Geotechnical Engg.

(Soil Mechanics)

(UNIT- I)

The term 'Soil' in soil engineering is defined as an unconsolidated material, composed of solid particles, produced by the disintegration of rocks.

→ The term 'Soil Mechanics' was coined by 'Dr. Karl Terzaghi' in 1925.

Soil Mechanics is therefore a branch of mechanics which deals with the action of forces on soil and with the flow of water in soil.

Soil Engineering and Geotechnical Engineering :-

Soil Engg. is an applied science dealing with the application of principles of soil mechanics to practical problems. It has a much wider scope than soil mechanics, as it deals with all engineering problems related with soil. It includes site Investigations, design and construction of foundations, earth-retaining structures and earth structures.

Geotechnical Engg. is a broader term which includes soil engg., rock mechanics, and ~~geology~~. Geology.

Scope of Soil Engineering:-

Soil Engg. has vast application in the construction of various civil engg. works. some of the important applications are a under:

(1). Foundation

(2). Retaining structures

(3). Stability of slopes

(4). Underground structures

(5). Pavement Design

(6). Earth Dam

(7). Miscellaneous soil Problems.

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 or decomposes into small particles and thus the soils are formed.

Soils may be considered as an a incidental material obtained from the geologic cycle which goes on continuously in nature. The geologic cycle consists of erosion, transportation, deposition and upheaval of soil.

Exposed rocks are eroded and degraded by various physical and chemical processes.

The products of erosion are picked up by agencies of transportation, such as water and wind, and are carried to new locations where they are deposited.

This shifting of the material disturbs the equilibrium of forces on the earth and causes large scale earth movements and upheavals. This process results in ~~future~~ further exposure of rocks and the geologic cycle gets repeated.

If the soil stays at the place of its formation just above the parent rock, it is known as 'Residual Soil or Sedentary soil'.

When the soil has been deposited at a place away from the place of its origin, it is called a 'Transported Soil'.

⇒

Formation of Soils :-

As mentioned above, soils are formed by either

(A) Physical Disintegration

(1). Temperature changes

(2). Wedging Action of Ice

(3). Spreading of roots of Plants

(4). Abrasion

(B). Chemical Decomposition

(1). Hydration

(2). Oxidation

(3). Solution

(4). Carbonation

(5). Hydrolysis

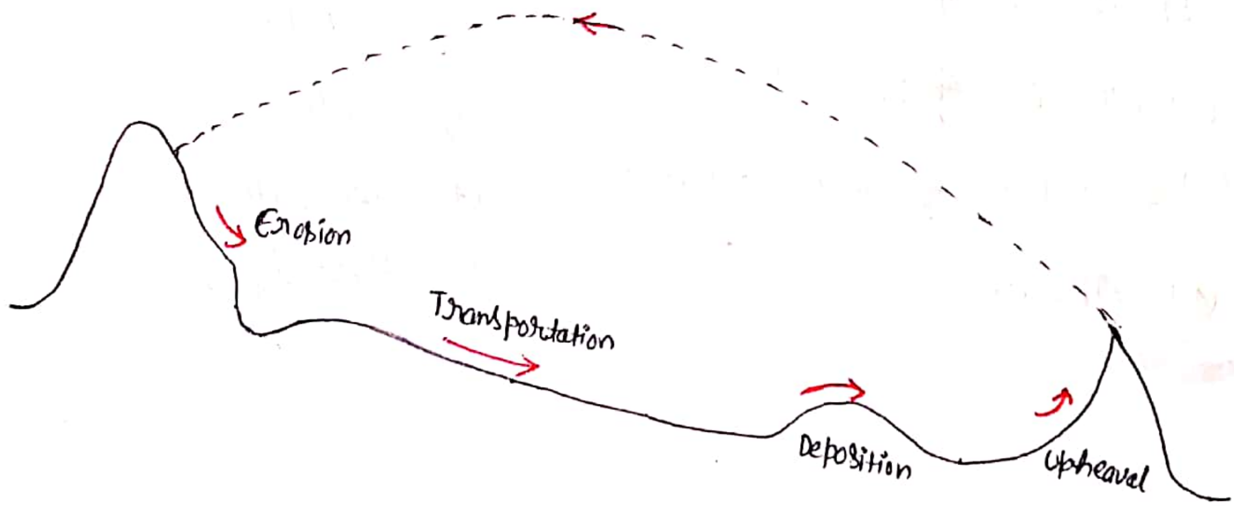
(A). Physical Disintegration :-

In all the processes of physical disintegration, there is no change in the chemical composition. The soil formed has the properties of the parent rock. Coarse grained soils, such as gravel and sand, are formed by the process of physical disintegration.

(B). Chemical Decomposition :-

~~When~~ chemical decomposition of rocks results in formation of clay minerals. These clay minerals impart plastic ~~pt~~ properties to soils. Clayey soils are formed by chemical decomposition.

⇒ Origin of Soils :- Geologic cycle



Geologic Cycle

Residual Soil:- Soil formed by weathering of rocks may remains in position at the place of origin are known as Residual soils.

Transported Soil:-

The soil formed at a place may be transported to other places be agents of transportation such as - water, wind, ice and gravity.

(1). **Water transported Soil:-** All types of soil carried and deposited by water such as river known as Alluvial Soil.
Deposited by lake water known as Lacustrine Soil.
Deposited by sea beds know as. Marine Deposite

(2). **Wind Transported Soil:-** Soil particles are transported by winds. Known as Aealian soil. (

(3). **Glacier Deposited Soil:-** Soil transported by glaciers (ice) Glacial till.

(4). **Gravity Deposited Soil:-** Soil can be transported through short distance under the action of gravit. (Talus / Colluvial soil)

(5) **Soils transported by Combined action:** Sometimes two or more agents of transportation act jointly and transport the soil.

Cohesive Soil:- Cohesive Soils are a type of soil that stick to each other. Cohesive Soils are the silts and clays, or fine-grained soil. It is type of soil where there is Inter-particular attraction. Soil in which the absorved water and particle attraction act such as that it deformed plastically and varying water content.

Non-Cohesive Soil (Cohesionless):- Non-Cohesive soil as the name indicates do not have Cohesive forces. They are comparatively Coarser particles with self weight governing their behaviour.

These soils are the sands and gravel.

Many soils are mixture of bulky grains and clay minerals and exhibit ~~and~~ some degree of plasticity with varying water Content.

Types of Soil :-

(1). Alluvial Soil :- Deposition from suspension in running -water (River water).

This type of soil is found along the length of rivers.

(2). Lacustrine Soil:- Formed due to deposition from suspension in fresh still water from lake.

(3). Marine Soil :- Deposition from suspension in Sea water.

(4). Aeoline Soil (Sand-Dunes) It is the soil which is transported by wind. (Sand – Dunes)

(5). Loess Soil :- It is uniformly graded wind blown silt, slightly cemented due to calcium compound or montmorllinite (a clay mineral).

Then it is wet it becomes soft and compressible because cementing action is lost and is collapsed.

(6). Colluvial Soil (Talus) :- It is formed due to transportation by gravitational force,
It is found in mountain vallies.

(7). Glacial Soil:- It is Soil which is transported by Ice.

(8). Marl Soil:- It is fine graded Calcium Carbonate Soil (due to animal bones) of marine origine, which is formed due to decomposition of animal bones and acquatic plants.

(9). Bentonite Soil:- It is chemically weathered valcanro ash.

⇒ Generally used as lubricant in drilling operation.

⇒ It is also clay containing a High amount of mont marillonite.

⇒ Highly plastic and have high Swelling & Shrinkage properties.

(10). **Black cotton Soil:-** It is residual formed from Basalt, containing a high amount of clay mineral montmorillonite.

It is dark in Colour & Suitable for growing cotton.

It has high plasticity, high swelling & shrinkage & low shear strength.

(11). **Laterite Soil:-** It is a type of soil formed due to leaching (washing out silicon compound) & accumulation of iron oxide and aluminium oxide.

⇒ Generally found in hilly areas, having humid climate (Western ghats & Eastern ghats).

(12). **Muck Soil:-** It is mixture of in organic soil & black decomposed organic matter.

(13). **Peat Soil:-** It is highly organic soil which almost entirely consist of vegetable matters in different stage of decomposition.

⇒ Its Colour is very strong black to dark brown and it poses organic odour.

⇒ It is highly Compressible Soil.

Note:- Peat & Muck soil are also termed as Cumulose Soil.

