{-6}\,(m^3)}$$

$$= 27562.5\ kgfm/m^3$$

Compactive energy per drop provided by the rammer per m^3 of the Soil

$$= \frac{50}{0.05 \times 250 \times 10^{-3}} = 4000\ kgfm/m^3$$

However, in each pass over a layer, the energy supplied will be 1.4 times this value on account of overlap of hammer foot print.

Let n be the number of passes required to develop compactive energy equivalent to IS heavy compaction.

$$\therefore\ n \times 1.4 \times 4000 = 27562.5$$

$$n = 4.92\ \text{Say}\ 5$$

* **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 :

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

For any degree of Saturation,

$$e = \frac{w G_s}{S}$$

$$\gamma_{d,s} = \frac{G_s \gamma_w}{1+\frac{w G_s}{S}} = \frac{\gamma_w}{\left(\frac{1}{G_s}\right)+\left(\frac{w}{S}\right)} \quad \text{—— (2)}$$

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 %.

$$\gamma_{do} = \frac{\gamma_w}{\left(\frac{1}{G_s}\right)+w} \quad \text{—— (3)}$$

where γ_{do} = dry unit weight at zero air void.

Note: Zero air voids line or Saturation line is always a steadily decreasing line.

* **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

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

$$S = 1 - \frac{n_a}{100} \qquad \text{—— (4)}$$

Substituting value of S into equation (2)

$$\gamma_d = \frac{G_s \gamma_w \left(1 - \frac{n_a}{100}\right)}{\left(1 - \frac{n_a}{100}\right) + w G_s}$$

where γ_d = dry unit weight at constant percentage air voids

problems

* 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.

Sol:- (i) we know,

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

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

$$n_a = 0.088 \text{ or } 8.80\%$$

(ii)

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

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

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

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

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

$$\rho_d = \frac{G\rho_w}{1+\frac{wG}{S}} = \frac{G\rho_w}{1+wG} = \frac{2.68\times1}{1+0.145\times2.68} = 1.93\ g/cc$$

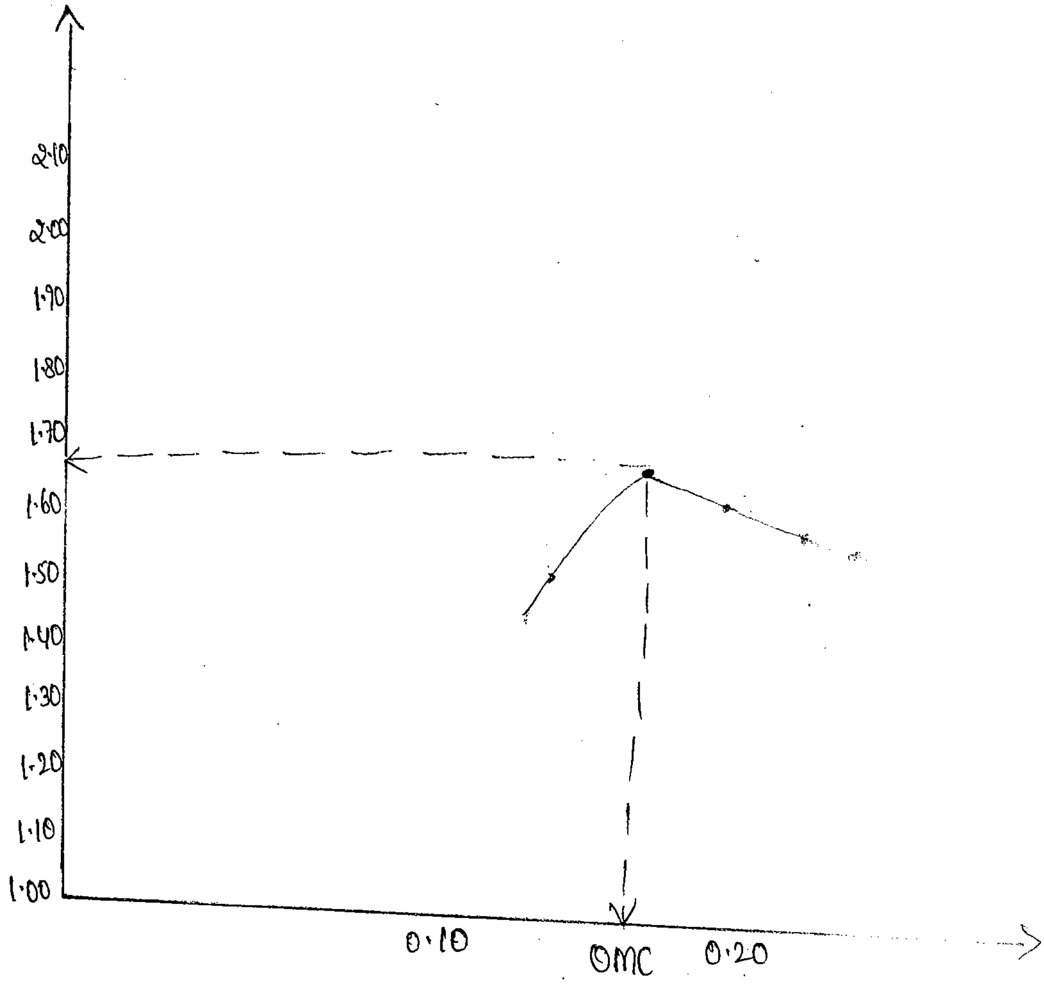
* The following results were obtained from a IS light compaction Test on sample of Soil

water content (%)	0.12	0.15	0.18	0.21	0.24
mass of wet soil (Kg)	1.65	1.95	1.93	1.90	1.86

plot the compaction curve. Hence obtain the maximum dry density and the optimum moisture content. Also calculate the void ratio the degree of saturation and the theoretical maximum dry density (G = 2.68).

