

19/08/20

Geotechnical Engineering

Branch - Civil Engg.
Sem - 5th

Module - I

- origin of soil
- Rock cycle & the origin of soil
- clay mineralogy
- weight volume relationship.
- specific gravity
- Unit weight, void ratio, moisture content & relationship
- Relative density
- Mechanical analysis of soil.
- Grain size distribution curve
- Particle shape and size
- Consistency of soil
- Atterberg limits - Liquidity index, consistency - index
- Activity of soil, soil structure problem.
- Engineering classification of soil
- Types of soil classification
- IS classification, USCS, HRB and ASTM.

Introduction :-

- The term soil has various meanings.
- To an agriculturist, soil is the substance existing on the earth surface which grows and develops plant life.
 - To the geologist, soil is the material in the relatively thin surface zone within which roots occur.
 - To an engineer, soil is the unaggregated mass of mineral.

Pt 2
Sugges-

Definition:-

Geotechnique is one of the youngest disciplines of civil Engineering involving the study of soil.

→ Soil mechanics was discovered by Dr. Terzaghi.

→ Soil mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated solid particles produced by mechanical or chemical disintegration of rocks.

Agricultural f Engineering, Soil

Top soil :- A layer of organic soil not more than 500mm thick is often found.

organic soil :- Humus (highly organic partly decomposed vegetable matter).

Sub soil :- portion of earth crust affected by current weathering and lying between the top soil and unweathered soil below.

Rock cycle :

→ The cycle consists of weathering or denudation, transportation, deposition and upheaval, again followed by weathering and so on.

→ Weathering are two types.

① Physical weathering

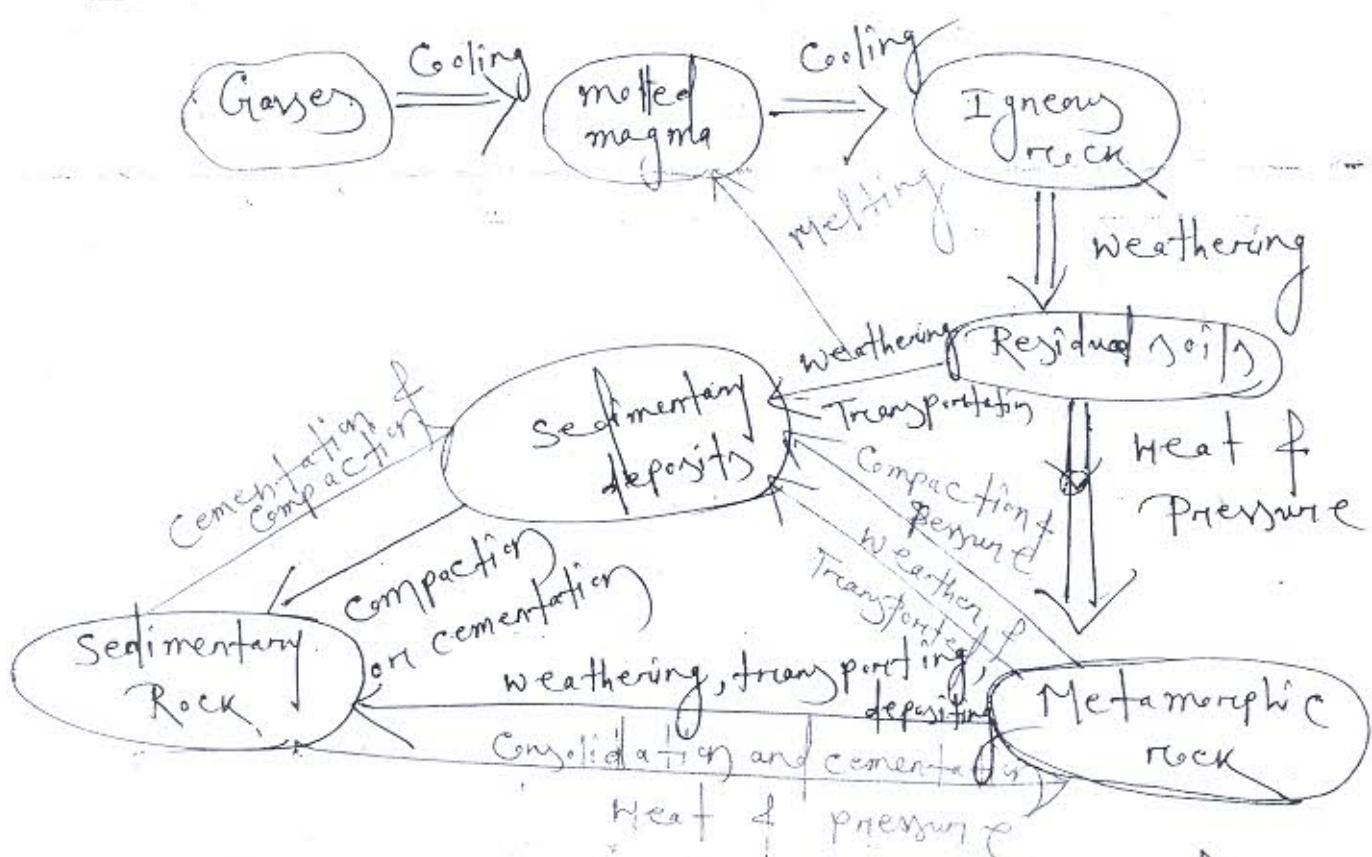
② Chemical weathering.

→ weathering is caused by the following factors such as periodical temperature changes, impact and splitting action of flowing water, ice and wind and splitting actions of ice, plants and animals.

- Cohesionless soils are formed due to physical disintegration of rocks.
- chemical weathering may be caused due to oxidation, hydration, carbonation and leaching by organic acids and water.
- clay minerals are produced by chemical weathering.
- soil obtained by due to weathering may be residual or translocated.
- Residual soil :- It is placed directly over the parent rock.
- Transported soil :- The various agencies of transporting and redepositing soils are water, ice, wind and gravity.
 - Soil transported by water → Alluvial, marine soil or lacustrine.
 - Soil transported & deposited by glacier → Drift.
 - Soil transported by wind → ex. Loess.
 - By gravitational forces → Aeolian soil
 - By gravitational forces → Colluvial soil

21/08/20 Soil:- The soft geological deposits from the subsoil to the bedrock. In some soils there is certain amount of cementation bet' the grains which affect the physical properties of the soil. If this cementation is such that a rock hard material has been produced then the material must be described as rock.

Rock cycle:-

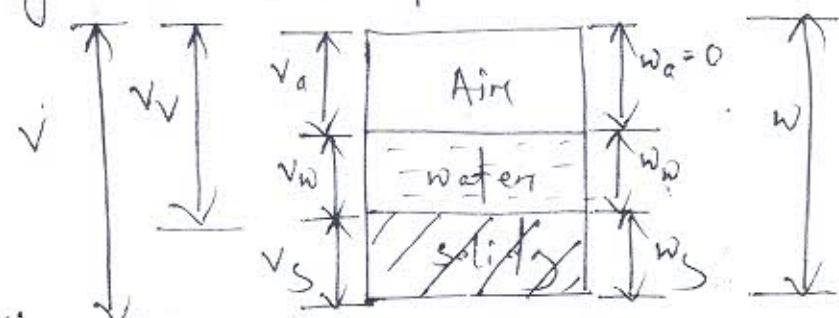


→ Rocks are made from various types of minerals. Minerals are substances of crystalline form makeup from a particular chemical combination. The main minerals in rocks include quartz, feldspar, calcite & mica. Geologists classify all rocks into three basic groups - Sedimentary and Metamorphic.

→ Preliminary relationships and definitions

Soil as a three phase diagram

→ A soil may be a three phase system consisting of solid particles called soil grains, water and air.



⇒ Soil Engineering :-

→ Soil Engineering is an applied science dealing

with the application of principles of soil mechanics to practical problems.

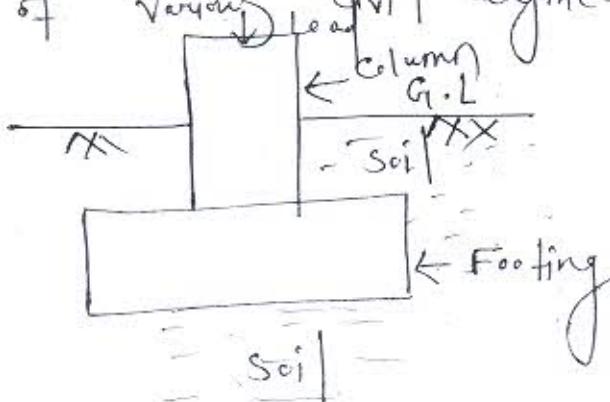
→ It includes site investigations, design and construction of foundations, earth retaining structures and earth-structures.

Geotechnical engineering :-

→ Geotechnical engineering is a broader term which includes soil engineering, rock mechanics and geology.

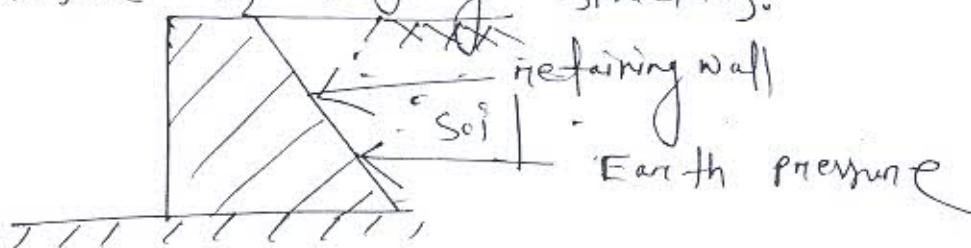
⇒ Scope of soil engineering :-

→ Soil engineering has vast application in the construction of various Civil Engineering works.



- 1) Foundations :- Every civil engineering structure where it is building, a bridge or a dam is founded on or below the surface of the earth.
- Foundations are required to transmit the load of the structures to soil safely and efficiently.
- Foundations engineering is an important branch of soil engineering.
- 2) Retaining structure :- When sufficient space is not available for a mass of soil to spread and form a safe slope, a structure is required to retain the soil.

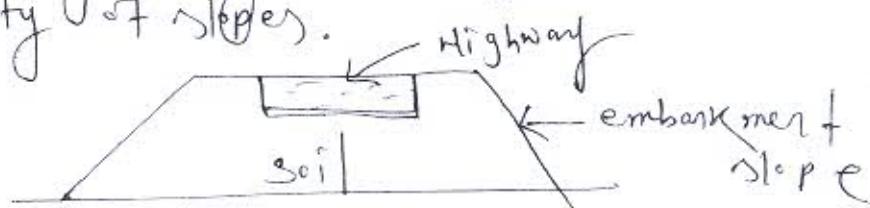
→ Soil engineering gives the theory of earth pressure on retaining structures.