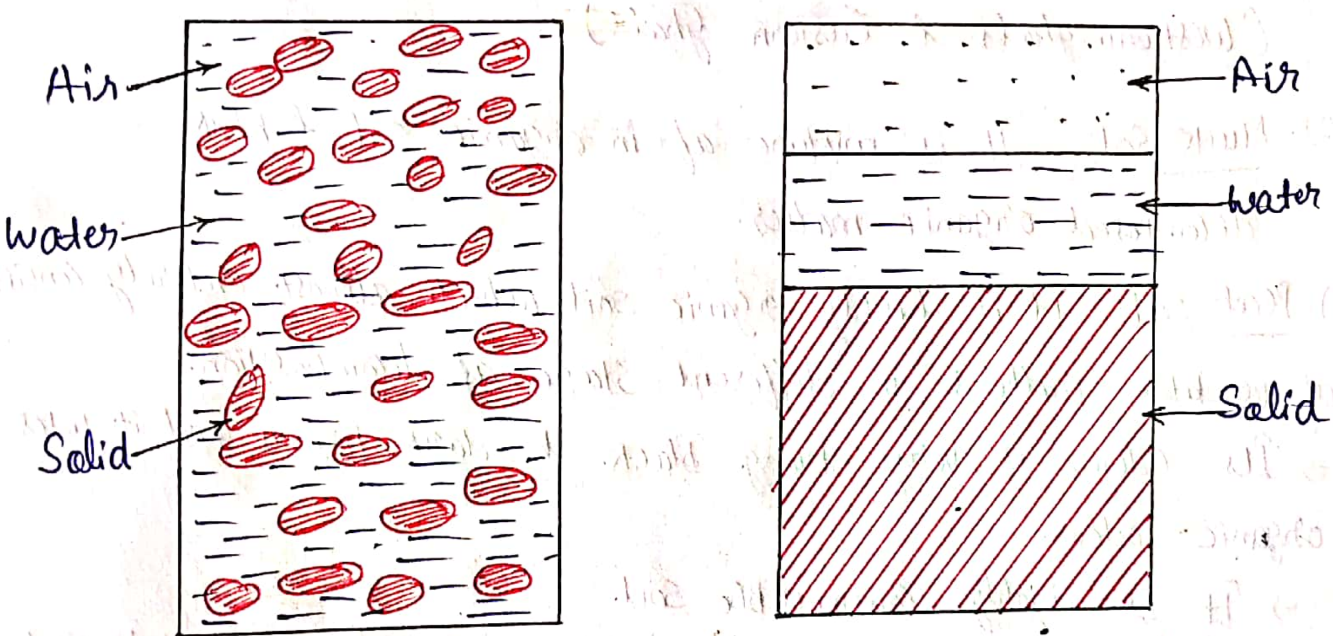
(14). **Loam Soil:-** It is mixture of clay, silt and sand.

Soil Composition :– (Three Phase Diagram) –

A soil mass consists of solid particles which form a porous structure. The voids in the soil mass may be filled with air, with water or partly with air and partly with water.

In general, a soil mass consists of solid particles, water and air.

The three constituents are blended together to form a complex materials. It is also known as 'Block Diagram' '3-Phase Diagram'.

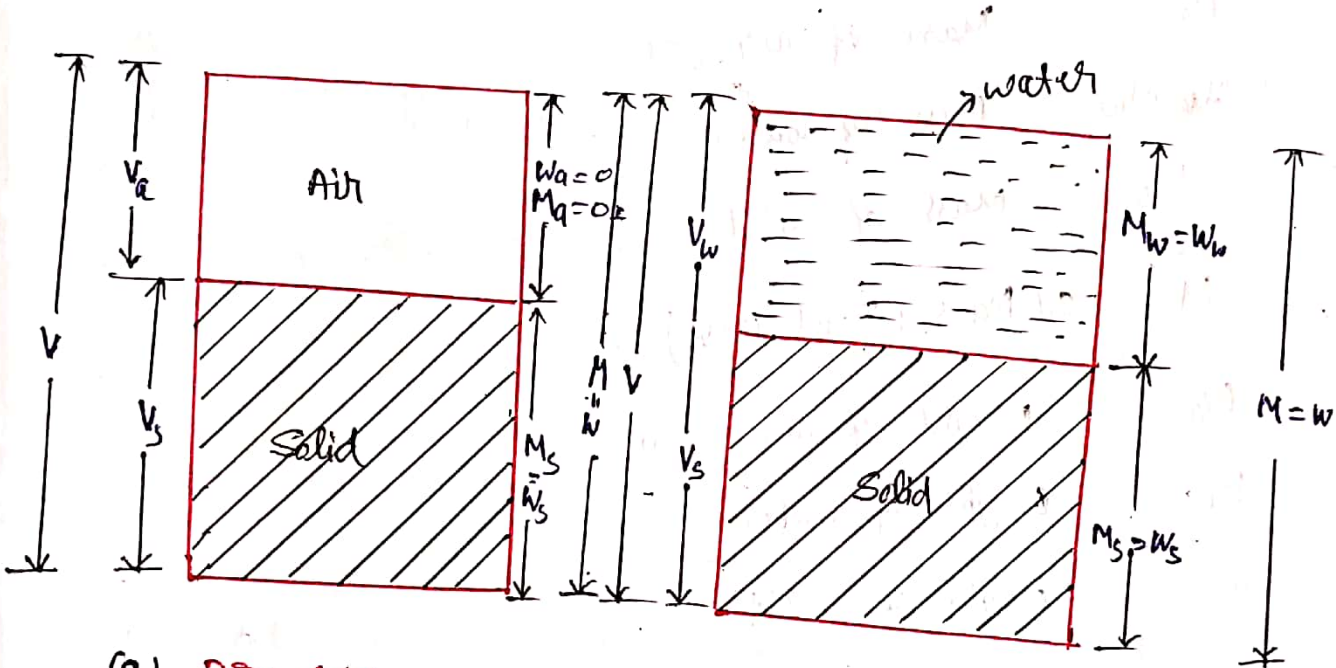


3- Phase Diagram

⇒ Although the soil is a three-phase system, it becomes a two-phase system :-

(a). When ~~wad~~ the soil is absolutely dry, the water phase disappears.

(b). When the soil is fully saturated, there is no air phase.



(a) Dry Soil (b). Saturated Soil

Two-phase Diagram

In a 3-phase diagram, it is conventional to write volume on the left side and the (mass and weight) on right side.

V = Total volume

V_a = Volume of air

V_w = Volume of water

V_s = Volume of Solids

V_v = Volume of voids

M_a = Mass of air = 0

M_w = Mass of water

M_s = Mass of Solid

M = Soil Mass (Total mass)

W_a = Weight of air = 0

W_w = Weight of water

W_s = weight of Solid.

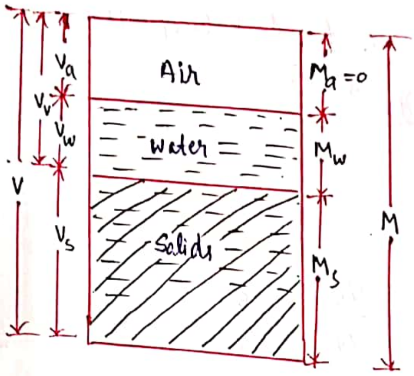
W = Soil weight

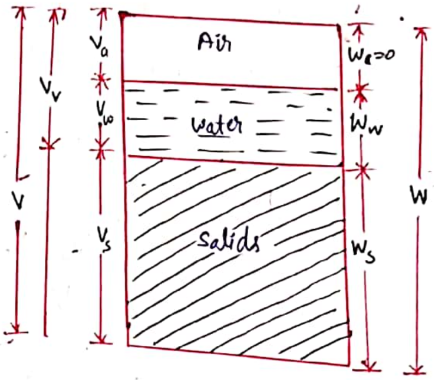
$$[\, V = V_s + V_v \,]$$

$$[\, V_v = V_a + V_w \,]$$

$$[\, W = W_s + W_w + W_a \,]$$

$$[\, W = W_s + W_w \,]$$





Volumetric Relationships:—

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

$$\left[\, e = \frac{V_v}{V_s} \,\right]$$

The void ratio is expressed as a decimal, such as 0.4, 0.5 etc. For coarse-grained soils, the void ratio is generally smaller than that for fine-grained soils. For some soils, it may have a value even greater than unity.