Sol:-

Water Content (w)	0.12	0.15	0.18	0.21	0.24
Mass of wet soil M(Kg)	1.65	1.95	1.93	1.90	1.86
Bulk density $\rho = \frac{m}{V} = \frac{m}{1.0}$ kg/m³	1.65	1.95	1.93	1.90	1.86
Dry density $\rho_d = \frac{\rho}{1+w}$	1.47	1.69	1.67	1.57	1.5
Void ratio $e = \frac{G\rho_w}{\rho_d} - 1$	0.82	0.58	0.60	0.70	0.79
Degree of Saturation $S = \frac{wG}{e}$	0.39	0.69	0.80	0.804	0.81
Theoretical max dry density $\rho_{d(max)} = \frac{G\rho_w}{1+wG}$	2.03	1.91	1.81	1.71	1.63



From the compaction curve, $\rho_{d(max)} = 1.66$ g/cc

optimum moisture content, OMC = 0.163 or 16.3 %

Ex-3

* The results of a standard compaction test are shown in the table below. Determine the maximum dry unit weight and optimum water content.

water content (%)	6.2	8.1	9.8	11.5	12.3	13.2
Bulk unit weight (kN/m³)	16.9	18.7	19.5	20.5	20.4	20.1

(a) what is dry unit weight and water content at 95% standard compaction?

(b) Determine the degree of situation at maximum dry density.

(c) plot the zero air voids line.

Compute the γ_d and then plot the results of γ_d versus ω (%). Then extract the required information.

Water content (%)	6.2	8.1	9.8	11.5	12.3	13.2
Bulk unit weight (Kg/m³)	16.9	18.7	19.5	20.5	20.4	20.1
Dry unit weight (Kg/m³) $\gamma_d = \frac{\gamma}{1+\omega}$	15.9	17.3	17.8	18.4	18.2	17.8

$\gamma_{d(max)} = 18.4\ KN/m^3$

and optimum moisture content,

$\omega_{opt} = 11.5\%$

From Graph below,

$\therefore$ At 95% compaction, $\gamma_d = 18.4 \times 0.95 = 17.5\ KN/m^3$

water content, $\omega = 9.2\%$

(b) Degree of saturation at maximum dry unit weight

We know, $\gamma_d = \dfrac{G_s \gamma_\omega}{\left(1 + \frac{\omega G_s}{S}\right)}$

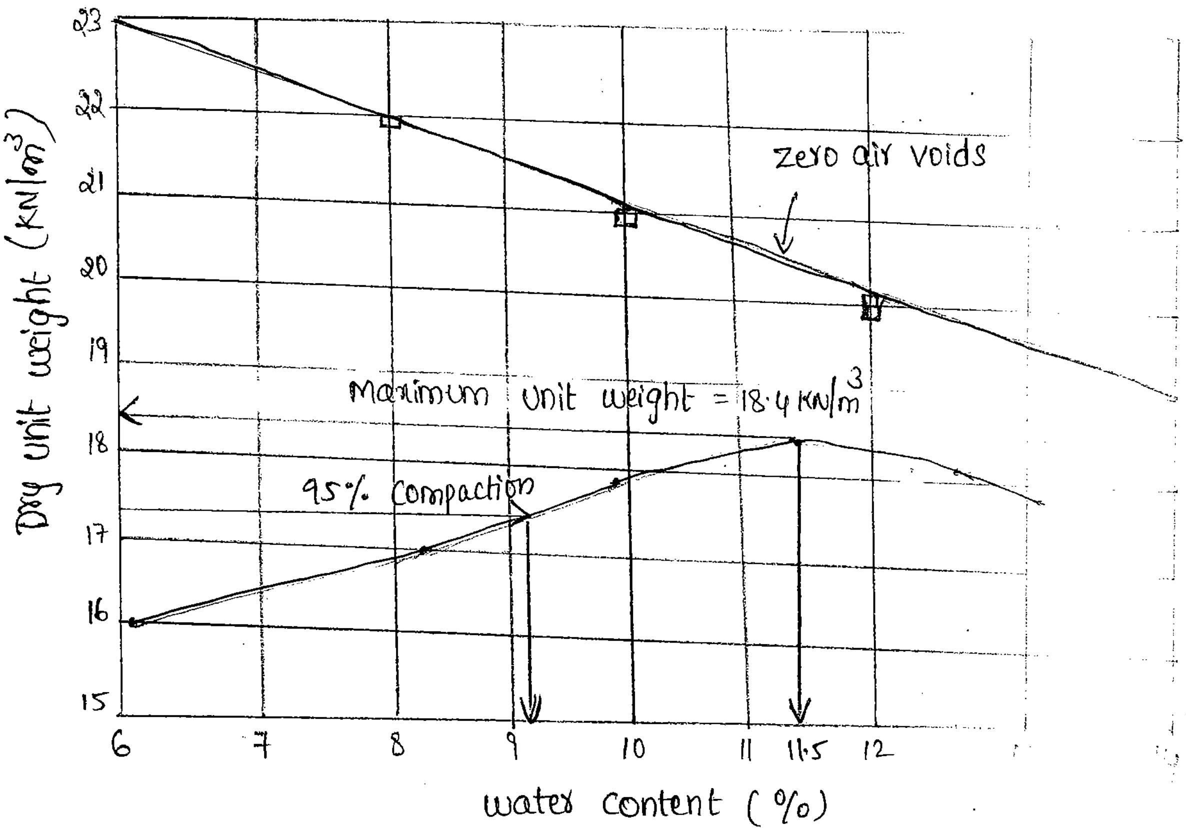
$$S = \frac{\omega G_s \gamma_{d(max)} / \gamma_\omega}{G_s - \gamma_{d(max)} / \gamma_\omega}$$

$$= \frac{0.115 \times 2.7 \times (18.4/9.8)}{2.7 - (18.4/9.8)}$$

$$= 0.71 \text{ or } 71\%$$

(c) Zero air void lines

water content (%)	6	8	10	12	14
Dry unit weight (kg/m³) $\gamma_d = \frac{G_s\gamma_\omega}{\left(1+\frac{\omega G_s}{S}\right)}$ at $S=1$	22.8	21.8	20.8	20.0	19.2



* Factors Affecting Compaction :

The major factors which affect compaction are :

(i) the water content (ii) the compactive effort

(iii) the type of soil (iv) the method of compaction

(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.