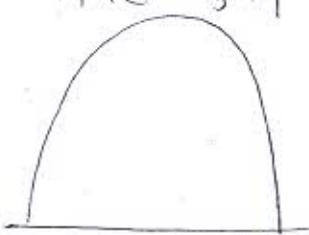
Retaining wall.

3) stability of slopes :- If soil surface is not horizontal, there is a component of weight of the soil which tends to move it downward and thus causes instability of slopes.

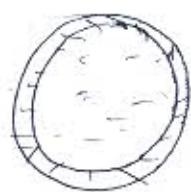
→ Soil engineering provides the method of stability of slopes.



4) Underground structure :- The design and construction of underground structures such as tunnels, shafts and conduits require evaluation of forces exerted by the soil on these structures.



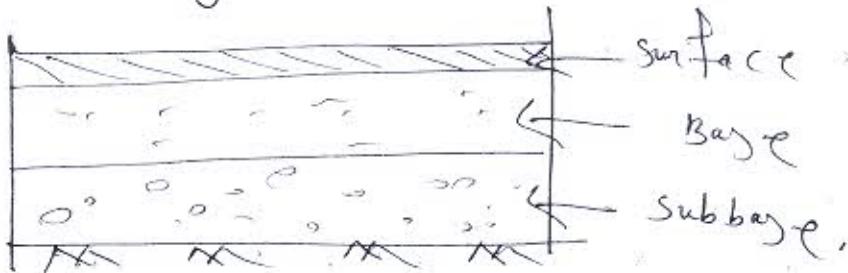
Tunnel



Conduit

5) Pavement design

→ A pavement is a hard crust placed on soil (subgrade) for the purpose of providing a smooth and strong surface on which vehicles can move.

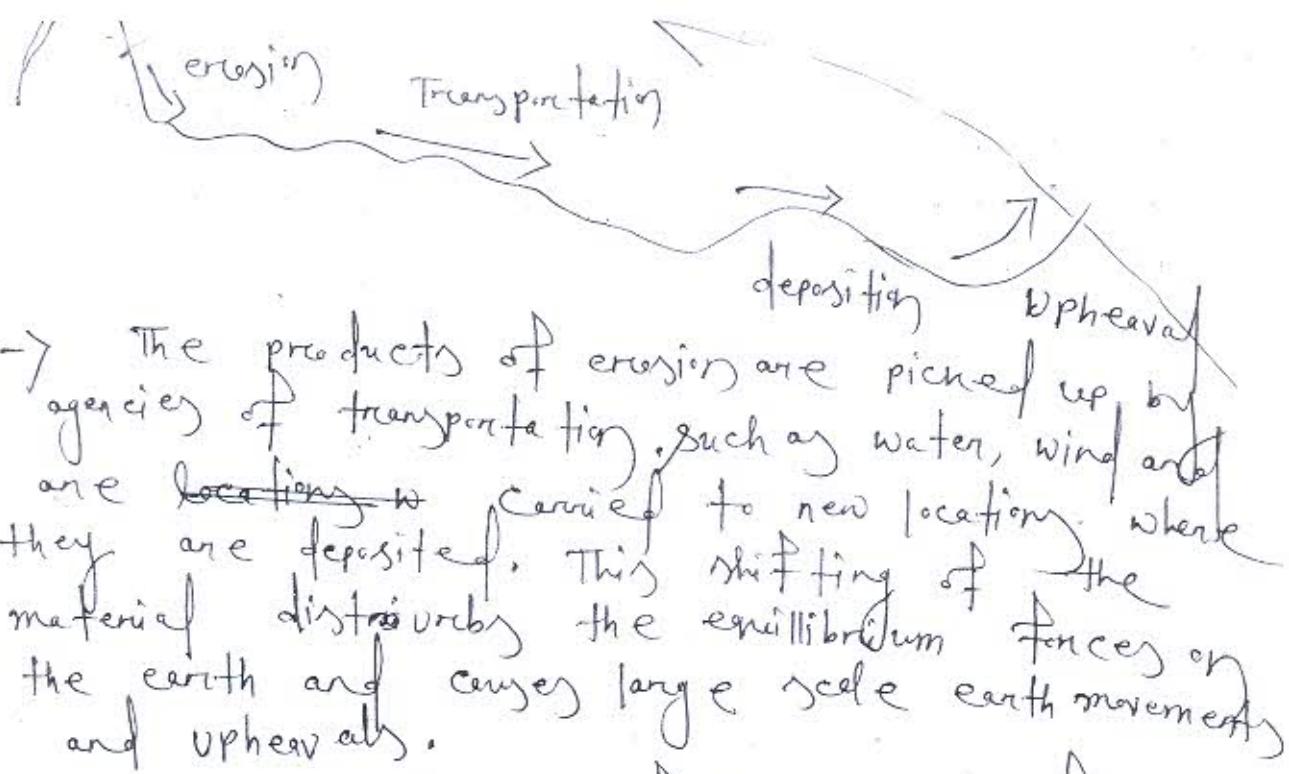


⇒ Origin of soils

→ Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition. When a rock surface gets exposed to atmosphere for an appreciable time, it disintegrates and decomposes into small particles and thus the soils are formed.

→ Soil may be considered as an incidental material obtained from the geologic cycle which goes on continuously in nature.

→ The soil-making cycle consists of four stages:



→ The products of erosion are picked up by agencies of transportation, such as water, wind and are ~~location~~ carried to new locations where they are deposited. This shifting of the material disturbing the equilibrium forces of the earth and causes large scale earth movements and upheavals.

This process results in further exposure of rocks and the geologic cycle gets repeated.

Residual soil

→ If the soil stays at the place of its formation or just above the parent rock it is known as residual soil or pedogenic soil.

Transported soil:

→ When the soil has been deposited at a place away from the ~~metopic~~ place of its origin it is called a transported soil.

Formation of soil

soils are formed by

- Physical disintegration
- Chemical deposition of rocks.

Igneous rock :- These rocks have become solid from a melted liquid state. Extrusive igneous rocks are those that arrived on the surface of the earth as molten lava & cooled. Intrusive igneous rocks are formed from magma (molten rock) that forced itself through cracks into rock beds below the surface & solidified there.

Ex:- Granite, Basalt, gabbro.

Sedimentary rock :- Weathering reduced the rock mass to fragmented particles, which can be more easily transported by wind, water and ice. When dropped by the agents of weathering they are termed sediments. These sediments are typically deposited in layers on beds called strata and when compacted and cemented together they form sedimentary rocks.

ex:- shale, sandstone, chert.

Metamorphic rock :- Metamorphism through high temperature & pressure acting on sedimentary or igneous rocks produces metamorphic rocks. The original rock undergoes both chemical & physical alterations.

ex:- slate, quartzite & marble.

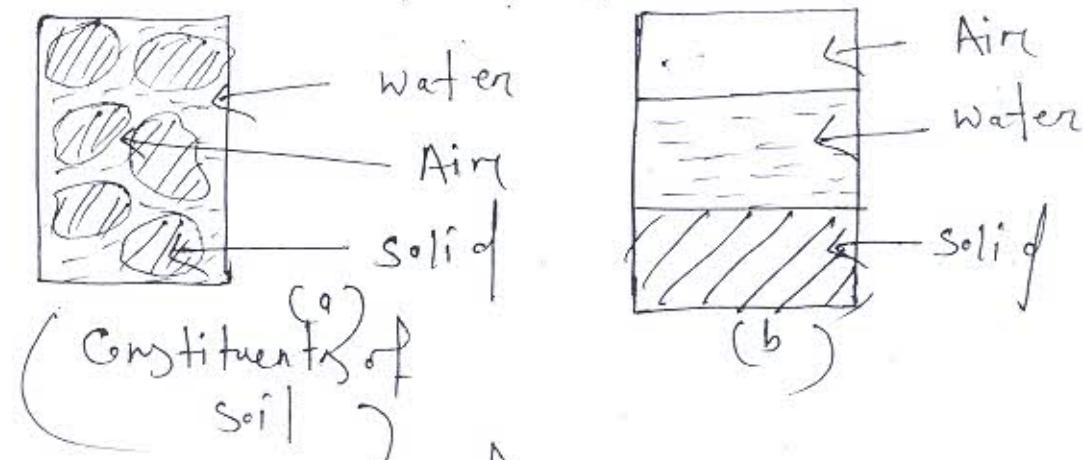
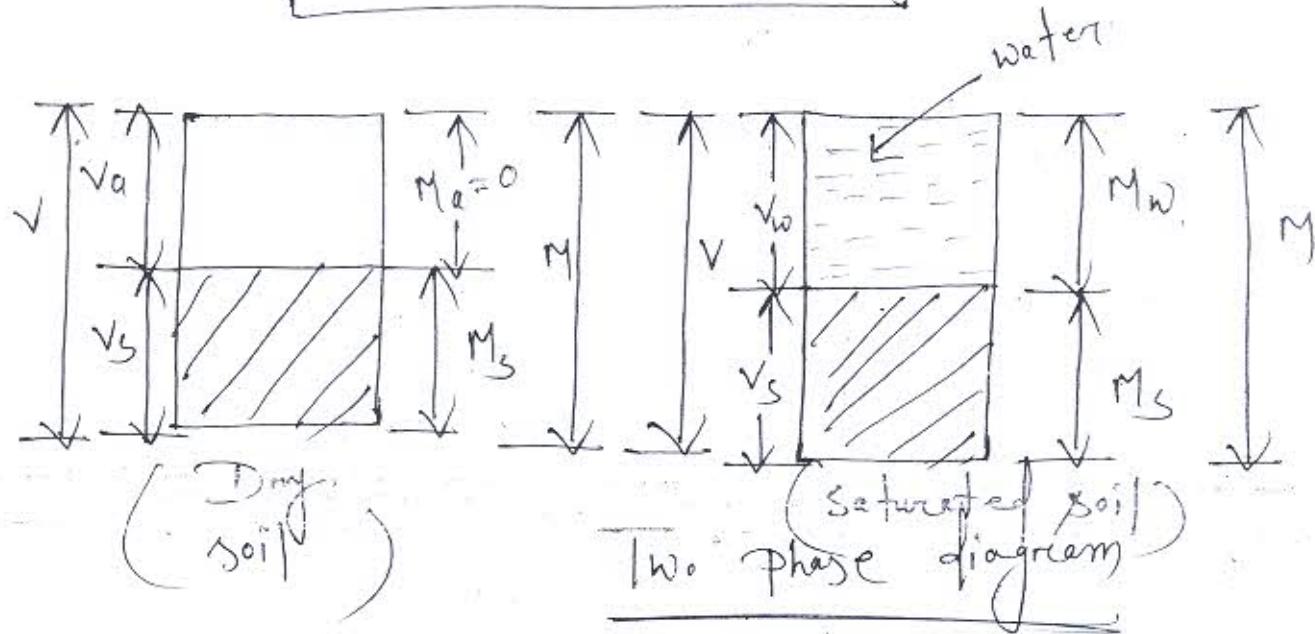
~~24/08/20~~ Terminology of different types of soils.