(2). Porosity (n):— It is defined as the ratio of the volume of voids to the total volume. It is expressed as percentage.

$$\left[\, n = \frac{V_v}{V} \,\right]$$

An inter-relationship can be found between the void ratio and the porosity as:—

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

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

$$\frac{1}{n} = 1 + \frac{1}{e} = \frac{1+e}{e} \quad \text{— (1)} \quad \left(\because e = \frac{V_v}{V_s}\right)$$

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

Also, From eq^n (1)

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

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

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

In both eq^n the porosity should be expressed as a ratio (and not percentage).

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

$$\left[S = \frac{V_w}{V_v} \right]$$

The degree of saturation is generally expressed as a percentage.

It is equal to zero when soil is absolutely dry and 100% when the soil is fully saturated.

(4). Percentage Air Voids (n_a):- It is the ratio of the volume of air to the total volume.

$$\left[n_a = \frac{V_a}{V} \right]$$

It is represented as a perentage.

(5). Air Content (a_c):- Air Content is defined as the ratio of the volume of air to the volume of voids.

$$\left[a_c = \frac{V_a}{V_v} \right]$$

It is usually expressed as a percentage.

Both air content and percentage air voids are zero when the soil is saturated ($V_a = 0$).

An Interrelationship b/w (a_c & n_a).

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

$$\left[n_a = n\, a_c \right]$$

Water Content :-

The water Content (w) is defined as the ratio of the mass of water to mass of solids.

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

It is also Known as 'Moisture Content'

or The water content or moisture content defined as the ratio of the weight of water to weight of solids.

UNITS :-

		Unit
(M) Mass	⟶	Kilogramme (Kg)
(L) Length	⟶	Metre (m)
(T) Time	⟶	Second (Sec or S)
Force	⟶	Newton (N)

~~[illegible] = [illegible]~~

1 Milligramme (mg) = 10^{-3} gram (gm or g)

1 Kilogramme (Kg) = 10^{3} gm

1 megagramme (Mg) = 10^{6} gm = 10^{3} Kg

1 millinewton (mN) = 10^{-3} newton (N)

1 Kilonewton (KN) = 10^{3} N

1 meganewton (MN) = 10^{6} N = 10^{3} KN

Volume - Mass Relationship :-

The volume - mass relationship are in terms of mass density. The mass of soil per unit volume is known as mass Density.

(1). Bulk Mass Density / Wet Mass Density / Density / Bulk Density :-

It is denoted by (ρ) It is defined as the total mass (M) per unit total volume (V).

$$\left[\rho = \frac{M}{V} \right]$$

gm / cm³ or gm / cc

It is expressed ~~as~~ in Kg/m³, gm/ml or Mg/m³.

(1 Mg/m³ = 1000 Kg/m³ = 1 gm/ml)

(2). Dry Mass Density :- The dry mass density (ρ_d) is defined as the mass of solids per unit total volume.
Also known as Dry density.

$$\left[\rho_d = \frac{M_s}{V} \right]$$

Kg/m³, gm/ml or Mg/m³.

(3). Saturated Mass Density :- The saturated mass density (ρ_{sat}) is the bulk mass density of the soil when it is fully saturated.

$$\left[\rho_{sat} = \frac{M_{sat}}{V} \right]$$

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

The submerged mass density (ρ') of the soil is defined as the submerged mass per unit of total volume.

$$\left[\rho' = \frac{M_{sub}}{V} \right]$$

$$\left[\rho' = \rho_{sat} - \rho_w \right]$$

(5). Mass density of solids :- The mass density of solids (ρ_s) is equal to the ratio of the mass of solids to the volume of solids.

$$\left[\rho_s = \frac{M_s}{V_s} \right]$$

(6). Density of water or Mass density of water :-

Density of water (ρ_w) is defined as the ratio of mass of water to volume of water.

$$\rho_w = \frac{M_w}{V_w} \quad Kg/m^3 \text{ or } g/cm^3$$

$$\left[1\, gm/cm^3 = \frac{9.81 \times 10^{-6}\, KN}{1 \times 10^{-6}\, m^3} = 9.81\, KN/m^3 \right]$$

For calculation purpose Hence $\left[\gamma (KN/m^3) = 9.81 \times \rho \ (g/cm^3) \right]$

$$\left(\rho_w = 1\, g/cm^3 \text{ or } \gamma_w = 9.81\, KN/m^3 \right)$$

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Volume-weight Relationship :-

The unit weight of a soil mass is defined as its weight per unit volume.

(1). Bulk unit weight or bulk weight density :-

of a soil mass is defined as the weight per unit volume of the soil mass. Bulk unit weight. It is denoted by 'γ'

$$\gamma = \frac{W}{V} \quad KN/m^3 \text{ or } N/m^3$$

(2). Dry Unit weight :- The dry unit weight is the weight of solids per unit of its total volume of the soil mass.

$$\gamma_d = \frac{W_s}{V}$$ → weight of solid.

(3). Unit weight of Solids :- The unit weight of soil solids is the weight of soil solids.

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

(4). Saturated unit weight :- when the soil mass is saturated, its bulk unit weight is called the saturated unit weight. It is ratio of the total weight of a saturated soil sample to its total volume.

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

(5). Submerged unit weight ( ) :-

The Submerged unit weight γ' is the Submerged weight of soil solids $(W_s)_{sub}$ per unit of total volume V of the soil mass.

$$\left[\gamma' = \frac{(W_s)_{sub}}{V} \right]$$

It is also expressed as,

$$\left[\gamma' = \gamma_{sat} - \gamma_w \right]$$

where γ_w is unit weight of water. For calculation purpose in SI units, γ_w may be taken as 9.81 KN/m³

$(\gamma_w = 9.81 \text{ KN/m}^3)$

Specific Gravity :-

Specific gravity 'G' is defined as the ratio of the weight of a given volume of soil solids at a given volume of soil solids at a given temp. to the weight of an equal volume of distilled water at that temp. both weight being taken in air. In other words, it is the ratio of the unit weight of soil solids to that of water.

$$\left[G = \frac{\gamma_s}{\gamma_w} \right]$$

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Relationships

Relationship b/w e, w, s, g:-

we know that -

$$\text{Void ratio}(e) = \frac{V_v}{V_s} \quad \text{---} (1)$$

multiplying by $\left(\frac{V_w}{V_w}\right)$ in equⁿ (1)

$$e = \frac{V_v}{V_s} \times \frac{V_w}{V_w} = \frac{1}{S} \cdot \frac{V_w}{V_s} \quad \text{---} (2)$$

we know that $\gamma_w = \frac{W_w}{V_w}$ & $g = \frac{\gamma_s}{\gamma_w}$

$$\left(V_w = \frac{W_w}{\gamma_w} \right) \qquad g = \frac{W_s}{V_s \cdot \gamma_w} \Rightarrow \left(V_s = \frac{W_s}{g \cdot \gamma_w} \right)$$

Putting the values of V_w & V_s in equⁿ (2)

$$e = \frac{1}{S}\left(\frac{W_w}{\gamma_w}\right) \cdot \left(\frac{g \cdot \gamma_w}{W_s}\right) \qquad \left[\because w = \frac{W_w}{W_s} \right]$$

$$\boxed{e = \frac{1}{S} \cdot w \cdot g}$$

$$\boxed{S \cdot e = w \cdot g}$$

e = Void ratio
w = water content
S = Degree of Saturation
g = Specific gravity.

Relationship b/w γ_d, γ and w :-

Water content $w = \frac{W_w}{W_s}$

$$1 + w = 1 + \frac{W_w}{W_s} = \frac{W_s + W_w}{W_s} = \frac{W}{W_s}$$ $[\because W = W_s + W_w]$

$$W_s = \frac{W}{(1+w)} \quad \text{--- (1)}$$

we know that,

Dry unit weight $\gamma_d = \frac{W_s}{V}$ --- (2)

Putting the value of eqn (1) in eqn (2) -

$$\gamma_d = \frac{W}{(1+w)V}$$

*

$$\boxed{\gamma_d = \frac{\gamma}{(1+w)}}$$ $\left[\because \gamma = \frac{W}{V}\right]$

or $W_s = \frac{W}{(1+w)}$ --- (1)

Dividing by V in eqn (1) on both sides.

$$\frac{W_s}{V} = \frac{W}{V(1+w)}$$ $\left[\because \gamma = \frac{W}{V} \ \& \ \gamma_d = \frac{W_s}{V}\right]$

*

$$\boxed{\gamma_d = \frac{\gamma}{(1+w)}}$$

Relationship b/w γ, γ_d, γ_{sat} and γ' :-

We know that-

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V} \quad \text{——— (1)}$$

(W_s = wt of Solid , W_w = wt. of water)