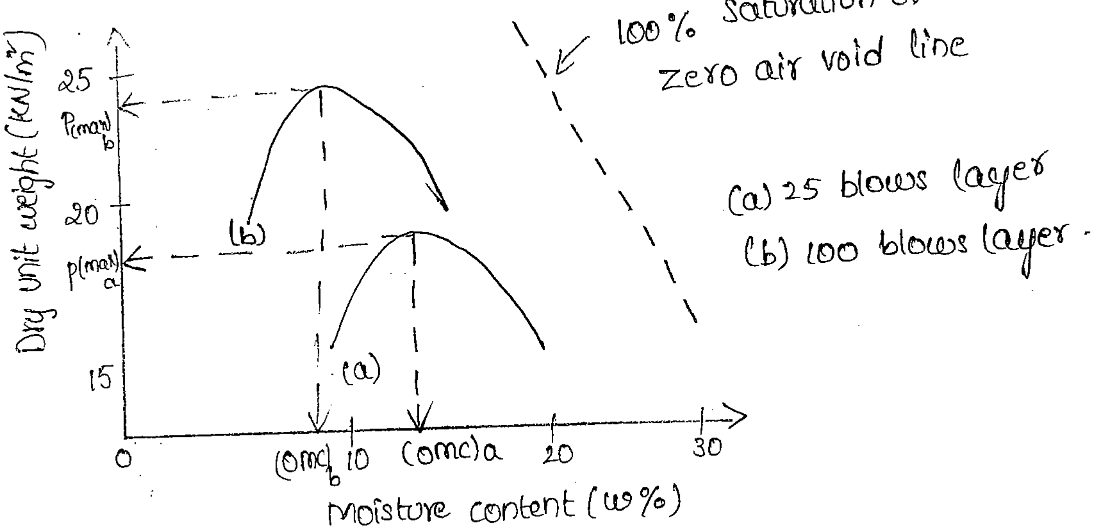
Using, $\gamma_d = \dfrac{G\gamma_w}{1+e} = \dfrac{G\gamma_w}{1+\frac{wG}{S}}$

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.



(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 clay 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.

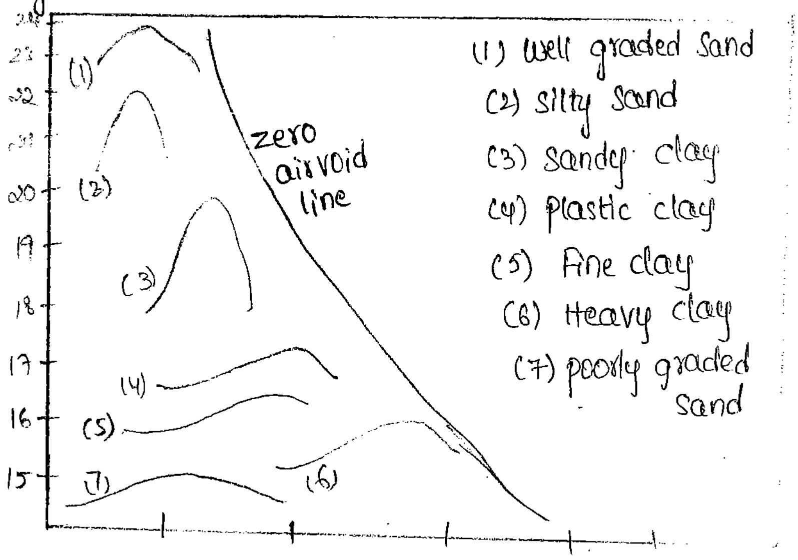


Fig: Typical proctor compaction curve for different soils.

(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.

* 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.

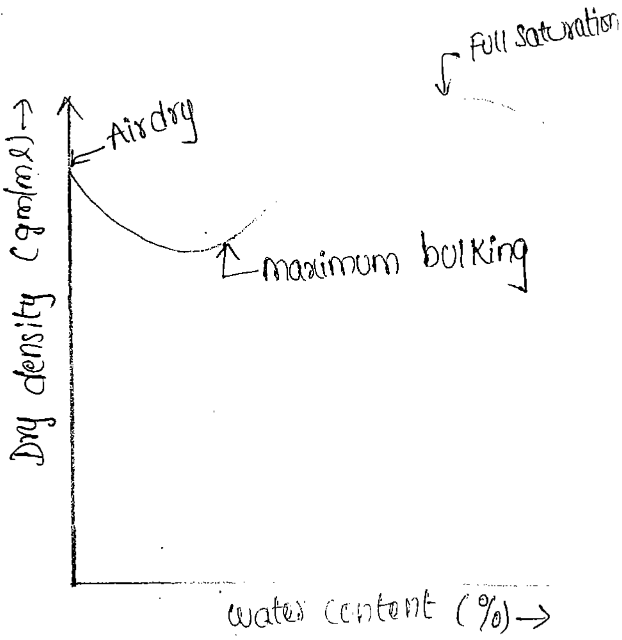


Fig: Compaction Behaviour of Sand

* Effect of compaction on properties of soils :

→ Soil Structure :