- 1) Bentonite :- It is a type of clay with a very high percentage of clay mineral montmorillonite.
It is a highly plastic soil.
- 2) Black Cotton Soil :- It is a residual soil containing a high percentage of the clay mineral montmorillonite.
- 3) Boulders - Boulders are rock fragments of large size, more than 300 mm in size.
- 4) Clay - Clay is fine grained soil. The particle size is less than 0.002 mm.
- 5) Gavel - Gavel is a type of coarse grained soil. The particle size ranges from 4.75 mm to 80 mm.
- 6) Cobbles - Cobbles are large size particles in the range of 80 mm to 300 mm.
- 7) Humus - It is a dark brown, organic amorphous earth of the top soil. It consists of partly decomposed vegetal matter.
- 8) Loom - It is a mixture of sand, silt & clay.
- 9) Sand - It is a coarse grained soil having particle size between 0.075 mm to 4.75 mm.
- 10) Silt - It is a fine grained soil with particle size between 0.002 mm and 0.075 mm.
- 11) Cohesive soils :- Soil in which the adsorbed water and particle attraction act such that it deforms plasticity at varying water contents.

12) Chesson's Law (σ₀₁₁)

Non plastic silts and coarse grained soils are Chesson's law.

$$1\text{m} = 10^6 \text{m} = 10^{-3} \text{mm}$$



- where,
- $V_a \rightarrow$ volume of air
 - $V_w \rightarrow$ volume of water
 - $V_v \rightarrow$ volume of voids
 - $V \rightarrow$ Total volume of soil mass
 - $M \rightarrow$ Total mass of the soil
 - $M_a \rightarrow$ Mass of air
 - $M_s \rightarrow$ Mass of solid

(A) Physical deposition (or disintegration) :-

→ physical disintegration or mechanical weathering of rocks occurring due to physical process.

1) Temperature changes:-

Different minerals of a rock have different coefficients of thermal expansion.

2) Wedging action of ice:-

When in the pores and minute cracks of rocks gets frozen in very cold climates.

3) Abrasion:- As water, wind and glacier move over the surface of rock, abrasion and scouring takes place. It results in the formation of soil.

(B) Chemical decomposition:-

→ When chemical decomposition or chemical weathering of rocks takes place, original rock minerals are transformed into new minerals by chemical reactions.

- 1) Hydration
- 2) Carbonation
- 3) Oxidation
- 4) Solution
- 5) Hydrolysis.

⇒ Translocation of soil :-

The soils formed at a place may be transported to other places by agents of translocation, such as water, wind, ice and gravity.

- 1) Water transported soils.
- 2) Wind transported soils.
- 3) Glacier-deposited soils.

→ Soil deposited by water in river bed - ~~Alluvial~~ Alluvial soils.

→ Soil deposited by water in lake - lacustrine soils.

→ Soil deposited by wind → Aeolian soils.

→ Soil transported by glaciation → ~~Glacial~~ Drift.

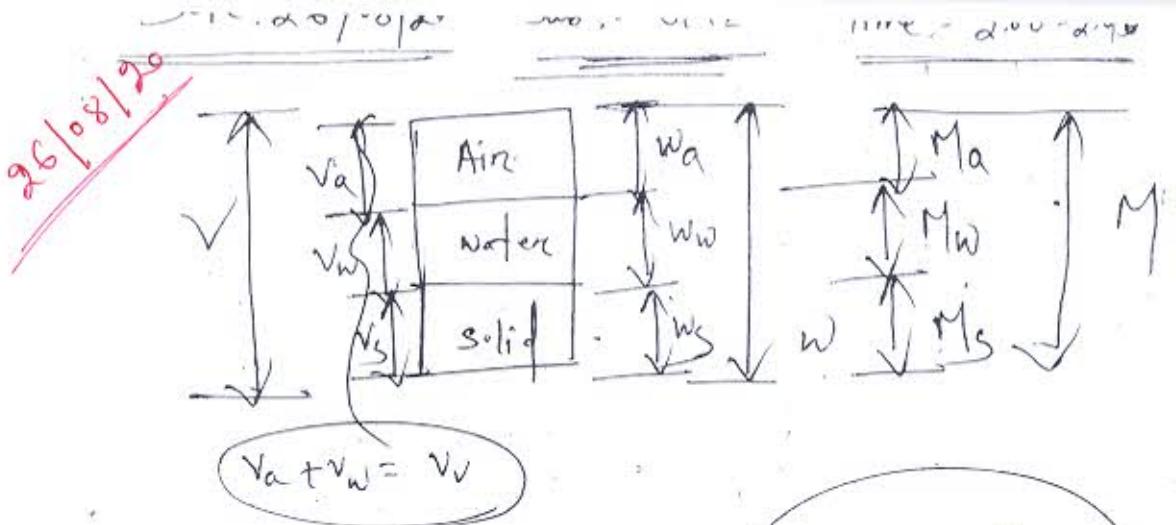
4) Gravity deposited soils → colluvial soils.

5) Soils transported by combined action.

Major soil deposits of India :-

- 1) Alluvial soils.
- 2) Black cotton soils.
- 3) Lateritic soils.
- 4) Desert soils.
- 5) Marine deposits.

* Black cotton soils are clays of high plasticity.
ex:- Montmorillonite



$$e = \frac{V_v}{V} \quad \left. \begin{array}{l} \\ \end{array} \right\}$$

$$n = \frac{V_v}{V}$$

$$e = \frac{n}{1-n}$$

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

$$\eta_{re} = \frac{V_w}{V_v}$$

$$(V_v = V_a + V_w)$$

$$\eta_a = \frac{V_a}{V}$$

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

$$\eta_a = n \cdot a_c$$

Water Content (w)

→ Moisture Content

$$w = \frac{M_w}{M_s}$$

Units

Force → Newton (N)

Mass = (m)

Length = (L)

Time (T) → sec

~~$1 mg = 10^{-3} g m$~~

$1 Mg = 10^6 g m = 10^3 kg$

SI

$1 mN = 10^{-3} N$

$1 KN = 10^3 N$

$1 MN = 10^6 N = 10^3 kN$

Volume mass relationship

$$\frac{\text{Mass of soil}}{\text{Unit volume}} = \text{Mass density}$$

kg/m^3

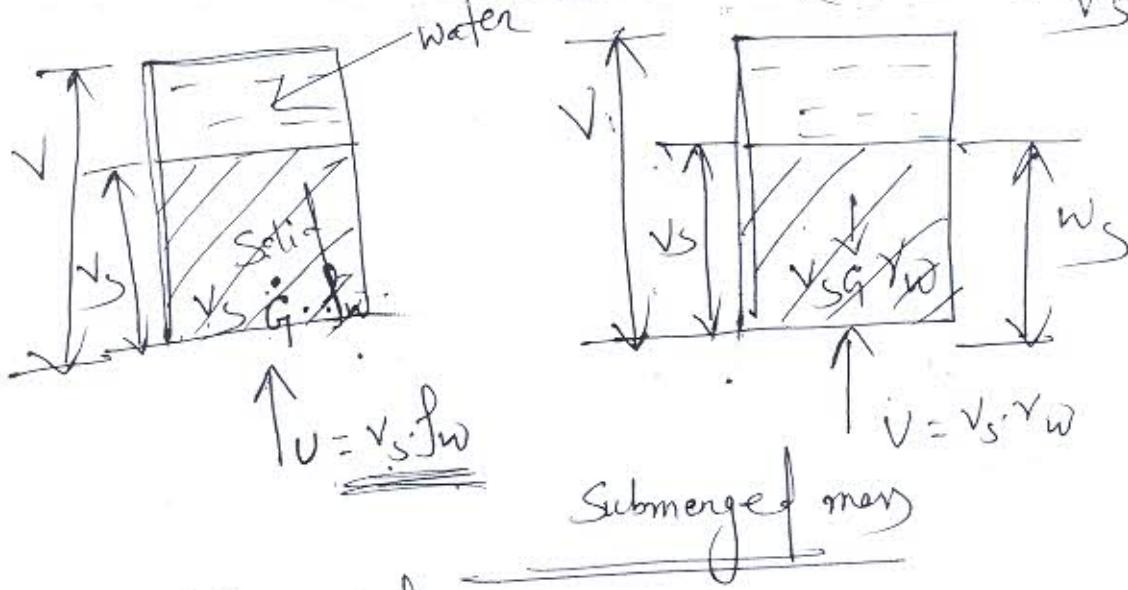
$$\underline{\text{Bulk mass density}} (\delta) = \frac{\text{Total mass} (M)}{\text{Total volume} (V)}$$

$$2) \underline{\text{Dry mass density}} (\delta_d) = \frac{\text{Mass of solid}}{\text{Total volume}} = \frac{M_s}{V}$$

$$3) \underline{\text{Saturated mass density}} (\delta_{sat}) = \frac{M_{sat}}{V}$$

~~$$4) \underline{\text{Submerged mass density}} (\delta') = \frac{\text{Submerged mass}}{\text{Volume}} = \frac{M_{sub}}{V}$$~~

~~$$5) \underline{\text{Mass density of solid}} (\delta_s) = \frac{M_s}{V_s}$$~~



$$M_{sub} = M_s - V$$

$$= V_s \cdot G \cdot \delta_w - V_s \cdot \delta_w$$

$$\therefore \underline{\delta' = \frac{M_{sub}}{V}} = \frac{V_s \delta_w (G-1)}{V} \Rightarrow \underline{\delta' = \frac{V_s \delta_w (G-1)}{V}}$$

$$\therefore \underline{\delta' = \frac{V_s \delta_w (G-1)}{V}}$$

$$M_{sat} = M_s + V \cdot f_w$$

$$V = V \cdot f_w$$

$$M_{sub} = (M_s + V f_w) - V f_w$$

$$\frac{\gamma'}{\gamma} = \frac{(M_s + V f_w) - V f_w}{V}$$

$$\Rightarrow \gamma' = \frac{M_{sat} - V f_w}{V}$$

$$= \frac{M_{sat}}{V} - \frac{V f_w}{V}$$

$$\boxed{\gamma' = \gamma_{sat} - f_w}$$

Volume weight relationship

$$(Unit weight) = \frac{\text{weight of soil}}{\text{volume}}$$

→ Specific weight.

$$① \text{ Bulk unit weight } = \gamma = \frac{w}{V} \quad (\text{kN/m}^3 \text{ or N/m}^3)$$

$$② \text{ Dry unit weight } = \gamma_d = \frac{w_s}{V}$$

$$③ \text{ Saturated } \gamma = \gamma_{sat} = \frac{w_{sat}}{V}$$

$$④ \text{ Submerged } \gamma = \gamma' = \frac{w_{sub}}{V}$$

$$⑤ \text{ Unit weight of soil/solid } = \gamma_s = \frac{w_s}{V_s}$$

1 2 3 4 5

specific weight of solid

(G)

$$G = \frac{f_s}{f_w}$$

Solid \rightarrow S.G. = $G = 2.65 - 2.80$

Mars specific gravity

$$G_m = \frac{f}{f_w}$$

Absolute specific gravity

$$G_a = \frac{(f_s)_a}{f_w}$$

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$w \rightarrow$ Total weight of soil mass
 $w_w \rightarrow$ Weight of water.
 $w_s \rightarrow$ weight of solid
 $w_a \rightarrow$ weight of air.