*

$$V = V_s + V_v$$

$$\frac{V}{V_s} = \frac{V_v}{V_s} + \frac{V_s}{V_s}$$

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

$$\boxed{V = V_s(1+e)}$$

$$G = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \cdot \gamma_w}$$

$$\boxed{W_s = G \cdot V_s \cdot \gamma_w}$$

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

$$\boxed{W_w = \gamma_w \cdot V_w}$$

Putting the values of V, W_s & W_w in eqn. (1)

$$\gamma = \frac{G \cdot V_s \cdot \gamma_w + \gamma_w \cdot V_w}{V_s \cdot (1+e)} = \frac{\gamma_w \left[\frac{G V_s}{V_s} + \frac{V_w}{V_s} \right]}{(1+e)}$$

$$\gamma = \gamma_w \left[G + \frac{V_w}{V_v} \times \frac{V_v}{V_s} \right] \quad \left(\text{Multiplying by } \frac{V_v}{V_v} \text{ in } \frac{V_w}{V_s} \right)$$

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

$$\left[S = \frac{V_w}{V_v} \ \& \ e = \frac{V_v}{V_s} \right]$$

If soil is dry

$\gamma = \gamma_d$ and $S = 0$

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

If soil is fully saturated

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

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

For $\gamma_{submerged} = \gamma_{sat} - \gamma_w$

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

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

Relationship b/w γ_d, n_a, w, G, γ_w :-

We know that,

$$V = V_v + V_s$$

$$V = V_a + V_w + V_s$$

Dividing by V at both sides –

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

$$\Rightarrow 1 = n_a + \frac{V_w + V_s}{V} \quad \text{—— (1)} \qquad \left[\because n_a = \frac{V_a}{V}\right]$$

$$\Rightarrow \left[\because \gamma_w = \frac{W_w}{V_w} \qquad \boxed{V_w = \frac{W_w}{\gamma_w}}\right]$$

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

$$\boxed{V_s = \frac{W_s}{G \gamma_w}}$$

$$\Rightarrow \left[w = \frac{W_w}{W_s} \Rightarrow \boxed{W_w = w \cdot W_s}\right]$$

Putting the values of W_w, V_s & V_w in eqn (1)

$$1 = n_a + \frac{\left(\frac{W_w}{\gamma_w} + \frac{W_s}{G\gamma_w}\right)}{V}$$

$$\Rightarrow 1 - n_a = \frac{w \cdot W_s}{\gamma_w V} + \frac{W_s}{V G \gamma_w}$$

$$\Rightarrow 1 - n_a = \gamma_d \cdot \frac{w}{\gamma_w} + \frac{\gamma_d}{G\gamma_w}$$

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

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

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Ques:- A soil sample has a porosity of 40%. The specific gravity of solid is 2.70. Calculate -

(a). Void ratio (b). Dry unit weight

(c). Unit wt. of soil, if 50% saturation.

(d). Unit wt. of soil, if soil is completly saturated.

Sol:- Given:- $n = 40\%$

$n = 0.40$

$G = 2.70$

(i) Void ratio - $e = \frac{n}{1-n} = \frac{0.40}{1-0.40}$

$$e = 0.667$$

(ii). $\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.70 \times 9.81}{1+0.667}$ $(\because \gamma_w = 9.81)$

$$\gamma_d = 15.88 \ KN/m^3$$

(c). If 50% saturation

Then $S = 50\%$

$S = 0.5$

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

$$\gamma = \frac{(2.70 + 0.5 \times 0.667) \times 9.81}{1 + 0.667}$$

$$\boxed{\gamma = 17.85 \ KN/m^3}$$

OR

$$Se = w \cdot G$$

$$w = \frac{Se}{G} = \frac{0.5 \times 0.667}{2.70}$$

$$\boxed{w = 0.124}$$

$$\gamma = \gamma_d (1 + w)$$

$$\gamma = 15.88 (1 + 0.124)$$

$$\boxed{\gamma = 17.85 \ KN/m^3}$$

(d). If 100% saturation

Then $S = 1$

$$\gamma = \left[\frac{G + Se}{1 + e}\right]\gamma_w$$

$$\gamma = \left[\frac{2.70 + 1 \times 0.667}{1 + 0.667}\right] 9.81$$

$$\boxed{\gamma = 19.88 \ KN/m^3}$$

OR

$$w_{sat} = \frac{Se}{G} = \frac{1 \times 0.667}{2.70}$$

$$\boxed{w_{sat} = 0.248}$$

$$\gamma = \gamma_d (1 + w)$$

$$\gamma = 15.88 (1 + 0.248)$$

$$\boxed{\gamma = 19.8 \ KN/m^3}$$

Ques:- A fully saturated clay sample has mass of 101.5 gm and a volume of 50 cm³. After oven drying, the clay has mass of 84.5 gm. Assuming that the volume does not change during drying, determine.

(i) ρ (ii) e. (iii) n and (iv) γ_d.

Sol:-

$S = 100\,\%$

$V_v = V_w$

$M = 101.5$ gm

$V = 50$ cm³

$M_s = 84.5$ gm

$M_w = M - M_s = 101.5 - 84.5$

$M_w = 17$ gm

$\rho = \frac{M}{V} = \frac{101.5}{50} = 2.03\ g/cm^3$

$\gamma = \rho \times 9.81 = 2.03 \times 9.81$

$\gamma = 19.91\ kN/m^3$

Water Content,

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

$$w = \frac{17}{84.5} = 0.201$$

$$w = 20\%$$

Dry unit weight

$$\gamma_d = \frac{\gamma}{(1+w)} = \frac{19.91}{(1+0.201)}$$

$$\gamma_d = 16.58 \ KN/m^3$$

$$\rho_w = \frac{M_w}{V_w} \Rightarrow V_w = \frac{M_w}{\rho_w}$$

$$V_w = \frac{17}{1} = 17 \ cm^3$$

Porosity -

$$n = \frac{V_v}{V} = \frac{V_w}{V} = \frac{17}{50} \qquad (\because V_v = V_w)$$

$$n = 0.34 = 34\%$$

Void ratio

$$e = \frac{n}{1-n} = \frac{0.34}{1-0.34} = 0.51$$

$$e = 51\%$$

$$Se = Gw$$

Specific gravity.

$$G = \frac{Se}{w} = \frac{1 \times 0.51}{0.20}$$

$$G = 2.55$$

Ques:- A undisturbed sample of soil has a volume of $100 cm^3$ and mass of 190 g. On oven drying for 24 hrs., the mass is reduced to 160 g. If the specific gravity of grains is 2.68, determine water content, void ratio and degree of saturation.

Sol:- Given,

$$M = 190 \text{ gm}$$

$$M_s = 160 \text{ gm}$$

$$V = 100 cm^3$$

Then $M_w = M - M_s = 190 - 160$

$$M_w = 30 \text{ gm}$$

$$\therefore \left[w = \frac{M_w}{M_s} = \frac{30}{60} = 0.188 = 18\ \% \right]$$

Bulk density $\left[\rho = \frac{M}{V} = \frac{190}{100} = 1.9\ g/cm^3 \right]$

Hence,

$$\gamma = 9.81 \times \rho$$

$$\gamma = 1.9 \times 9.81$$

$$\gamma = 18.64\ KN/m^3$$

Or

$$\gamma = \frac{W}{V} = \frac{190}{100} \times 9.81 = 18.64\ KN/m^3$$

(since, $1 gm/cm^3 = 9.81 KN/m^3$)

$$\therefore \gamma_d = \frac{\gamma}{1+w} = \frac{18.64}{1+0.188} = 15.69\ KN/m^3$$

OR

$$\Rightarrow \gamma_d = \frac{W_s}{V} = \frac{160}{100} \times 9.81 = 15.69\ KN/m^3$$

Void Ratio–

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

$$e = \frac{2.68 \times 9.81}{15.69} - 1$$

$$\boxed{e = 0.67}$$

$$(e = 67\%)$$

Degree of Saturation —

$$S = \frac{wG}{e} = \frac{0.188 \times 2.70}{0.67}$$

$$\boxed{S = 0.744}$$

$$\boxed{S = 74.4\%}$$

Ques: A partially saturated soil sample from a barrow pit has in natural moisture content of 15% and bulk unit weight 1.9 gm/cm³ or 18.64 KN/m³. The specific gravity of solid is 2.70. Determine the degree of saturation and void ratio. What will be the unit weight of the sample on saturation?