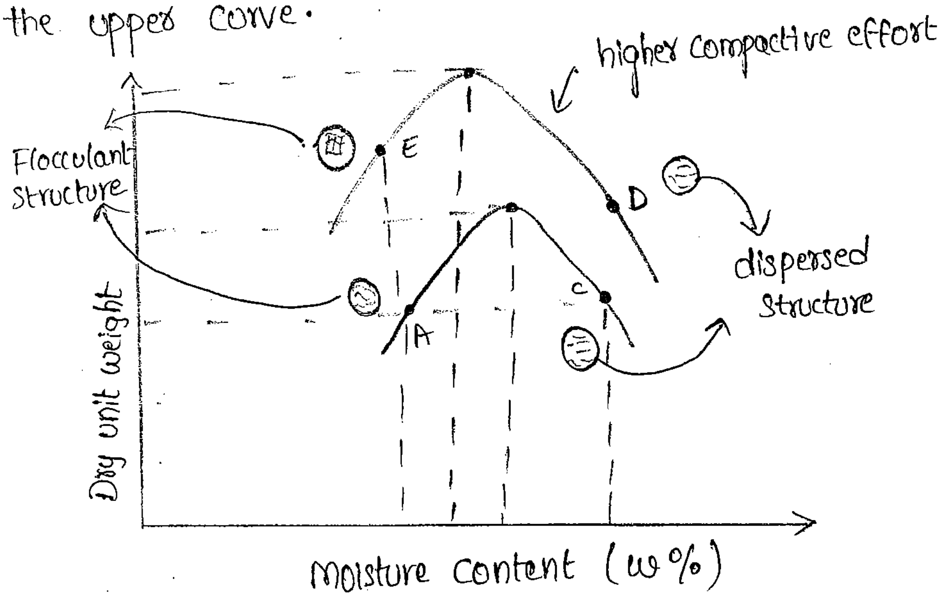
→ The water content at which the soils is compacted plays an important role in the engineering properties of the soils.

→ At low water content, attractive forces between the particles are stonger than repulsive forces.

→ 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.

→ Hence, soils compacted at a water content less than the optimum water content generally have a flocculated 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.



→ permeability :

→ The permeability of a soil depends upon the size of voids

→ 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.

Th. → Beyond OMC, the permeability may show a slight increase, but always remain much smaller than on the dry side of optimum.

→ If compactive effort is increased, the permeability of the soil decrease due to increased dry density and better orientation of particle.

→ Compressibility:

* At relatively low stress levels, a soil compacted wet side of optimum is more compressible than the soil compacted dry side of optimum.

* At higher 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.

→ 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.

→ Shrinkage:

→ soils compacted on the wet of optimum, have more order, nearly parallel orientation of particles 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.

→ Shear strength:

→ The shear strength of the compacted soils depends upon the soil type, the moulded water content, drainage conditions, the method of composition 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.

* Field compaction and Equipment:

→ 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.N.	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, trenchfills 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, airfield and earth dams.
4.	Sheep foot rollers	Clayey soils	Core of earth dams
5.	Vibratory rollers	Sands	Embankments for oil storage tanks etc.

* 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.

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

* Compaction Quality control :

The compacted dry unit weights attained in the field should be checked occasionally for quality control.

Three methods are generally used to check the in-situ density.

(i) Sand cone method

(ii) Rubber - balloon method

(iii) Nuclear density meters

(i) Sand cone method: A sand cone apparatus is shown in figure.

Procedure:

* Fill the jar with a Standard Sand of Known density.
* Determine the weight of the Sand cone apparatus with the jar filled with Sand (say W_1).
* Determine the weight of sand to fill the Cone (say W_2).
* Excavate the Small hole in the soil and determine the weight of the excavated soil (say W_3).

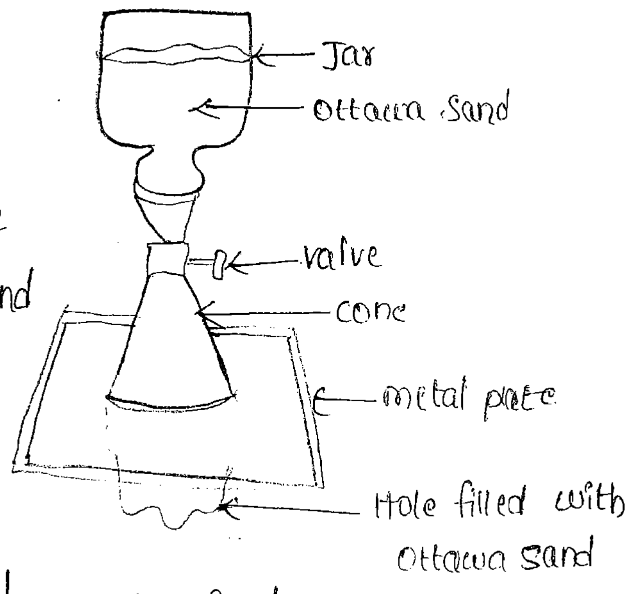


Fig: Sand cone Apparatus

Fill the hole with the standard sand by inverting the sand cone apparatus over the hole and opening the valve.

* Determine the weight of the sand cone apparatus with the remaining sand in the jar (say W_4).
* Calculate the unit weight of the soil as follows:

weight of sand to fill hole,

$$W_s = W_1 - (W_2 + W_4)$$

Volume of hole, $V = \dfrac{W_s}{\gamma_{d(sand)}}$

weight of dry soil, $W_d = \dfrac{W_3}{1+w}$

Dry unit weight, $\gamma_d = \dfrac{W_d}{V}$

(ii) Rubber – balloon Method : Figure shows balloon test apparatus

Procedure :

* Fill the cylinder with water and record its volume V_1.
* Excavate a small hole in the soil and determine the weight of the excavated soil (W).
* Determine the water content of the excavated soil(w).
* Use the pump to invert the ballon to fill the hole.
* Record the volume of water remaining in the cylinder, V_2.
* Calculate the unit weight of soil as follows:

$$\gamma = \frac{W}{V_1 - V_2} \quad ; \quad \gamma_d = \frac{\gamma}{1+w}$$

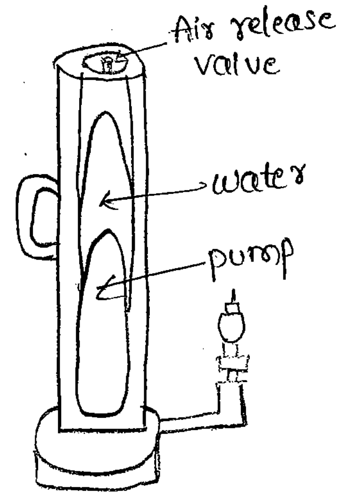


Fig: Balloon test method.