\Rightarrow Weight volume relationship :-

- 1) volumetric relationships
- 2) volume weight relationships
- 3) volume mass relationships.

volumetric relationship :-

Void ratio (e): It is defined as the ratio of the volume of voids to the volume of solids.

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

Generally $e = 0.4, 0.5$.

It may have a value even greater than unity.

2) porosity :- (η)

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

$$\eta = \frac{V_v}{V}$$

→ Generally it is expressed as percentage.

→ Porosity is also called as percentage voids.

→ It cannot exceed 100%.

Relationship between 'e' & 'n'

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

$$\eta = \frac{v_v}{v}$$

$$= \frac{(v_a + v_w)}{v}$$

$$\frac{1}{\eta} = \frac{v}{v_v} = \frac{v_v + v_s}{v_v}$$

$$= \frac{v_v}{v_v} + \frac{v_s}{v_v}$$

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

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

$$\Rightarrow \frac{1}{\eta} = \frac{e+1}{e}$$

$$\Rightarrow \eta(e+1) = e$$

$$\Rightarrow \boxed{\eta = \frac{e}{1+e}}$$

$$\therefore \frac{1}{\eta} = \frac{1+e}{e}$$

$$\Rightarrow \frac{1}{\eta} = \frac{1}{e} + 1$$

$$\Rightarrow \frac{1}{\eta} - 1 = \frac{1}{e}$$

$$\Rightarrow \frac{1}{e} = \frac{1-\eta}{\eta}$$

$$\Rightarrow e(1-\eta) = \eta$$

$$\Rightarrow \boxed{e = \frac{\eta}{1-\eta}}$$

3) Degree of Saturation (S_s):- It is the ratio of the volume of water to the volume of voids.

$$S_s = \frac{V_w}{V_v}$$

* It is zero when the soil is absolutely dry and 100%.

4) Percentage of voids (n_a):- When the soil is fully saturated.

→ It is ratio of the volume of air to the total volume.

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

→ It expressed as %.

5) Air Content (a_c):-

Air content is defined as the ratio of the volume of air to the volume of voids.

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

Relationship between % air voids and the air content.

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

$$n_a = a_c \times n$$

$$n_a = n \times a_c$$

Water Content

→ Water content (w) is defined as the ratio of the mass of water to the mass of solid.

$$w = \frac{M_w}{M_s}$$

→ Water content is also called as moisture content (m). It is expressed as percentage.

Units :-

Mass = m

Mass is expressed as = Kilogramme

Length = (L)

(kg)

Time = (T)

Force is expressed as = Newton

(N)

$$\{ 1 \text{ milligramme (mg)} = 10^{-3} \text{ gm}$$

$$1 \text{ kg} = 10^3 \text{ gm}$$

$$1 \text{ Mg} = 10^6 \text{ gm} = 10^3 \text{ kg}$$

$$1 \text{ MN (millinewton)} = 10^3 \text{ N}$$

$$1 \text{ KN} = 10^3 \text{ N}$$

$$1 \text{ MN (meganewton)} = 10^6 \text{ N} = 10^3 \text{ kN}$$

Volume mass relationships

→ The mass of soil per unit volume is known as mass density.

$$[d - M]$$

Bulk mass density:

→ The bulk mass density is also known as the wet mass density.

$$1 \text{ Mg/m}^3 = 1000 \text{ kg/m}^3 = 1 \text{ gm/ml}$$

→ Bulk density (γ) is defined as the total mass (M) per unit total volume (V)

$$\gamma = \frac{M}{V}$$

2) Dry mass density :- (γ_d)

→ It is defined as the mass of solids per unit total volume.

$$\gamma_d = \frac{M_s}{V}$$

→ It is also known as the dry density.

3) Saturated mass density (γ_{sat})

→ It is the bulk mass density of the soil when it is fully saturated.

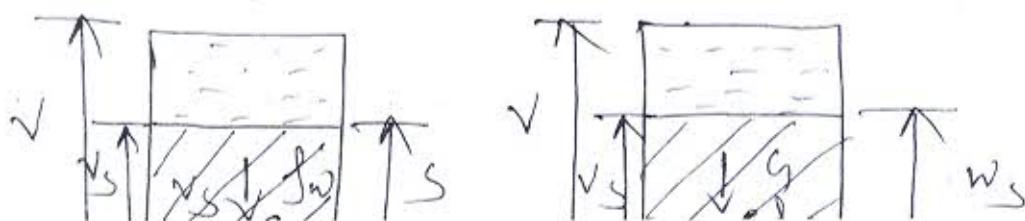
$$\gamma_{sat} = \frac{M_{sat}}{V}$$

4) Submerged mass density :- When the soil exists below water, it is in a submerged condition.

→ It is defined as the submerged mass per unit of total volume.

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

→ It is also called as buoyant mass density (γ_b).



$$V = V_s f_w$$

$$M_{sub} = M_s - V$$

$$= \cancel{V_s} g f_w - V_s f_w$$

$$\boxed{f' = \frac{V_s f_w (g-1)}{V}}$$

$$\Rightarrow M_{sat} = M_s + V_v f_w$$

$$V = V_v f_w$$

$$M_{sub} = (M_s + V_v f_w) - V_v f_w$$

$$\frac{M_{sub}}{V} = \frac{(M_s + V_v f_w) - V_v f_w}{V}$$

$$f' = \frac{M_{sat}}{V} - f_w \quad \left(\frac{M_{sub}}{V} = f' \right)$$

$$\boxed{f' = f_{sat} - f_w}$$

Mass density of solid: (f_s)

The mass density of solid is equal to the ratio of the mass of solids to the volume of solids.

$$\boxed{f_s = \frac{M_s}{V}}$$

Volume weight relationship:

→ The weight of soil per unit volume is known as unit weight or specific weight).

1) Bulk unit weight :- It is defined as the total weight per total volume.

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Dry unit weight

→ γ_d is defined as weight of solids per unit total volume.

$$\gamma_d = \frac{w_s}{V}$$

Saturated unit weight

→ γ_s is the bulk unit weight when the soil is fully saturated.

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

Submerged unit weight

→ γ' is defined as the submerged weight per unit of total volume

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

5) Unit weight of soil solids :- γ_s is equal to the ratio of the weight of solids to the volume of solids.

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

* When the soil exists below water, it is in a submerged condition. A buoyant force acts on the soil solids. According to Archimedes principle the buoyant force is equal to the weight of water displaced by the solids. The net mass of the solids is reduced. The reduced mass is known as submerged mass or buoyant mass.

$$V = V_s \gamma_w$$

$$w_{sub} = w_s - V$$

$$= V_s G \gamma_w - V_s \gamma_w$$

$$= V_s \gamma_w (G-1)$$

$$\therefore \frac{w_{sub}}{V} = \frac{V_s \gamma_w (G-1)}{V}$$

$$\Rightarrow \gamma' = \frac{V_s \gamma_w (G-1)}{V}$$

$$\gamma' = \gamma_{sat} - \gamma_w$$

(The buoyant force (V) is equal to the weight of water displaced by the solids.

$$w_{sub} = (w_s + V \gamma_w) - V \gamma_w$$

$$\gamma' = \frac{(w_s + V \gamma_w) - V \gamma_w}{V}$$

$$= \frac{w_{sat} - V \gamma_w}{V}$$

$$\gamma' = \sqrt{V} \cdot \gamma$$

(influence) between Mass and Weight units.

The mass and weight are related by Newton's law of motion.
i.e. $\boxed{\text{Force} = \text{Mass} \times \text{Acceleration}}$

$$\text{Unit weight} = \gamma = w/v$$

$$\text{Mass density } (\rho) = m/v$$

$$\therefore \gamma = \frac{w}{v} = \frac{m \cdot g}{v} = \rho \cdot g$$

$$\text{Unit weight } (N/m^3) = \text{Mass density } (kg/m^3) \times 9.81$$

ex:- For water $\rho_w = 1000 \text{ kg}/\text{m}^3$

$$\gamma_w = 1000 \times 9.81 = 9.81 \text{ kN}/\text{m}^3$$

$$1 \text{ kg}/\text{cm}^2 = 10^4 \text{ kg}/\text{m}^2$$

$$= 10^4 \times 9.81 \text{ N}/\text{m}^2$$

$$= 98.1 \text{ kN}/\text{m}^2 = 98.1 \text{ kPa}$$

Specific gravity of solids :-

→ g_t is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water.

$$\boxed{G_t = \frac{\rho_s}{\rho_w}}$$

* The specific gravity of solids for most natural soils falls in the general range 2.65 to 2.80.

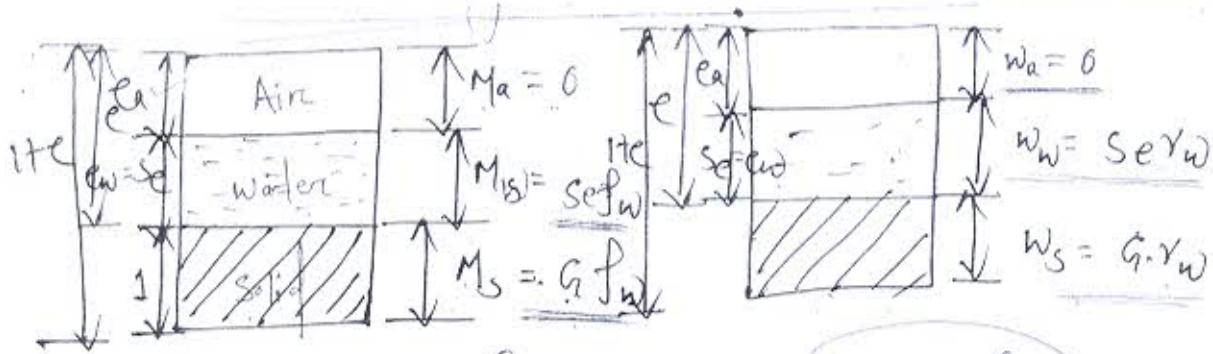
Mass specific gravity

→ g_m is defined as the ratio of the mass density of the soil to the mass density of water.