Sol: Given —

$w = 15 = 0.15$

$\gamma = 1.9\ gm/cm^3 = 18.64\ KN/m^3$

$G = 2.70$

$S \cdot e = wG$

$S \cdot e = 0.15 \times 2.70 = 0.405$ —— (1)

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

$$18.64 = \frac{(2.70 + 0.405) \times 9.81}{1+e}$$

$$e = \left(\frac{3.105}{18.64}\right) \times 9.81 - 1$$

$$\boxed{e = 0.635}$$

Putting the value of e in Eqn (1)

$$S = \frac{0.405}{0.635}$$

$$\boxed{S = 0.638}$$

If $S = 1$ (Fully Saturated)

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

$$\gamma_{sat} = \left(\frac{2.70 + 0.634}{1+0.634}\right)9.81$$

$$\boxed{\gamma_{sat} = 20.01\ KN/m^3}$$

Ques:- A moist sample of soil has a mass of 633 g and a volume of 300 cm^3 at a water content of 11 %. Taking $G = 2.68$, determine e, S and n_a. Also determine the water content at which the soil gets fully saturated without any increase in the volume. What will be the unit weight at saturation?

Sol:- Given, -

$$M = 633 g$$

$$V = 300 \, cm^3$$

$w = 11 \%$

$G = 2.68$

$$\rho = \frac{M}{V} = \frac{633}{300} = 2.11 \, gm/cm^3$$

$$\gamma = \rho \times 9.81 = 2.11 \times 9.81 \, KN/m^3$$

$$\boxed{\gamma = 20.69 \, KN/m^3}$$

$$eS = wG$$

$$eS = 0.11 \times 2.68$$

$$\boxed{eS = 0.294} \quad \text{--- (1)}$$

$$\gamma_d = \frac{\gamma}{(1+w)}$$

$$\gamma_d = \frac{20.69}{(1+0.11)} = 18.69 \, KN/m^3$$

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

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

$$e = \frac{(2.68 + 0.294) \times 9.81}{20.69} - 1$$

$e = 0.41$ | $e = 41\%$

Putting the value of $e = 0.41$ in eqn (1)

$$eS = 0.294$$

$$\left(S = \frac{0.294}{0.41} = 0.717 \right)$$

$S = 71.7\%$

We know that, —

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

$$(1 - n_a) = \frac{18.63}{9.81}\left(0.11 + \frac{1}{2.68}\right)$$

$$1 - n_a = 0.9175$$

$n_a = 0.0825$ | $n_a = 8.25\%$

For saturation $S = 1$

$$w_{sat} = \frac{eS}{G} = \frac{0.41 \times 1}{2.68}$$

$w_{sat} = 0.15$

$w_{sat} = 15\%$

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

$$\gamma_{sat} = \frac{(2.68 + 0.41) \times 9.81}{1 + 0.41}$$

$\gamma_{sat} = 21.49\ kN/m^3$

Various properties of soil are grouped under two heads:-

(a). Engineering Properties

(b). Index Properties

(a). Engineering Properties of Soil :-

These are mainly four engg. properties of soils are as given below:-

(1). Permeability (2). Compressibility

(3). Shear strength (4). workability

(b). Index Properties :- Index properties of soils are those soils properties which are mainly used in the identification and classification of soil and help geotechnical engineer in predicting the suitability of soil as Foundation / Construction material.

Various index properties are as given below:

(1). Water Content

(2). Specific gravity of soil particles

(3). Particle Size distribution

(4). Consistency Limits and Indices or Consistency of soil

(5). Density Index.

(1). Water Content (w) :- water content or moisture content of soil is expressed as the ratio of the weight of water to the weight of solid (dry weight) of the soil.

It is denoted by 'w'.

$$\left[w = \frac{W_w}{W_s} \times 100 \right]$$

Water content of soil can be determined by any of the following method:-

(a). Oven drying Method $w \Rightarrow \frac{W_2 - W_3}{W_3 - W_1} \times 100$

(b). Sand bath Method

(c). Alcohol Method

(d). Calcium Carbide Method

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

(f). Radiation method

(g). Torsion Balance Method.

(2). Specific gravity of Solid Particles :-

Specific gravity of sold Solids is very useful parameter. It is used in Computation of Void ratio, degree of Saturation, differents Unit weight etc.

Method for determination of specific gravity:-

It is determined by Using a 50 ml / 100 ml density bottle or 500 ml Pycnometer.

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

(3). Particle Size Distribution :-

Percentage of different size of particles present in a given dry sample of soil is computed by particle size analysis or mechanical analysis. It is generally being carried out in two stages.

(i). Sieve Analysis

(ii). Sedimentation Analysis.

0.002 mm — 0.075 mm — 0.425 mm — 2 mm — 4.75 mm — 20 — 80 mm

Clay (size)	Silt Size	Sand			gravel	
		fine	med.	Coarse	fine	Coarse

- (i). <u>Sieve Analysis:-</u> Sieves are designed by the size of aperture in mm as per IS: 460 – 1962.

⇒ It is being carried out for coarse grained particle having size greater than 0.075 mm (75 μm).

Sieve analysis is further divide into <u>two groups</u> —

(a). Coarse Sieving ($4.75 < d < 80 mm$)

(b). Fine Sieving ($0.075 < d < 4.75 mm$)

⇒ In sieve analysis diff. sieves arranged one over other in vertical plane with the sieve having maximum size of aperture at the top and min. size opening at the bottom.

⇒ An oven dry sample is placed at top most sieve. Sieve is done for 10 min. either manually or in sieve shaker.

⇒ % of weight of the particle on each sieve is noted after sieving to computed the % finer corresponding to each sieve size.

% Finer = 100 − Cummulative weight retained.

Sieve Size (mm)	Wt. retained (gm)	% Wt. Retained	Cummulative wt. retained	% finer
80	5	$\frac{5}{100}\times 100 = 5$	5	95
40	25	= 25	30	70
20	35	= 35	65	35
10	15	= 15	80	20
4.75	20	= 20	100	0

Total = 100 gm

(ii). Sedimentation Analysis :— It is being carried out for the particles having size less than 0.075 mm.

Particles having size less than 0.00022 mm cannot be analyzed even by sedimentation. These particles can be analysed by electron microscope or by X-ray diffraction.

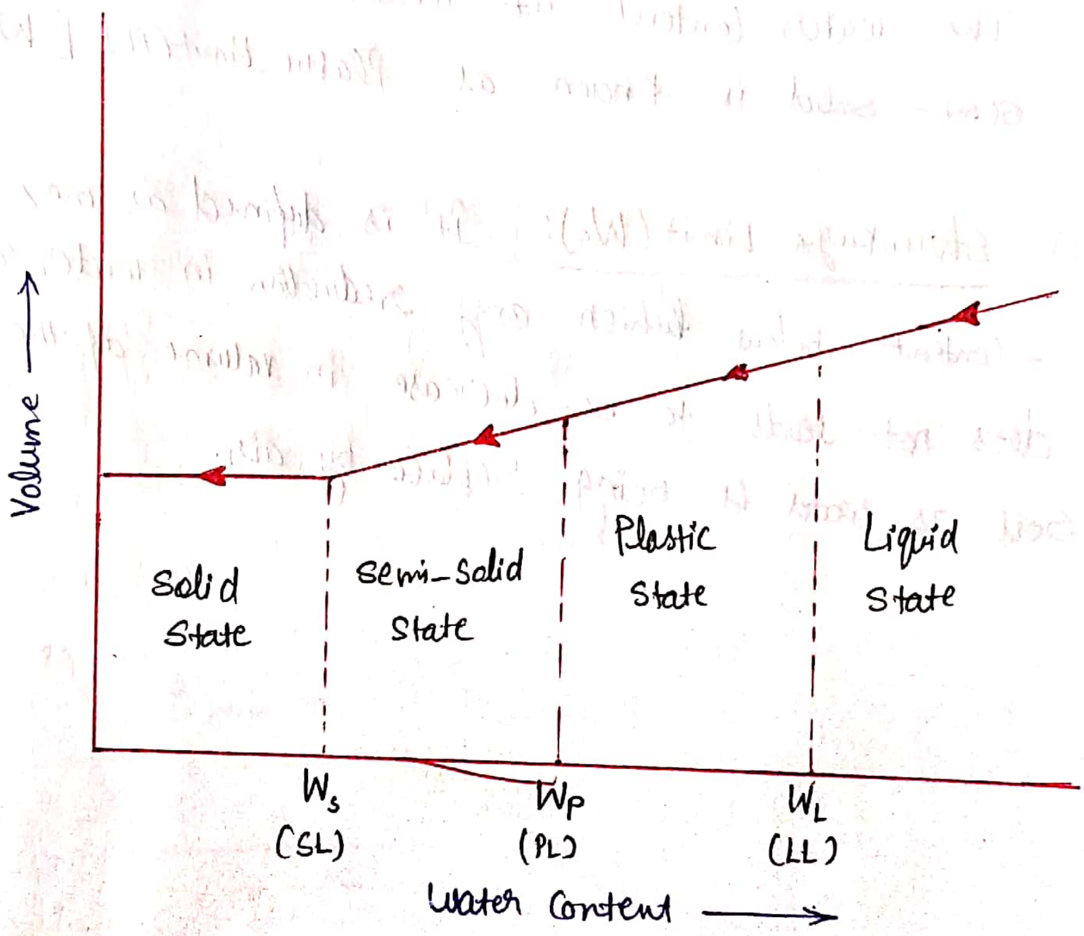
(a). Pipette Method

(b). Hydrometer Method.