(iii) Nuclear Density Meter :

→ Nuclear density meter are used for direct determination of compacted unit weights and water content. Therefore, nuclear field density tests are much faster than conventional tests.

→ Nuclear density meter works on the principle of scattering. Soil particles cause radiation to scatter to a detector tube and the amount of scatter is counted.

→ The scatter count rate is inversely proportional to the unit weight of soil.

→ If water is present in the soil, the hydrogen in water scatters the neutrons and the amount of scatter is proportional to the water content

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

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

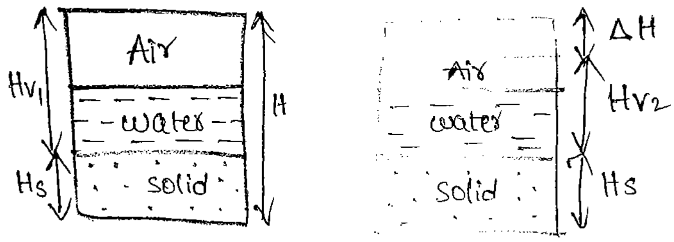


Fig: Settling compaction

$$e_0 = \frac{H_{v_1}}{H_s}$$

$$\Rightarrow H_{v_1} = e_0 H_s$$

Similarly, $H_{v_2} = e_f H_s$

$\therefore$ change in the thickness of soil layer

$$\Delta H = H_{v_1} - H_{v_2} = (e_0 - e_f) H_s$$

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

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

Problems: ① 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 percent and 60.7 % respectively. what was the degree of compaction achieved in field? Assume water content remain constant (G = 2.7)

Sol:- Given, $\gamma_{(field)} = 1738 \text{ Kg/m}^3$

$$w = 10.2\%$$

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

For laboratory sample, $w = 10.2\%$

$e = 0.607$

we know, $\gamma(lab) = \left(\frac{G+se}{1+e}\right)\gamma_w = \frac{G(1+w)}{1+e}\gamma_w$

$$= \frac{2.7(1+0.102)}{1+0.607} \times 1000 = 1851.5\ kg/m^3$$

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

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

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.

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

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

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

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

$$\boxed{e = 0.406}$$

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

(iii) Using, $se = wG$

$$s = \frac{wG}{e} = \frac{0.12 \times 2.7}{0.406} = 0.798 \text{ or } 79.8\%$$

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

3. During a Compaction test, a soil attains the maximum dry unit weight of 18.6 KN/m^3 at a water Content of 15 percent. The Specific gravity of soil is 2.7. Determine the degree of Saturation, air content at the maximum dry unit weight. what would be the maximum theoretical dry density corresponding to zero air voids at optimum water Content?

Sol:- Given, $\gamma_{d(max)} = 18.6$ KN/m^3

OMC, $w = 15\%$ or 0.15

Using, $\gamma_d = \dfrac{G\gamma_w}{1+\frac{wG}{S}}$

$$18.6 = \frac{2.7 \times 9.81}{1+\frac{0.15 \times 2.7}{S}}$$

$$1+\frac{0.405}{S} = 1.424$$

$$S = 0.955 \text{ or } 95.5\%$$

$$\text{Air content} = \frac{V_a}{V} = 1-S$$

$$= 1-0.955$$

$$= 0.045 \text{ or } 4.5\%$$

At omc of 15%, the theoretical maximum dry density will occur when air voids reduce to zero i.e. soil is completely saturated (S=1).

$$\gamma_{d(max)} = \frac{G\gamma_w}{1+\frac{wG}{S}} = \frac{2.7 \times 9.81}{1+\frac{0.15 \times 2.7}{1}} = 18.85 \text{ KN/m}^3$$

(4) As per the Compaction Specification, a highway fill has to be Compacted to 90% of IS light compaction test dry density. A borrow pit available near the project site has a dry density of 1.78 g/cc at 100% compaction and a void ratio of 0.63. Compute the volume of borrow material needed to construct a highway fill of height 5m and length 1.5 m with side slope of 1:2. The top width of the fill is 10.5 m. G = 2.7.

Sol:- Given, $\rho_{d(borrow)} = 1.78$ g/cc,

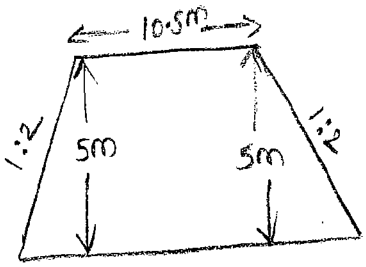
$e_{(borrow)} = e_b = 0.63$, $G = 2.7$

Base width of highway fill = 2(2×5) + 10.5

= 30.5 m

Volume of highway fill = $\frac{1}{2}$ (10.5 + 30.5) × 5 × 1500

= 153750 m^3



Dry density of highway fill (90%)

= 0.9 × 1.78

= 1.602 g/cc

To find void ratio of fill :

we know $\rho_{d(fill)} = \frac{G\rho_w}{1+e_f}$

$1.602 = \frac{2.7 \times 1}{1+e_f}$

$e_f = 0.685$

Since volume of soil solid remain constant in both borrow pit and fill,

Hence $\frac{V_b}{1+e_b} = \frac{V_f}{1+e_f}$

$V_b = \frac{1+e_b}{1+e_f} \times V_f = \frac{1+0.63}{1+0.685} \times 153750 = 57486\ m^3$

(5) The in-situ void ratio of a granular soil deposit is 0.59. The void ratios in loosest and densest state were found to be 0.81 and 0.37 respectively. Determine the relative density and relative compaction of the soil deposit. G = 2.7.