$$\boxed{G_m = \frac{\rho_s}{\rho_w}}$$

Absolute specific gravity

→ The mass density of the absolute solids (ρ_s) is used for the determination of the absolute specific



$$\text{porosity } (\eta) = \frac{V_v}{V} = \frac{e}{1+e}$$

$$\text{degree of saturation } (S_r) = \frac{V_w}{V_v} = \frac{e_w}{e}$$

$$\text{volume of air } V_a = (e - S_e) = e(1-S) \quad V_a + V_w = V_v$$

$$\% \text{ of air voids}, n_a = \frac{V_a}{V} = \frac{e(1-S)}{1+e}$$

$$\text{air Content } a_c = \frac{V_a}{V_v} = \frac{e(1-S)}{e} = 1-S$$

$$\text{density } (\delta) = \frac{M}{V} = \frac{M_s + M_w}{1+e} = \frac{G f_w + S e f_w}{1+e}$$

$$\boxed{\delta = \frac{(G+S_e) f_w}{1+e}}$$

$$\delta_d = \frac{M_s}{V} = \frac{G f_w}{1+e} \Rightarrow \boxed{\delta_d = \frac{G f_w}{1+e}}$$

$$\delta_{sat.} = \frac{M_{sat}}{V} \Rightarrow \boxed{\delta_{sat.} = \frac{(G+e) f_w}{1+e}}$$

$$\delta' = \delta_{sat.} - \delta_w = \frac{(G+e) f_w}{1+e} - f_w$$

$$\boxed{\delta' = \frac{(G-1) f_w}{1+e}}$$

$$\delta' = \frac{(G+S_e) f_w}{1+e} - f_w$$

$$\boxed{\delta' = \delta_{sat.} - \delta_w}$$

$1+e$

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

$$\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e}$$

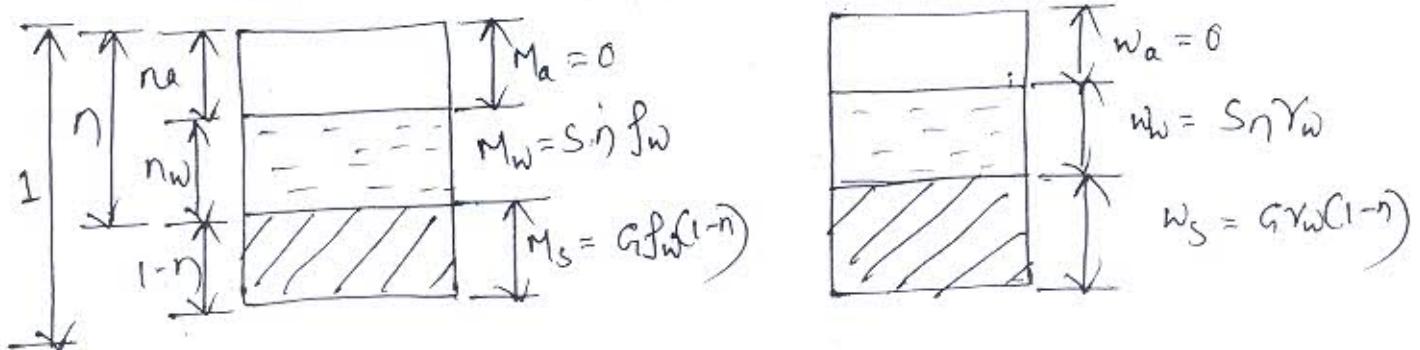
$$\gamma' = \left\{ \frac{(G-1)}{1+e} \right\} \gamma_w$$

$$\gamma' = \frac{[(G-1) - e(1-s)] \gamma_w}{1+e}$$

For water $f_w = 1 \text{ gm/ml}$, $\gamma_w = 9.81 \text{ kN/m}^3$

For soil $f = 2 \text{ gm/ml}$, $\gamma = 19.62 \text{ kN/m}^3$

Three phase diagram in terms of porosity.



$$n = \frac{V_v}{V} = \frac{V_v}{1} = V_v$$

$$e = \frac{n}{1-n}$$

$$f = \frac{M}{V} = \frac{M_s + M_w f_w}{V} = \frac{G f_w (1-n) + S_n f_w}{V}$$

$$f = [G(1-n) + S_n] f_w$$

$$G f_w (1-n) = f_w = G f_w (1-n)$$

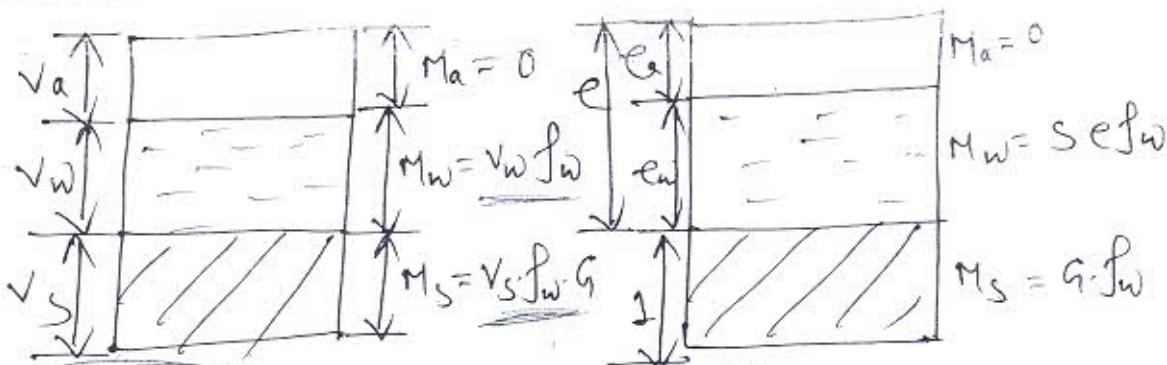
$$f_{sat} = \frac{M_{sat}}{V} = \frac{G f_w (1-n)}{V}$$

$$\boxed{f_{sat} = [G(1-n) + n] f_w} \quad \checkmark$$

$$f' = \frac{V_s f_w (G-1)}{V} = \frac{(1-n) f_w (G-1)}{V}$$

$$\boxed{f' = (G-1)(1-n) f_w} \quad \checkmark$$

Relationship between the void ratio and the water content :-



$$w = \frac{M_w}{M_s}$$

$$w = \frac{V_w f_w}{V_s f_s}$$

$$\boxed{\frac{f_s}{f_w} = G}$$

$$\boxed{f_s = G \cdot f_w} \quad \checkmark$$

$$\boxed{\frac{V_w}{V_v} = S} \Rightarrow \boxed{V_w = S \underline{V_v}}$$

$$w = \frac{S V_v f_w}{V_s \cdot G \cdot f_w} = \frac{S V_v}{V_s G}$$

$$e = \frac{V_v}{V_s} \Rightarrow w = \frac{S \cdot e \cancel{V_s}}{\cancel{V_s}}$$

$$\left. \begin{array}{l} \gamma = \frac{(1+w) G \gamma_w}{1 + wG/S} \\ \gamma_{sat} = \frac{(1+w) G \gamma_w}{1 + wG} \\ \gamma_{Sub} = \frac{(G-1) \gamma_w}{1 + wG} \\ \gamma_d = \frac{G \gamma_w}{1 + wG/S} \\ \boxed{\gamma_d = \frac{\gamma}{1+w}} \\ (\gamma_d)_{sat} = \frac{G \gamma_w}{1+w \cdot G} \end{array} \right\} \text{grnp}$$

Relationship betⁿ Dry mass density and percentage air voids

$$\boxed{\gamma_d = \frac{(1-n_e) G \gamma_w}{1 + e}}$$

~~Q2/09/20~~ A soil specimen has a water content of 10% and a wet unit weight of 20 kN/m^3 . If the specific gravity of solids is 2.70. Determine the dry unit weight, void ratio, and the degree of saturation. Take $\gamma_w = 10 \text{ kN/m}^3$.

Soln:- Given data
 $w = 10\% = 0.1$

$$\gamma = 20 \text{ kN/m}^3$$

$$G = 2.70$$

$$\gamma_d = ?$$

$$e = ?$$

$$SSoS = ?$$

$$\gamma_w = 10 \text{ kN/m}^3$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{20}{1+0.1} = 18.18 \text{ kN/m}^3$$

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

$$\Rightarrow e = \frac{G\gamma_w}{\gamma_d} - 1 = \frac{2.70 \times 10}{18.18} - 1$$

$$= 0.49$$

$$SSoS = \frac{w \cdot G}{e} \Rightarrow \frac{0.1 \times 2.70}{0.49}$$

$$= 0.551 = 55.1\%$$

Q.) A sample of dry soil weighs 68 gm. Find the volume of voids if the total volume of the sample is 40 ml and the specific gravity of solids is 2.65. Also determine the void ratio.

Soln:- Given data

$$M_s = 68 \text{ gm}$$

$$V = 40 \text{ ml}$$

$$G = 2.65$$

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

$$V_v = V - V_s$$

$$M_s = 68 \quad - 95.66 \text{ ml}$$

$$C = \frac{V}{V_s}$$

$$= \frac{14.34}{25.66} = 0.56$$

~~Water Content determination :-~~

Water Content of soil sample can be determined by any one of the following methods:

- 1) ~~Oven drying method~~
- 2) Torsion balance "
- 3) Pycnometer "
- 4) Sand bath "
- 5) Alcohol "
- 6) Calcium Carbide "
- 7) Radiation "

Oven drying method

→ This is a standard, laboratory method.
This method is a very accurate method.

$$\underline{110^{\circ}\text{C} \pm 5^{\circ}\text{C}} \leftarrow 24\text{ hrs.}$$

60° - 80° C - temp. - organic soil

Water content of the soil sample is calculated from the equation.

$$w = \underline{M_w} = \underline{\frac{M_2 - M_3}{M_2}} \times 100$$

$M_1 \rightarrow$ Mass of Container, with lid

$M_2 \rightarrow$ Mass of Container, lid and wet soil.