(4). Consistency of Soil :-

Consistency represents the relative ease with which soil may be deformed. This term is used for fine grained soils only as it denotes the degree of firmness of the soil which may termed as soft, medium, firm, stiff or hard.

Consistency of soil related to its water content and the water content at which soil passes from I-stage of consistency to another is termed as consistency limit.



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(i). <u>Liquid Limit (W_L)</u>:- The water Content at which the Soil changes from liquid states to plastic state is known as Liquid Limit (L.L.) [W_L].

It is the minimum water Content at which the soil mass still flow like a liquid.

(ii). <u>Plastic Limit (W_P)</u>:- It is defined as min. water Content at which the soil mass can still be deformed without cracking.

The water Content at which the Soil becomes semi- Solid is known as Plastic Limit (PL) [W_P].

(iii). <u>Shrinkage Limit (W_S)</u>:- It is defined as max water-Content below which any reduction in water content does not leads to be decrease in volume of the Soil as water is being replace by air.

(5) Density Index (I_D):-

I_D in the earlier day referred to as relative density. It is the ratio of difference b/w max. void ratio and natural void ratio to the diff. b/w max. void ratio and min void ratio.

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \quad \text{---} (1)$$

where,

e_{max} = void ratio in loosest state

e_{min} = Void ratio in densest state

e = natural void ratio.

we know that,

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

If

$$e_{max} = \frac{G\gamma_w}{(\gamma_d)_{min}} - 1$$

&

$$e_{min} = \frac{G\gamma_w}{(\gamma_d)_{max}} - 1$$

In eqn:-

$$I_D = \frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}} \times \frac{(\gamma_d)_{max}}{\gamma_d}$$

Ques: The natural dry density of a soil deposite was found to be 17.5 KN/m³. A sample of the soil was brought to the labaratary and the minimum and max. dry densities were found as 16.0 KN/m³ and 19.0 KN/m³ respectively. Calculate the density index for the soil deposite.

Given,

$$\gamma_d = 17.5 \text{ KN/m}^3$$

$$(\gamma_d)_{min} = 16.0 \text{ KN/m}^3$$

$$(\gamma_d)_{max} = 19.0 \text{ KN/m}^3$$

$$\text{Density Index} = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$$I_D = \frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}} \times \frac{(\gamma_d)_{max}}{\gamma_d}$$

$$I_D = \frac{17.5 - 16}{19 - 16} \times \frac{19}{17.5} = 0.543$$

$$I_D = 54.3\ \%$$

Atterberg Indices :-

1. Plasticity Index
2. Flow Index
3. Toughness Index
4. Consistency Index
5. Liquidity Index

(1). Plasticity Index:- (I_p) It is defined as difference between liquid limit and plastic limit.

$$I_p = W_L - W_p$$

(2). Flow Index:- (I_F) Flow index is the slope of flow curve obtained by plotting water content as ordinate on natural scale against number of blows on log scale.

where,

$$I_F = \frac{W_1 - W_2}{\log_{10} \frac{N_2}{N_1}}$$

W_1 = water content corresponding to no. of blows N_1.

W_2 = water content corresponding to no. of blows N_2.

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(3). Toughess Index: - (I_T) It is defined as the ratio of plasticity Index to Flow Index.

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

(4). Consistency Index: (I_C) It is defined as the ratio of diff. b/w liquid limit and natural water content to the plasticity Index.

$$I_C = \frac{W_L - W}{I_P}$$

(5). Liquidity Index: (I_L) It is defined as the ratio of diff b/w natural water content and plastic limit to plasticity index

$$I_L = \frac{W - W_P}{I_P}$$

Soil Structure :- The geometrical arrangement of the soil particles with respect to one another is known as soil structure. The soil is nature have diff. structure depending upon the particle size and the made of formation.

Type of Soil Structure :-

There are mainly 3 types :-

(1). Coarse-grained soil structure.

(i). Single grained structure

(ii). Honey comb structure.

(2). Clay soil structure

(i). Flucculated structure

(ii). Dispersed structure

(3). Mixed soil structure.

(i). Coarse-grained skelton

(ii). clay Matrix structure.

Important shapes of particles:-

(1). Angular  } In gravel, sand, silt

(2). Rounded 

(3). Flaky  → In clays

(4). Needle  → In coral deposits.

(1). Coarse grained soil structure :-

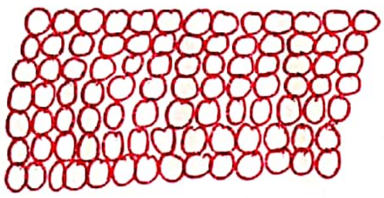
(i). Single grained structure :- An arrangement composed of individual soil particles. It is present in soils like gravel and sand.

(a). Loosest Packing

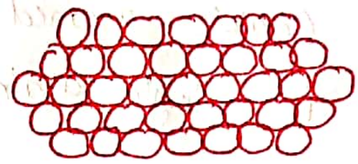
The void ratio for loosest state is 0.91, when the particles are assumed as perfect sphere.

(b). Densest Packing

The void ratio for densest state is 0.35, when the particles are assumed as perfect sphere.



Loosest packing

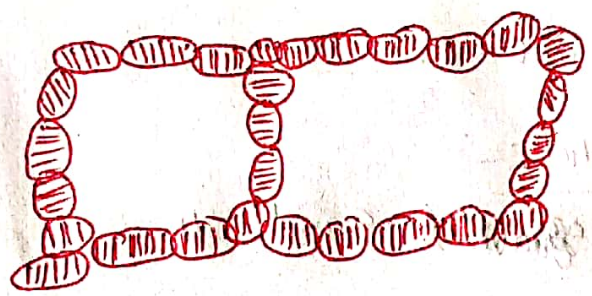


Densest packing.

(ii). Honey Comb Structure :- An arrangement of soil particles having a comparatively loose, stable structure resembling a honey comb.

Present in fine sand or silts.

Under vibrations and shocks, the structure collapses and large deformation take place.



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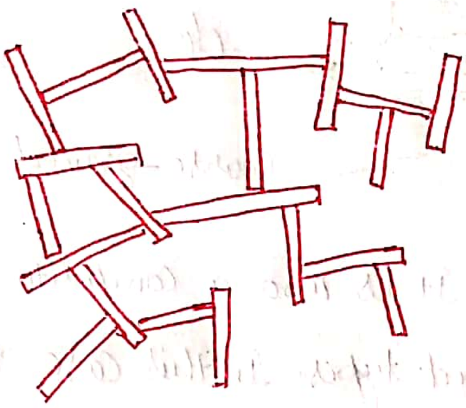
(2). Clay Soil Structure :-

(i). Flocculated Structure :- An arrangement composed of 'flocs' of soil particles instead of individual soil particle. The particles are oriented 'edge-to-edge' or 'edge-to-face' with respect to one another.

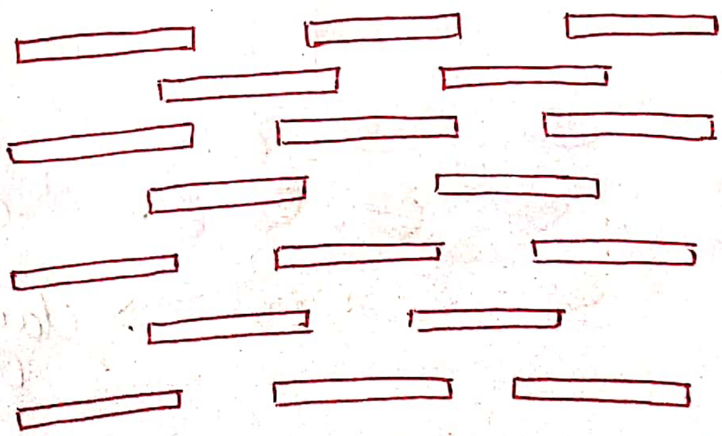
⇒ It occurse in clays.