Sol:- Given $e = 0.59$, $e_{max} = 0.81$, $e_{min} = 0.37$

Relative density (% I_D) $= \frac{e_{max} - e}{e_{max} - e_{min}} \times 100\%$

$= \frac{0.81 - 0.59}{0.81 - 0.37} \times 100$

= 50 %

$\gamma_{d(max)} = \frac{G\gamma_w}{1+e_{min}} = \frac{2.7 \times 9.81}{1+0.37} = 19.33\ KN/m^3$

$$\gamma_{d(in-situ)} = \frac{G\gamma_w}{1+e} = \frac{2.7 \times 9.81}{1+0.59} = 16.65 \ KN/m^3$$

$$\text{Relative compaction} = \frac{\gamma_{d(in-situ)}}{\gamma_{d(max)}} = \frac{16.65}{19.33} \times 100 = 86.13\%$$

6) In IS light compaction test, the bulk unit weight of soil sample was found to be 18 KN/m³ 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~~]

$G = 2.68$

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

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

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

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

(ii) Void ratio at 53.56% saturation

$$e = \frac{wG}{S} = \frac{0.13 \times 2.68}{0.5356} = 0.65$$

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

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

∴ Additional water content required for complete saturation

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

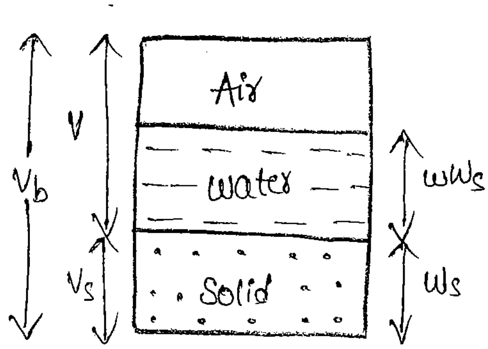
(7) In the construction of levee by compacting soil excavated from a borrow area to dry density of 1.78 g/cc, to make the compaction process more workable, an optimum water content of 15% is necessary.

However the natural moisture content and bulk density of the soil were 9% and 1.83 g/cc respectively. Find out the quantity of water to be added for every 100 m^3 of finished embankment.

Sol:- For embankment Given :

$\gamma_{d(max)} = 1.78\ g/cc = 1.78\ t/m^3$

$W_s = 1.78 \times 100 = 178$ tonns



Borrow area

The weight of water needed in embankment

$W_w = wW_s = 0.15 \times 178 = 26.7$ ton

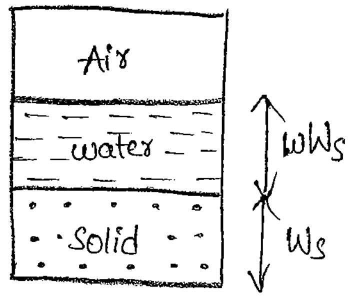
For borrow area given : $\gamma_t = 1.83\ g/cc = 1.83\ t/m^3$

$w = 9\%$ or 0.09

$$\gamma_t = \frac{\text{Weight of soil}}{\text{Volume of soil}} = \frac{W_s + W_w}{V_b} = \frac{W_s(1+w)}{V_b}$$

$$1.83 = \frac{178(1+0.09)}{V_b}$$

$$V_b = 106.02\ m^3$$



Finished embankment 100 (m^3)

Weight of water present in the soil taken from borrow area, $W_w = wW_s = 0.09 \times 178$

$= 16.02$ ton

Therefore quantity of water to be added

$= 26.70 - 16.02 = 10.68$ ton

$\therefore$ volume of water to be added $= \frac{W_w}{\rho_w} = \frac{10.68}{10^{-3}} = 10680$ litres

Note :

→ Soil Compaction is the process of increasing the density of the soil by applying some mechanical energy and thereby reducing air voids.

→ Factors affecting the compaction of a soil are moisture content, compactive effort and method of compaction.

→ Higher compactive effort increases the maximum dry unit weight and reduces the optimum water content.

Comparison of properties of cohesive soil on dry and wet sides of OMC.

property	Dry optimum	Wet of optimum
Structure after compaction	Flocculated (random)	Dispersed (oriented)
water deficiency	more	less
permeability	more, isotropic	less isotropic ($K_H > K_V$)
compressibility		
at low stress	low	Higher
at high stress	High	lower
Swellability	High	low
Shrinkage	low	High
Stress strain behaviour	Brittle; high peak higher elastic modulus	Ductile; no peak lower elastic modulus.
construction pore water pressures	low	High
Strength (undrained) as moulded after saturation	High Somewhat higher if swelling prevent	Much lower low

Problem-1:

compare the compactive energy used in the IS heavy compaction test with that of the IS light compaction test.

Solution:

compactive energy in IS heavy compaction test

$$= \frac{4.9(kgf) \times 0.45(m) \times 5(layers) \times 25\ (blows/layer)}{10^3 \times 10^{-6} (m^3)}$$

$= 27562.5\ kgf\ m/m^3$.

compactive energy in IS light compaction test

$$= \frac{2.6(kgf) \times 0.31(m) \times 3(layers) \times 25\ (blows/layer)}{10^3 \times 10^{-6} (m^3)}$$

$= 60450\ kgf\ m/m^3$.

IS heavy compaction test uses 4.56 times the compactive energy that is used in the IS light compaction test.

Problem-2:

The compaction of an embankment is carried out in 300mm thick lifts (layers). The rammer used for compaction has the foot of area 0.05 sq. m. The energy developed per drop of the rammer is 40 kg m. Assuming 50 percent more energy in each pass over the compacted area due to overlap, calculate the number of passes required to develop compactive energy equivalent to IS light compaction for each layer.

Solution:

compactive energy as per IS light compaction test

$$= \frac{2.6(kgf) \times 0.31(m) \times 3(layers) \times 25}{10^3 \times 10^{-6} (m^3)}$$

= 60450 kgf m/m³

ompactive energy per drop provided by the rammer per cum of the soil

$$= \frac{40}{0.05 \times 300 \times 10^{-3}}$$

$$= 2666.67 \, kgf \, m/m^3$$

However, in each pass over a layer, the energy supplied will be 1.5 times this value on account of overlap of rammer footprints. If n is the number of passes required to develop compactive energy equivalent to IS light compaction.

$$n \times 1.5 \times 2666.67 = 60,450$$

$$n = 15.11 \cong 16$$

Problem-3:

The in situ 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. Gs =2.67. Determine the relative density and relative compaction of the deposit.