$M_3 \rightarrow$ Mass of Container, lid and dry soil.

$$w = \frac{M_w}{M_d} \times 100$$

$$w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$$

\rightarrow

→ Pycnometer method

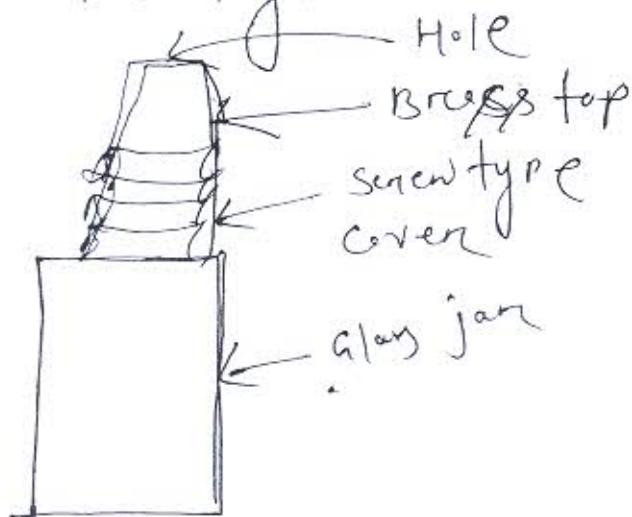
$$W = \frac{M_w}{M_s} \times 100 \\ = \left[\frac{(M_2 - M_1)}{(M_3 - M_4)} \frac{(G-1) - 1}{G} \right] \times 100$$

M_1 = Mass of pycnometer

M_2 = Mass of pycnometer + wet soil

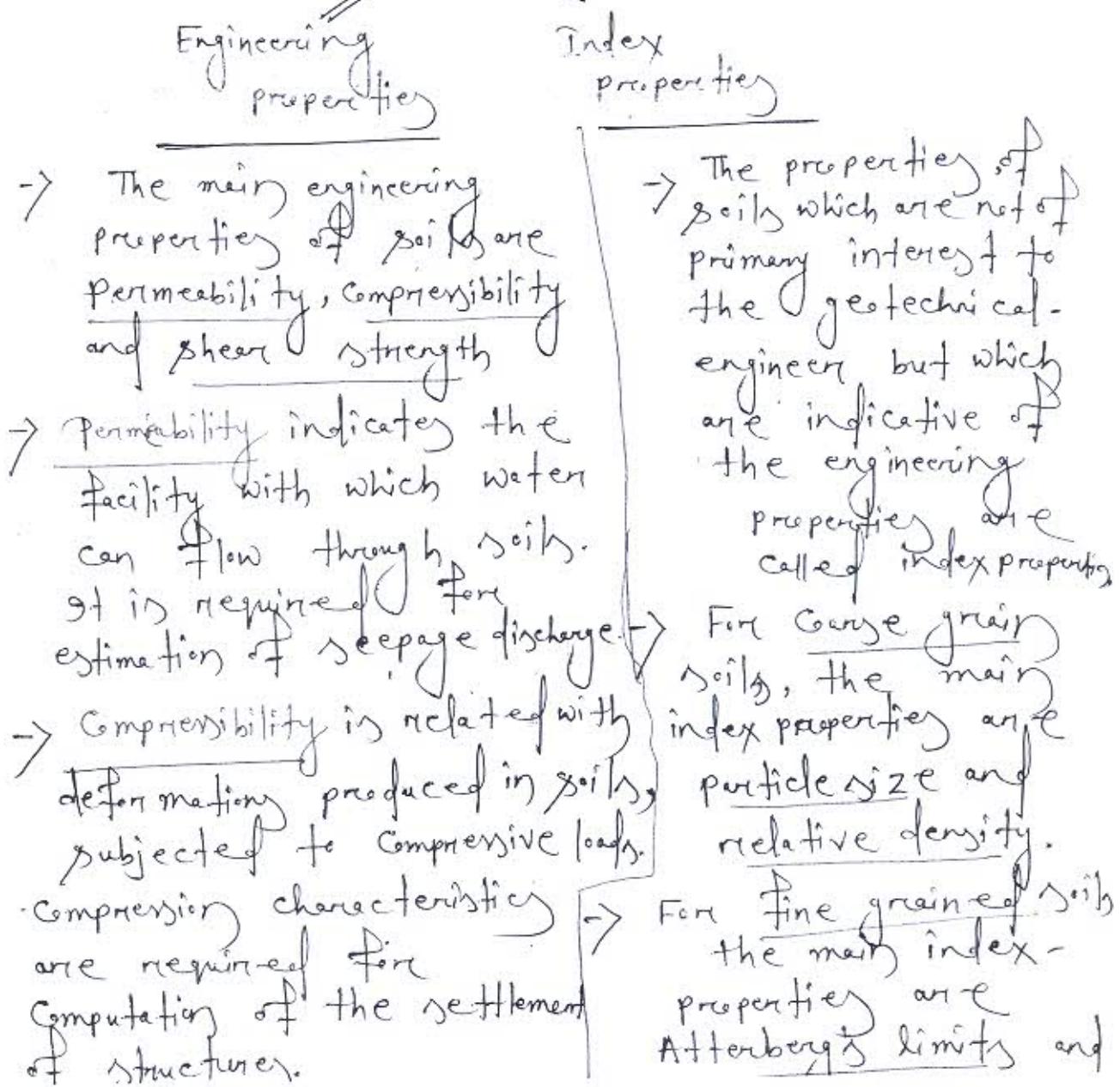
M_3 = Mass of " + wet soil + water

M_4 = Mass of pycnometer filled with
water only.



- ~~0410120~~
- Grain size distribution curve
 - Particle shape and size
 - Mechanical analysis of soil
 - Consistency of soil, Atterberg limits - liquidity index and consistency index
 - Activity, soil structure.
 - clay mineralogy.

Particle size analysis



→ Shear strength of soil is its ability to resist shear stress. It determines the stability of slopes, bearing capacity of soil and the earth pressure on retaining structures.

⇒ Mechanical analysis of soil :-

→ It is also known as particle size analysis.

→ It is a method of separation of soils into different fractions based on the particle size.

→ Mechanical analysis is done in two stages.

1) Sieve analysis (It is used for coarse grained soils)

2) Sedimentation analysis.

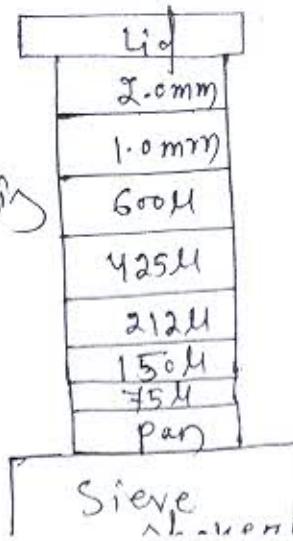
→ It is used for fine grained soils (size smaller than 75μ) i.e. particle size greater than 75μ.

→ It is also called wet analysis.

Sieve analysis

① wet dry sieve analysis

② wet sieve analysis



- The soil is sieved through a set of sieves.
Sieves are generally made of spun brass and phosphor bronze / stainless steel.
- Sieves are designated by the size of square opening, in mm or μ (micron)

$$1 \text{ micron} = 10^{-6} \text{ m} = 10^3 \text{ mm}$$
- Sieve analysis is done for coarse grained soils. The coarse grained soils can be further divided into gravel fraction (size $> 4.75 \text{ mm}$) and sand fraction ($75 \mu < \text{size} < 4.75 \text{ mm}$)
- A set of coarse sieves, consisting of the sieves of size 80mm, 40mm, 20mm, 10mm & 4.75mm is required for gravel fraction. All sieves may not be required for a particular soil.
- The sieve of the largest opening is kept at the top. A lid or cover is placed at the top to the bottom. A receiver known as pan, which has no openings, is placed at the bottom of the smallest sieve.
- Dry sieve analysis is suitable for coarser soils with little or no fines.

Computation of percentage finer :-

For determination of the particle size distribution curve, percentage of particles finer than a particular size is required.

Let's consider the case when the sieving has been done through seven sieves no 1 to no (7) i.e Coarsest to finest.

Let the mass of soil retained on these sieves be respectively $M_1, M_2 \dots M_7$. If the mass of soil retained on the pan (receiver) be M_8 . The sum of all these masses is equal to the total mass of sample M .

i.e., the material retained on sieves and pan are.

$$P_1 = \frac{M_1}{M} \times 100, P_2 = \frac{M_2}{M} \times 100, P_3 = \frac{M_3}{M} \times 100$$

$$P_8 = \frac{M_8}{M} \times 100$$

The cumulative % (c) of material retained on any sieve is equal to the sum of the % of soil retained on the sieve and that retained on all sieves coarser than that sieve.

$$C_1 = P_1$$

$$C_2 = P_1 + P_2 \\ \dots \dots \dots + P_n$$

The percentage finer (N) than any sieve size is obtained by subtracting the cumulative % retained on the sieve from 100%.

$$N_1 = 100 - C_1$$

$$N_2 = 100 - C_2$$

$$N_7 = 100 - C_7$$

Stokes law

- Soil particles finer than 75μ size cannot be sieved. The particle size distribution of such soils is determined by sedimentation analysis.
- The analysis is based on Stokes law.
- It gives the terminal velocity of a small sphere settling in a fluid of infinite extent.
- The terminal velocity can be obtained from the equilibrium of the particle.

$$v = \frac{1}{18} \frac{g D^2 (G-1) f_w}{\eta}$$

where, D = Diameter of the sphere

G = Specific gravity of the material of sphere.

g = Acceleration due to gravity

η = Viscosity in poise

$g = 981 \text{ cm/sec}^2$ (dyne-sec/cm²)

f_w = Unit weight of water

use of particle size distribution curve

- > The particle size distribution curve is extremely useful for coarse grained soils.
- > It is useful in soil stabilisation and for the design of pavement.
- > The particle size distribution curve may indicate the mode of deposition of soil.
- ex:- gap graded soil indicated by two different agencies.
- > The particle size distribution curve of a residual soil may indicate the agent of the soil deposit.
- > It is required for the design of drainage filters.
- > It is used to know the susceptibility of a soil to frost action.

Grading of soils :- The distribution of particles of different sizes in a soil may be called grading. The grading of soil can be determined from the particle size distribution curve.

1) Gap graded :- The soil in which some of the intermediate size particles are missing.

2) well graded / uniformly graded :- The

Uniform Soil :- The soil containing the particles of almost the same size.

The uniformity of soil is called by uniformity coefficient (C_u)

$$C_u = \frac{D_{60}}{D_{10}}$$

where, D_{60} = particle size such that 60% of soil is finer than this size.

D_{10} = particle size such that 10% of the soil is finer than this size.

(D_{10} is also known as effective size)

$$\text{Coefficient of curvature } (C_c) = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

where, D_{30} is the particle size corresponding to 30% finer.

Relative density

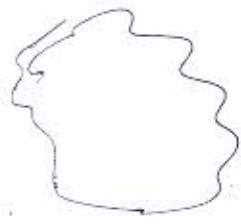
$$D_n(\text{or}) \text{ density index } (I_d) = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \times 100$$

where, e_{\max} = maximum void ratio of the soil in the loosest condition

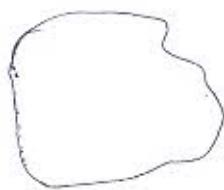
e_{\min} = minimum void ratio of the soil in the densest condition.

e = void ratio in the natural state.

Shape of particles:-



Angular



Sub angular



well rounded



rounded.

Angularity (R) of a particle is defined as
 $R = \frac{\text{average radius of corners and edges}}{\text{radius of maximum inscribed circle}}$

→ Cohesive soils have bulky particles.