⇒ Formed when there is a net attractive force b/w particles.

⇒ High shear strength, low compressibility, high permeability.

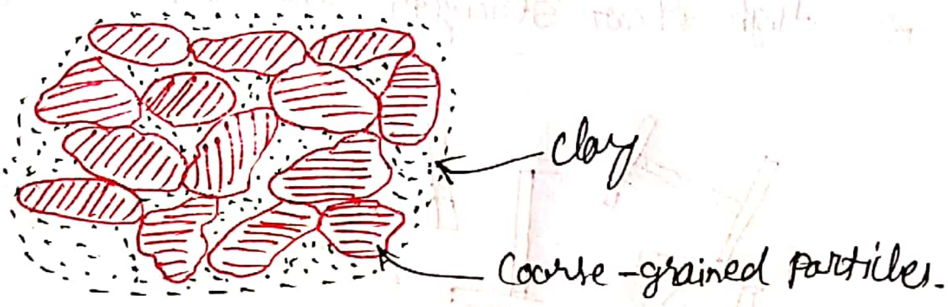


(ii). Dispersed :- An arrangement composed of particles having a 'face-to-face' or parellel orientation.

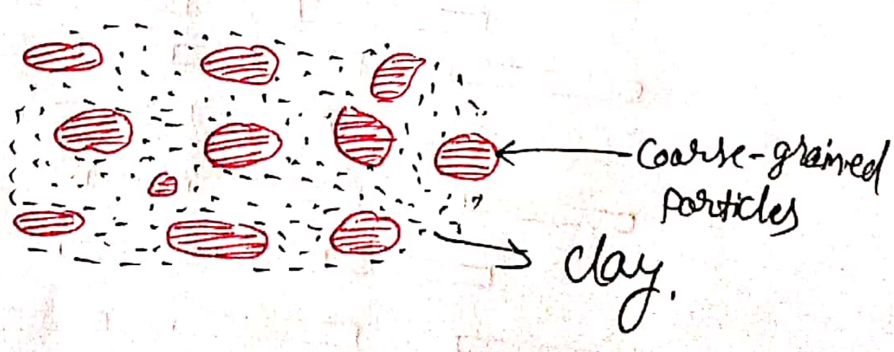


(3). Mixed soil structure

(i). Coarse-grained skelton :- It is a composite structure which formed when the soil contains particles of different types. When the amount of bulky, cohesionless particles is large compared with that of fine-grained clayey particles, the bulky grains are in particles-to-particles contact. These particles form a framework or skelton.



(ii) Clay-Matrix structure :- It is also a composite structure formed by soils of different types. In this case the amount of clay particles is very large as compared with bulky, coarse-grained particles. The clay forms a matrix in which bulky grains appears floating without touching one another.



Classification of soils

The Purpose of soil classification is to arrange various types of soils into groups according to their engineering or agricultural properties and various other characteristics.

From Engineering point of view, the classification may be done with the objective of finding the suitability of the soil for construction of dams, highways or foundations etc. Soils may be classified by the following system.

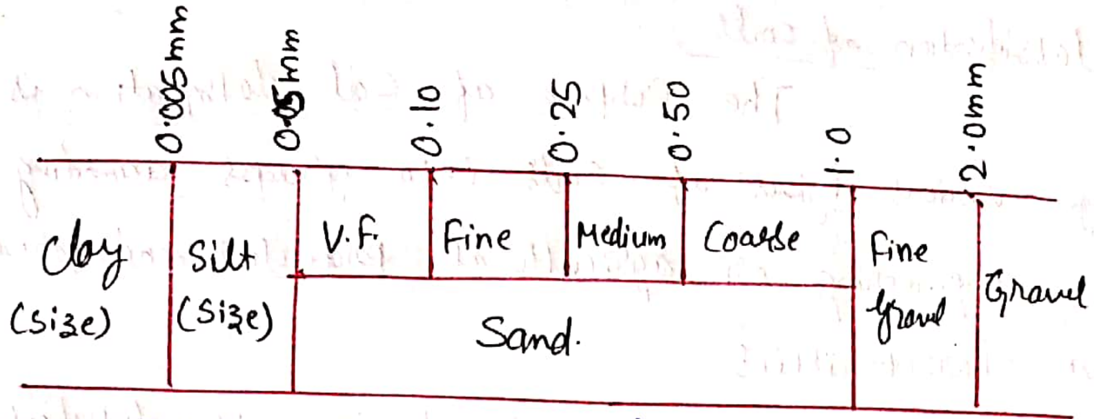
(1). Particle size classification.

(2). Textural classification

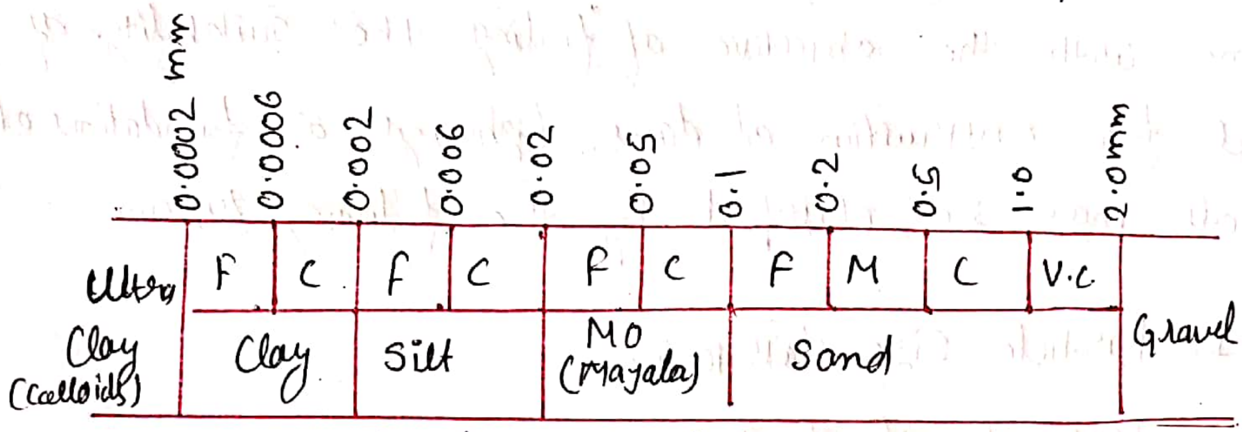
(3). Highway Research Board (HRB) classification.

(4). Unified soil classification and IS (Indian standard) classification system.

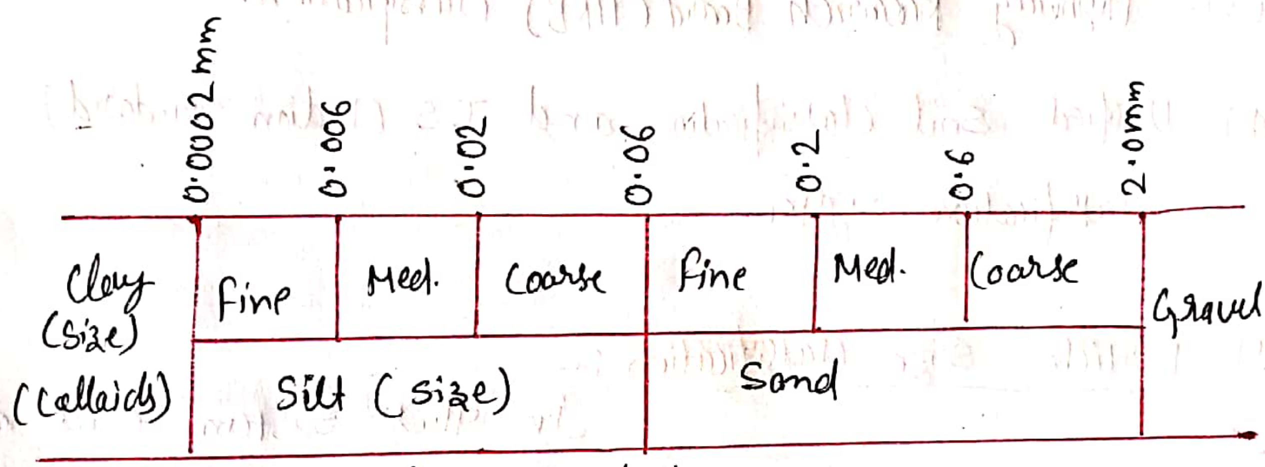
(1). **Particle size classification:–** In this system soils are arranged according to their grain size. Terms such as gravel, sand, silt and clay are used to indicate grain sizes. These terms are used only as designation of particle sizes, and do not signify the naturally occuring soil types, which are mixtures of particles of different sizes.