Solution:

$$\text{Relative density} = \frac{e_{max} - e_{nat}}{e_{max} - e_{min}} \times 100\%$$

$$= \frac{0.75 - 0.50}{0.75 - 0.35} \times 100$$

$$= 62.5\%$$

$$\gamma_d(max) = \frac{G_s \gamma_w}{1+e_{min}} = \frac{2.67 \times 9.8}{1+0.35} = 19.38 \, KN/m^3$$

$$\gamma_d(min) = \frac{G_s \gamma_w}{1+e_{max}} = \frac{2.67 \times 9.8}{1+0.75} = 14.95 \, KN/m^3$$

$$\gamma_d(in\ situ) = \frac{G_s \gamma_w}{1+e_{in\ situ}} = \frac{2.67 \times 9.8}{1+50} = 17.44 \, KN/m^3$$

Relative compaction $\frac{\gamma_{d(in\ situ)}}{\gamma_{d(max)}} = \frac{17.44}{19.38} \times 100$

$= 89.9\%$

Problem - 4:

A compacted fill is to be constructed using one of the two potential borrow areas A and B. The in situ properties of soil at these sites are as follows:

Borrow area A : $e_n = 0.80$; $W_n = 17.5\%$, $G_s = 2.65$

Borrow area B : $e_n = 0.68$; $W_n = 14.0\%$, $G_s = 2.65$

The compacted volume of the embankment will be $50,000\ m^3$, its unit weight $20\ KN/m^3$ at a placement water content of 20%.

Soil from the borrow area is to be excavated and transported to the site in trucks of $10\ m^3$ capacity. During excavation and dumping of soil in the trucks, the soil increases in volume by 10% at the site, the required additional amount of water is added to the soil and compacted to the desired extent by pneumatic rubber tyred rollers. The cost of excavation, transportation and compaction is Rs 400 per truck for borrow area A and Rs 500 per truck for borrow area B. Water charges per truck is Rs 150.

Which of the two borrow areas is more economical?

Solution:

Embankment : $\gamma_t = 20 KN/m^3$; $V = 50,000 m^3$; $W = 20\%$

Weight of soil $= \gamma_t \times V \Rightarrow 20 \times 50,000 \Rightarrow 10^6 KN$

Weight of solids $= \frac{W}{1+w} \Rightarrow \frac{10^6}{1+0.2} \Rightarrow 8.33 \times 10^5 KN$

Weight of water $= 10^6 - (8.33 \times 10^5) \Rightarrow 1.67 \times 10^5 KN$

Volume of solids = $\frac{\quad}{2.65 \times 9.8}$ = 32,075 m^3

These values are shown in the phase diagram as below.

Borrow area A : $e_n = 0.80$

Volume of soil needed to have 32,075 m^3 of solids is

$= 32075 (1 + 0.8)$

$= 57,736 m^3$

Number of truck trips required to be made making allowance for 10% increase in volume

$= \frac{57,736 \times 1.1}{10}$

$= 6,351$

Amount of water present in 57,736 m^3 of soil

$= W_n \times W_s$

$= 0.175 \times 8.33 \times 10^5$

$= 1,45,775 KN$

Additional amount of water needed = 1,67,000 − 1,45,775

= 21,225 KN

Number of truck loads required to transport water

$= \frac{21,225}{10 \times 9.8}$

$= 217$

Cost of excavation, transport and compaction of soil

$= 6351 \times 400$

$= 25,40,400$ Rs.

Cost of transport of water = 217×150

= 32,550 Rs.

Total cost of using soil from borrow area A = 25,40,400 + 32,550

= 25,72,950 Rs

Borrow area B: $e_n = 0.68$

Volume of soil needed to contain 32075 m^3 of solids

= 32,075 (1 + 0.68)