Cohesive, clayey soils have particles which are thin and flaky. Soil composed of flaky particles are highly compressible.

$$D_n = \left(\frac{G_f w}{f_{\min}} - 1 \right) - \left(\frac{G_f w}{f_d} - 1 \right)$$

$$\left(\frac{G_f w}{f_{\min}} - 1 \right) - \left(\frac{G_f w}{f_{\max}} - 1 \right)$$

$$D_n = \frac{f_{\max}}{f_d} \left(\frac{f_d - f_{\min}}{f_{\max} - f_{\min}} \right)$$

- The consistency limits are very important index properties of fine grained soils. The water contents at which the soil changes from one state to the other are known as consistency limits or Atterberg's limits.
- The water content alone is not an adequate index properties of a soil. At the same content one soil may be relatively soft, whereas another soil may be hard. However, the soils with the same consistency limits behave somewhat in a similar manner.
- A soil containing high water content is in a liquid state. It offers no shearing resistance and can flow like liquids. It has no resistance to shear deformation and therefore the shear strength is equal to zero. As the water content is reduced, the soil becomes stiffer and starts developing resistance to shear deformation. At some particular point water content, the soil becomes plastic.
- The water content at which the soil changes from the liquid state to the plastic state is known as liquid limit.
- The difference between the liquid limit and the plastic limit is known as plasticity index.

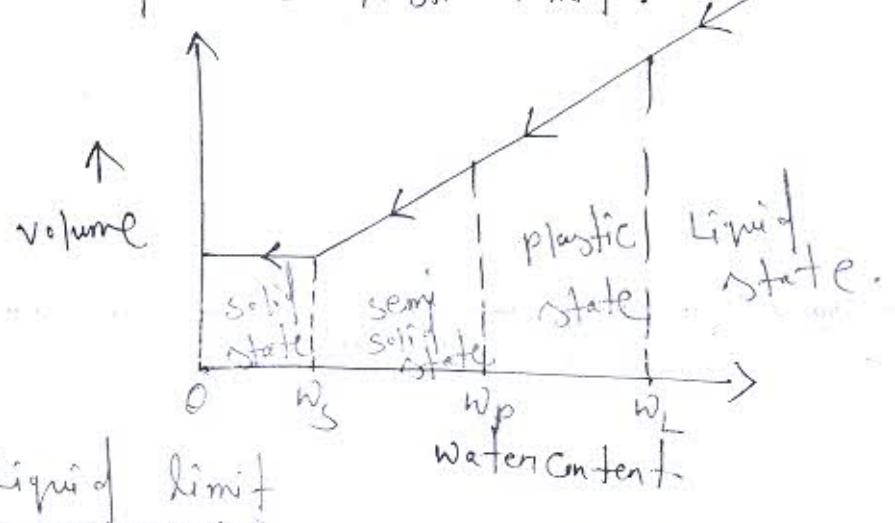
$$PI = LL - PL$$

→ The water content at which the soil becomes semi-solid is known as plastic limit.

$$I_p = w_L - w_p \quad \text{where, } w_L = \text{Liquid limit}$$

w_p = Plastic limit.

→ The soil remains plastic when the water content is between the liquid limit and the plastic limit.



→ The liquid limit is defined as the water content at which the soil changes from the liquid state to plastic state.

→ At the liquid limit the clay is practically like a liquid but possesses a small shearing strength.

→ The liquid limit is determined in the laboratory either by Casagrande's apparatus (ore) or by cone penetration test.

→ The device used in Casagrande's method consists of a brass cup which drops through a height of 1 cm on a hard base when operated by handle.

help of adjusting screws.

procedure

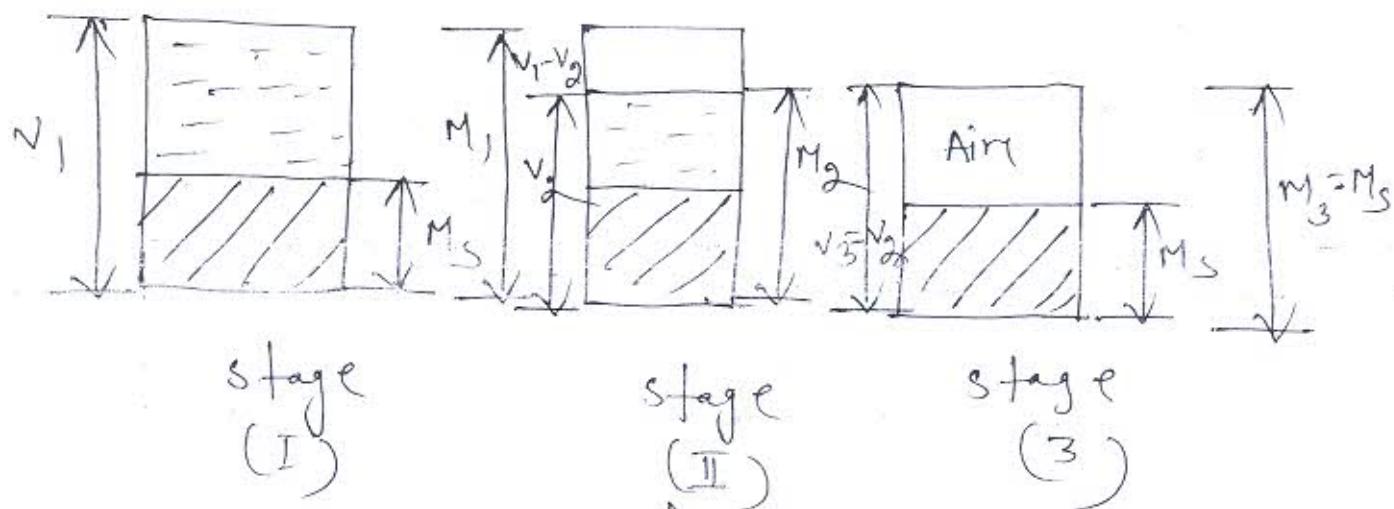
- > About 120g^m of an air dried sample passing through 425^{ll} IS sieve is taken in a dish and mixed with distilled water to form a uniform paste.
- > A portion of this paste is placed in the cup of the liquid limit device and the surface is smoothed and a levelled with a spatula to a maximum depth of 1cm.
- > A groove is cut through the sample along the symmetrical axis of the cup preferably in one stage.
- > Standard grooving tools are
 - 1> Casagrande tool
 - 2> ASTM tool.

Plastic limit :-

- > Plastic limit is the water content below which the soil stops behaving as a plastic material.
- > It begins to crumble when rolled into a thread of soil of 3mm diameter.
- > At this water content, the soil loses its plasticity and passes to a semi solid state.
- > For determination of the plastic limit of a soil, it is air dried and sieved through a 425^{ll} IS sieve.

Shrinkage limit:-

→ Shrinkage limit is the smallest water content at which the soil is saturated. It is also defined as the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass.



Let M_s = Mass of solids

$V_2 = V_3$ = Total volume

Mass of water in stage I = $M_1 - M_s$

Loss of mass of water from

Stage I to Stage II = $(V_1 - V_2) f_w$

Mass of water in Stage (II) = $(M_1 - M_s) - (V_1 - V_2) f_w$

Shrinkage limit = Water content in Stage II

$$w_s = \frac{(M_1 - M_s) - (V_1 - V_2) f_w}{M_s}$$

$$w_s = w_i - \frac{(V_1 - V_2) f_w}{M_s}$$

Q) A soil has a dry density of 1.816 gm/ml in the natural condition. When 410 gm of the soil was poured in a vessel in a very loose state, its volume was 290 ml. The same soil when vibrated and compacted was found to have a volume of 215 ml. Determine the relative density.

Soln. $M_{min} = 410 \text{ gm}$

$$V_{m_1} = 290 \text{ ml.}$$

$$V_{m_2} = 215 \text{ ml.}$$

$$\delta_{min} = \frac{M_{min}}{V_m} = \frac{410}{290} = 1.414 \text{ gm/ml.}$$

$$\delta_{max} = \frac{M_{max}}{V_m} = \frac{410}{215} = 1.907 \text{ gm/ml}$$

$$Dr = \frac{\delta_{max}}{\delta_d} \left(\frac{\delta_d - \delta_{min}}{\delta_{max} - \delta_{min}} \right) \times 100$$

$$= \frac{1.907}{1.816} \left(\frac{1.816 - 1.414}{1.907 - 1.414} \right) \times 100$$

$$= 85.63\%$$

Shrinkage index

$$I_s = w_L - w$$

→ It is the numerical difference between the liquid limit & shrinkage limit.

Shrinkage ratio

$$SR = \frac{(V_1 - V_2)/V_d}{w_1 - w_2} \times 100$$

where, V_1 = volume of soil mass at water content w_1

V_2 = volume of soil mass at water content w_2

V_d = Volume of dry soil mass.

Volumetric Shrinkage

$$VS = \frac{(V_1 - V_d)}{V_d} \times 100$$

Consistency index

$$I_c = \frac{w_L - w}{I_p} \times 100$$

w = water contents of the soil in natural condition.

Liquidity index

$$I_L = \frac{w - w_p}{I_p} \times 100$$

The liquidity index is also known as water plasticity ratio.

Flow index :-

$$I_F = \frac{w_1 - w_2}{\log_{10}(N_2/N_1)}$$

where, N_1 = Number of blows required at water content of w_1 ,

N_2 = Number of blows required at water content of w_2 .

Toughness index :-

$$I_T = \frac{I_p}{I_F}$$

~~water~~ → Toughness index of a soil is defined as the ratio of the plasticity index to the flow index.

Activity of soils:-

→ Activity (A) of a soil is the ratio of the plasticity index and the percentage of clay fraction. (minus 2li)

$$A = \frac{I_p}{F}$$

Where, I_p = plasticity index.

F = clay fraction.

2) Fine grained soil:

- silt (M) \rightarrow inorganic silt and very fine sand.
- clay (C) \rightarrow inorganic clay
- organic matter (O) \rightarrow organic silt and clay and organic matter.

Based on liquid limit and plasticity index

- silts and clays of low compressibility (L)
 w_L less than 35. It is represented as 'L'
- silts and clays of medium compressibility (I)
 w_L greater than 35 and less than 50.
- silts and clays of high compressibility (H)
 w_L greater than 50.