= 53,886 m^3

Number of truck trips required to be made = $\frac{53,886 \times 1.1}{10}$

= 5,928

Amount of water present in 53,886 m^3 of soil = $W_n \times W_s$

= $0.14 \times 8.33 \times 10^5$

= 1,16,620 m^3

Additional account of water needed = 1,67,000 − 1,16,620

= 50,380 KN

Number of truck trips required to transport water

= $\frac{50,380}{10 \times 9.8}$

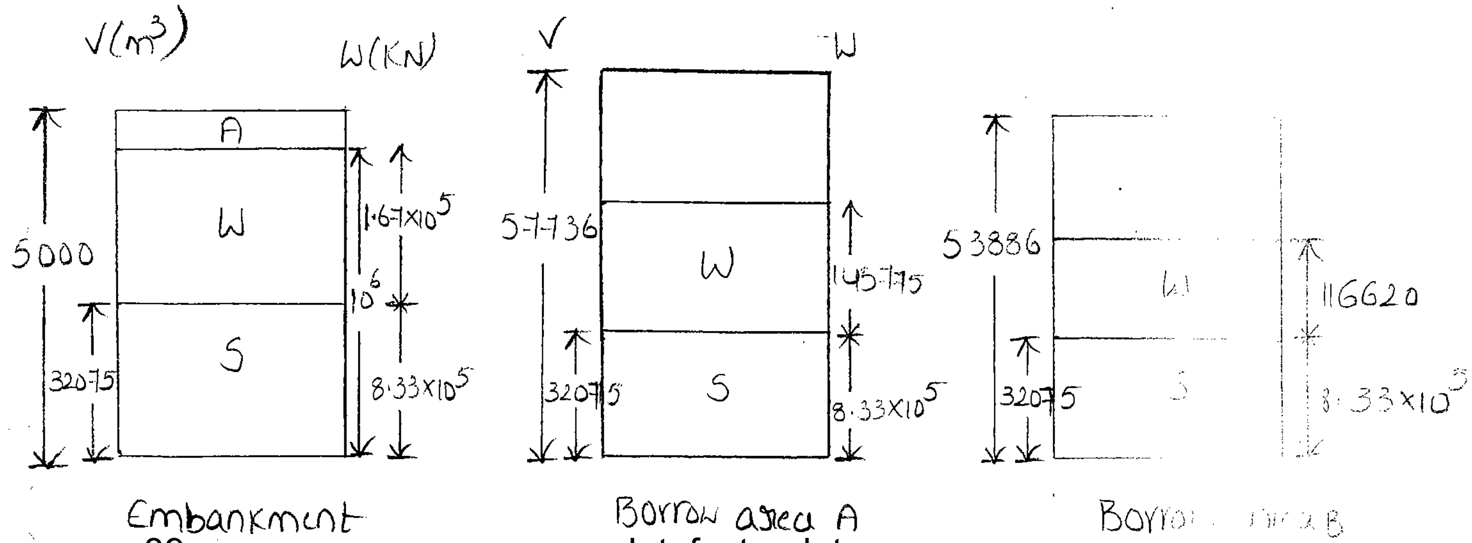
= 514

Total cost of using borrow area B = 5,928 × 500 + 514 × 150

= 29,64,000 + 77,100

= Rs 30,41,100

Using borrow area A is, therefore, more economical.



The following data refers to a compaction test as per Indian standard (light compaction):

Water content (%)	8.5	12.2	13.75	15.5	18.2	20.2
weight of wet sample (kg)	1.80	1.94	2.00	2.05	2.03	1.98

If the specific gravity of soil grains was 2.7,

i) Plot the compaction curve and obtain the maximum dry unit weight and the optimum moisture content

ii) Plot the 80 % and 100% saturation lines

iii) If it is proposed to secure a relative compaction of 95 % in the field, what is the range of water content that can be allowed, and

iv) would the 20% air voids curve be the same as the 80% saturation curve.

Solution:

In the Indian standard (light compaction) test, a cylindrical mould of volume 1,000 cc is used. The wet unit weight can be obtained by dividing the weight of wet sample by the volume of the mould. As the water content is known, the dry unit weight can be found by the equation.

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

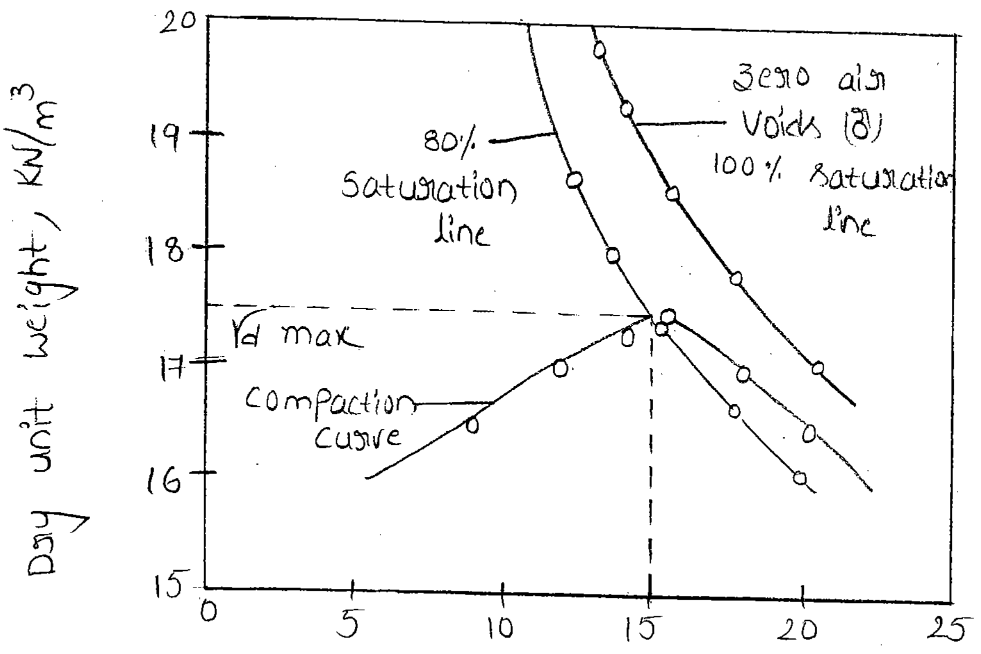
The dry unit weight of a soil compacted at a certain content to achieve a certain degree of saturation can be calculated using the equation.

$$\gamma_d = \frac{G\gamma_w}{1+\left(\frac{wG}{S}\right)} \text{ (given } G=2.7)$$

The calculations can be made and tabulated as below:

Water content (%)	8.5	12.2	13.75	15.5	18.2	20.2
Dry unit weight γ_d (KN/m^3)	16.26	16.94	17.23	17.39	16.83	16.14
γ_d for S = 80% (KN/m^3)	20.56	18.74	18.07	17.37	16.39	15.73
γ_d for S = 100% (KN/m^3)	21.52	19.89	19.30	18.65	17.74	17.12

i) The compaction curve is the plot between W and γ_d and is shown in fig.



from the figure,

maximum dry unit weight = 17.45 KN/m^3

optimum moisture content = 15.17%

ii) The 80 and 100% saturation lines can be drawn by using tabulated values. They are shown in fig.

iii) Relative compaction = $\frac{\gamma_d \text{ field}}{\gamma_d \text{ max}} \times 100$

$$95 = \frac{\gamma_d \text{ field}}{17.45} \times 100$$

$$\gamma_d \text{ (field)} = 16.58 \text{ KN/m}^3$$

[illegible]
field is 10 to 17%

iv) $\gamma_d = \dfrac{G\gamma_w(1-n_a)}{1+wG}$

for $w = 8.5\%$, $n_a = 0.2$, $\gamma_d = \dfrac{2.7 \times 9.8(1-0.2)}{1+0.085 \times 2.7}$

$= 17.22\ kN/m^3$

Which is different from $20.56\ kN/m^3$ for $S = 80\%$ and $w = 8.5\%$. Hence the 20% air voids curve is not the same as the 80% saturation curve.