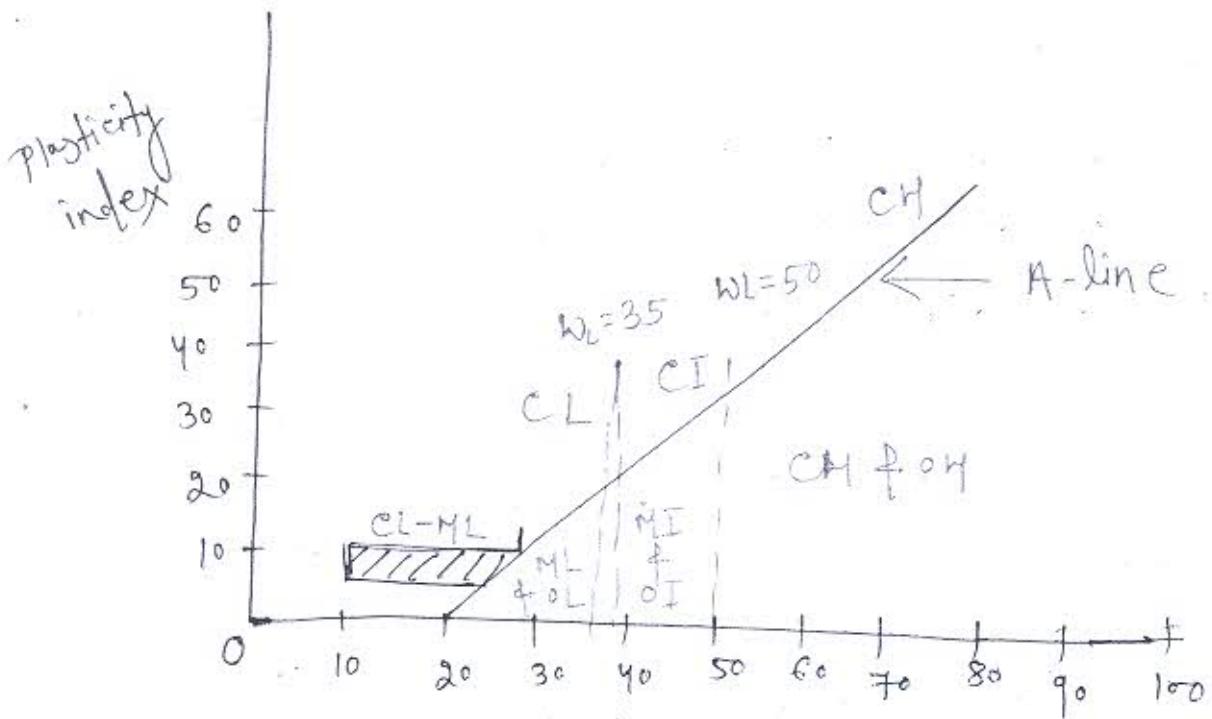
ex:- ML \rightarrow inorganic silt with low to medium compressibility.

GC \rightarrow clayey gravel.

\Rightarrow Laboratory classification of fine grained soil is done with the help of plasticity chart.

The A-line dividing inorganic clay from silty and organic soil has the following equation.

$$I_p = 0.73(w_L - 20)$$



(Plasticity chart) (IS-soil classification system)

Group symbols

Laboratory classification criteria

GW - C_u greater than
 C_c betⁿ 1 + 3

GP - Not meeting all gradation requirements for GW.

GM - Atterberg limit below A-line on
 $I_p < 4$

GC - Atterberg limit Above 'A'-line

$I_p > 7$
SW - $C_u > 6$, C_c = between 1 + 3

SP - Not meeting all gradation requirements for SW

SM - Below A-line, $I_p < 4$

SC - Above A-line, $T_b > 7$

~~Q10 Q12~~ Sketch the plasticity chart used for classifying the fine grained soil in the IS soil classification system.

Give the IS soil classification system.

Give the group symbols for the following soils.

(i) Liquid limit = 40%, Plastic limit = 22%.

(ii) Liquid limit = 20%, Plastic limit = 14%.

(iii) Passing 4.75 mm sieve = 70%, passing 75 μ sieve = 8%.
Unsaturation coefficient = 7 Plasticity index = 3
Coefficient of curvature = 3
Plasticity index = 3

Sol:- (i) $w_L = 40\%$,
 $w_p = 22\%$.

$$I_p = w_L - w_p = 40 - 22 = 18\%$$

Plotting the point for $I_p = 18\%$, $w_L = 40\%$ on the plasticity chart, group symbol for the soil will be (CI).

(ii) $w_L = 20\%$, $w_p = 14\%$.

$$I_p = 20 - 14 = 6\%$$

Plotting the point for $I_p = 6\%$, $w_L = 20\%$. The soil falls in the (CL-MI) sector. Above A line (I) clay present.

(iii) More than half the portion (50%) of the soil passes through 4.75 mm sieve, the is essentially sand (S), $C_u = 7$ (greater than 6)
 $C_c = 3$

The soil is well graded soil (SW)

$\frac{w_L}{35-50} \rightarrow$ Medium
Compressibility

The percentage passing 75μ size is 8%.
(between 5 and 12%), $I_p = 83$ (< 4)
it satisfies the requirement of SM.
(silty sand)

⇒ Indian standard classification system (ISCS)

The ISCS classifies the soils into 18 groups as against 15 groups of USCS. (Unified soil classification system)

→ Soils are broadly divided into three groups.

1) Coarse grained soil :-

Coarse grained soils are those for which more than 50% of the material has particle size more than 0.075 mm .

2) Fine grained soil :- ex- Gravel, sand

Fine grained soils are those for which more than 50% of the material has particle sizes less than 0.075 mm . ex- clay, silt

These soil contain large percentage of fibrous organic matter, such as peat, and the particles of decomposed vegetation.

1) Coarse grained soils :-

a) Gravel - (G)

b) Sand - (S)

Each of the above subdivisions are further subdivided into four groups, depending upon grading and inclusion of the other materials.

W → well graded (clean)

C → well graded with excellent clay binder

Particle size classification :-

- In this system soils are arranged according to the grain size. Terms such as gravel, sand, silt and clay are used to indicate grain sizes.
- The terms are used only as designation of particles size and do not signify the naturally occurring soil types.

Texture classification :-

- Soils occurring in nature are composed of different percentage of sand, silt and clay size particles.
- Soil classification of composite soils exclusively based on the particle size distribution is known as texture classification.

		2	5	10	20	50	100	200	500	1000
		P	H	G	H	G	H	G	H	G
		0	0	0	0	0	0	0	0	0
clay	silt	Fine	Medium	Coarse	Fine	Coarse	Cobble	Boulder		
	size		Sand		Gravel					

Highway research board (HRB) classification :-

- The HRB classification system also known as Public road administration (PRA) classification system.
- Classification system is based on both the particle size composition as well as plasticity characteristics.
- Soils are divided into 7 primary groups

- The group index of soil depends upon
- The amount of material passing through 75μ IS-sieve
 - The liquid limit
 - The plastic limit

$$\boxed{\text{Group index} = 0.2a + 0.005ac + 0.01bd}$$

where, a = That portion of percentage passing 75μ sieve greater than 35 and exceeding 75 (0 to 40)

b = That portion of percentage passing 75μ sieve greater than 15 and not exceeding 55. (0 to 40)

c = That portion of the numerical liquid limit greater than 40 if not exceeding 60. (0-20)

d = That portion of the numerical plasticity index greater than 10 and not exceeding 30. (0-20)

⇒ Unified Soil classification System :-

- Various soils are classified into four major groups
- Coarse grained
 - Fine grained
 - Soil

→ There are in all 15 groups of soils 3 groups of coarse grain soils and 6 groups of fine grain soils (including organics) and 1 group of peat.

Soil Structure and Clay Mineralogy :-

→ Soil structure is usually defined as the arrangement and state of aggregation of soil particles in a soil mass.

→ The following types of soil structure are generally recognised:

- 1) Single grained
- 2) Honey Comb
- 3) Flocculent
- 4) Dispersed
- 5) Coarse grained
- 6) Cohesive Matrix.

→ Structure of Composite soils:- Depending upon the relative proportion of coarse grained & fine grained particles two types of structures of composite soil can be possible. The coarse grained skeleton structure of cohesive matrix.

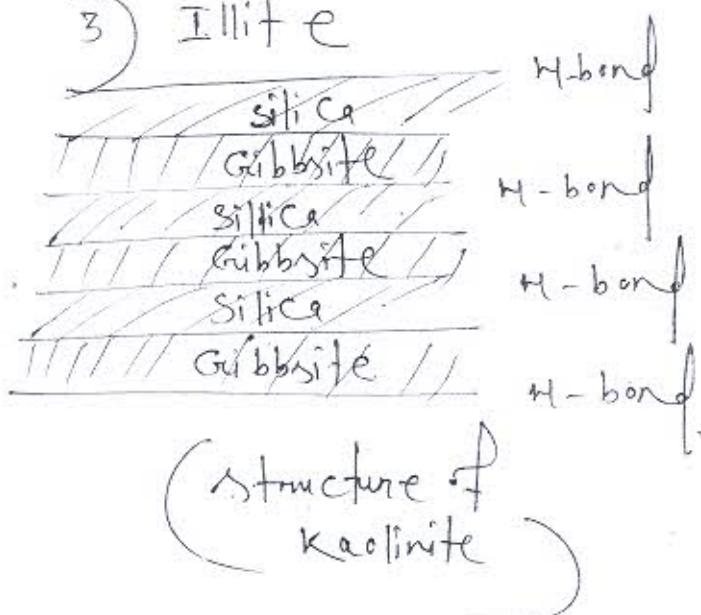
Clay minerals:-

→ About 15 minerals are ordinarily classified as clay minerals, and these belong to

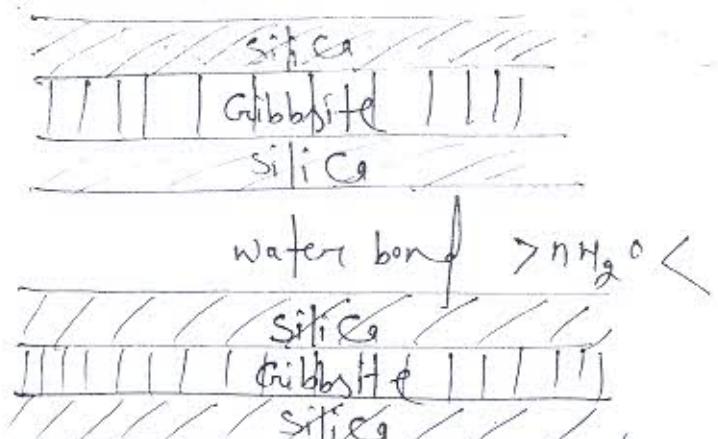
1) Kaolinite

2) Montmorillonite

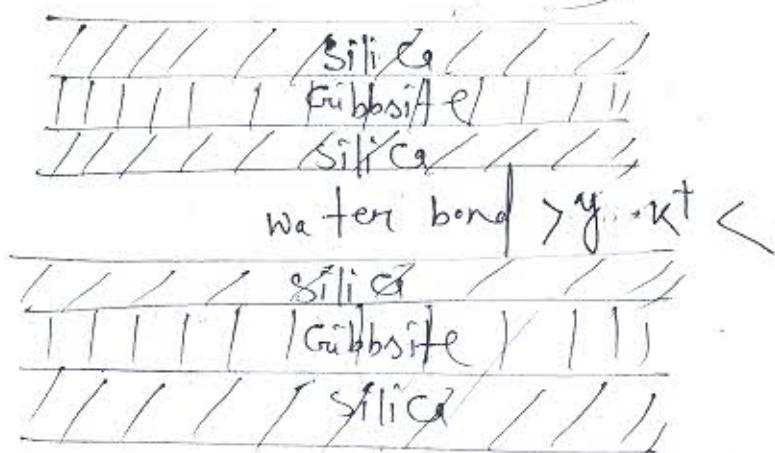
3) Illite



(Structure of
Kaolinite)



(Structure of
Montmorillonite)



(Structure of
Illite)