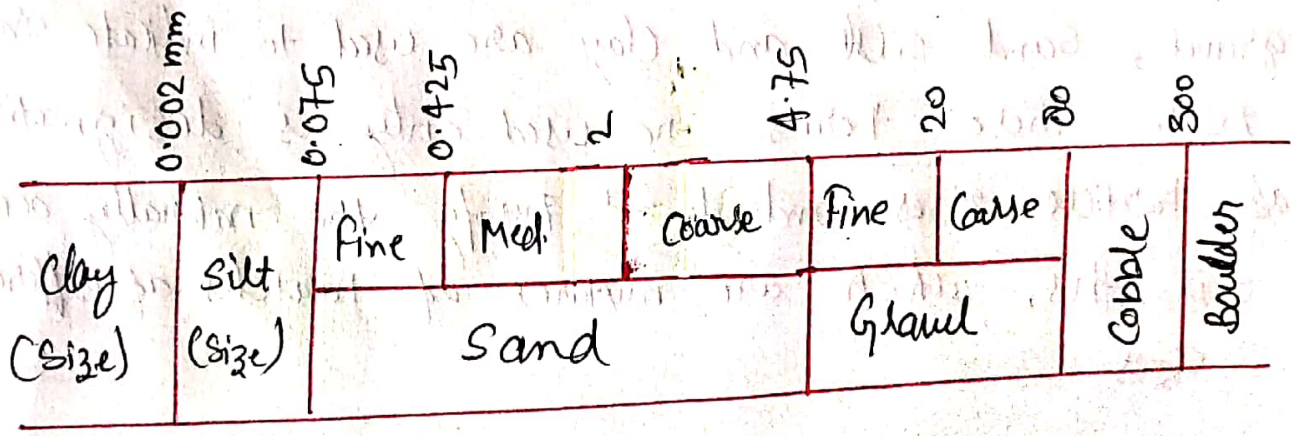
(a) U.S. Bureau of Soil and PRA classification.



(b). International Classification.

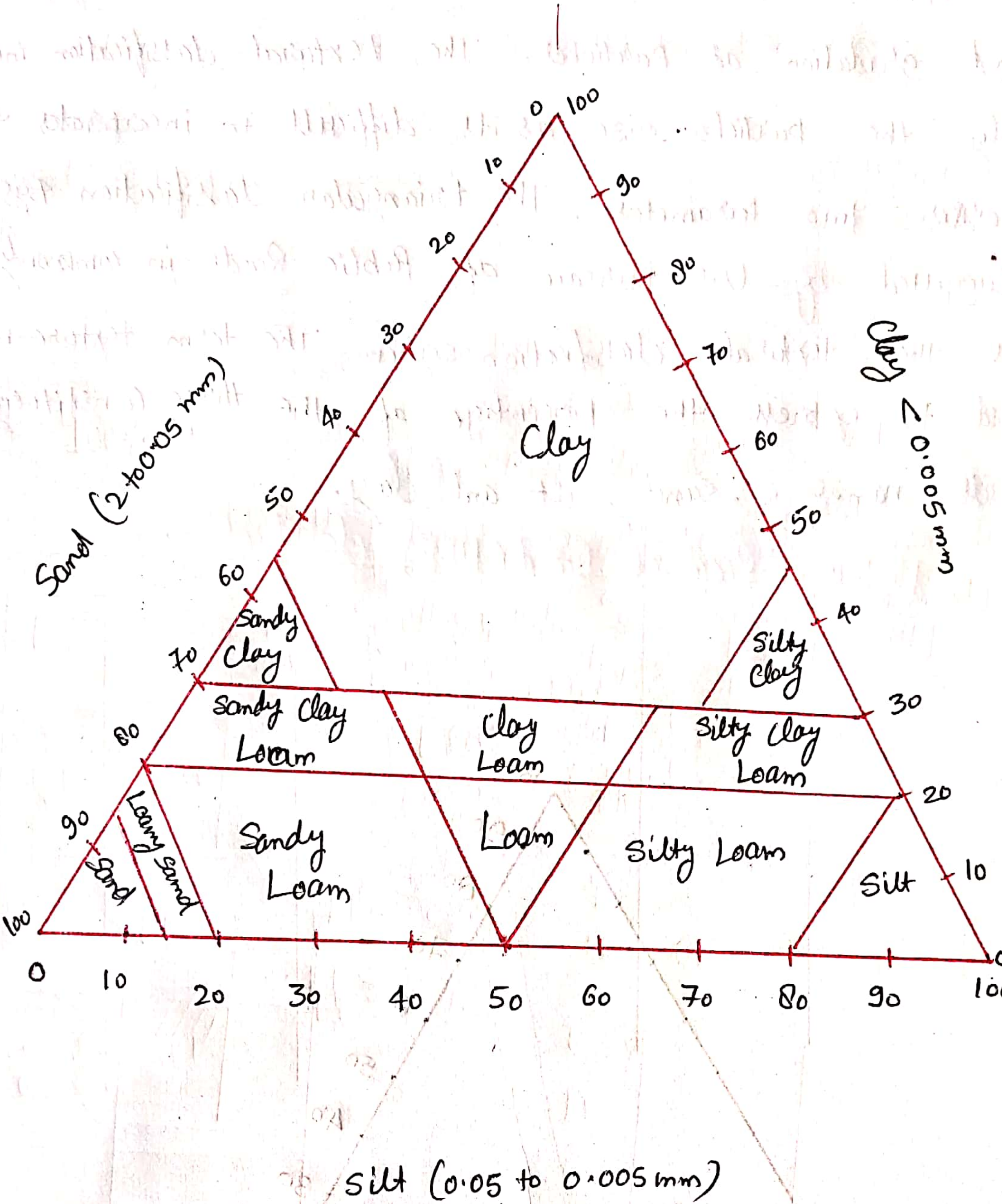


(c). MIT Classification.



(d) I.S. Classification (IS: 1498-1970)

(2). Textural classification :- Texture means visual appearance of the surface of a mineral such as fabric and cloth. The visual appearance of soil is called its texture. The texture depends upon the particle size, shape of particles and gradation of particles. The textural classification incorporates only the particle size as its difficult to incorporates the other two parameters. The triangular classification system suggested by U.S. Bureau of Public Roads is commonly known as the textural classification system. The term texture ~~~~ is used to express the percentage of the three constituents of soils, namely, sand, silt and clay.



0
100
10
90
20
80
30
70
40
60
50
50
60
40
70
30
80
20
90
10
100
0
Sand (2 to 0.05 mm)
Clay < 0.005 mm
Clay
Sandy Clay
Silty Clay
Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sand
Loamy Sand
Sandy Loam
Loam
Silty Loam
Silt
0
10
20
30
40
50
60
70
80
90
100
Silt (0.05 to 0.005 mm)

(3). Highway Reshearce Board (HRB) Classification :-

HRB is also known as PRA (Public Road Administration) Classification system based on both the particle-size Composition as well as the plasticity characteristics. This system is mostly used for pavement Construction. Soils are divided into 7 primary groups, designated as A-1, A-2, ----- A-7. Group A-1 is divided into two Sub-groups and group A-2 into 4 sub groups.

The characteristics group index is used to describe the performance of soils when used for pavement Construction.

The group Index of a soil depends upon
(i). the amount of materials passing the 75-micron IS sieve.
(ii). the liquid limit and (iii). the plastic limit,

Group Index = $0.2a + 0.005ac + 0.01bd$.

$$\text{Group index} = 0.2\,a + 0.005\,ac + 0.01\,bd \qquad \ldots(4.1)$$

where a = that portion of percentage passing 75 mircon sieve greater than 35 and not exceeding 75 expressed as a whole number (0 to 40)

b = that portion of percentage passing 75 micron sieve greater than 15 and not exceeding 55 expressed as a whole number (0 to 40)

c = that portion of the numerical liquid limit greater than 40 and not exceeding 60 expressed as positive whole number (0 to 20)

and d = that portion of the numerical plasticity index greater than 10 and not exceeding 30 expressed as a positive whole number (0 to 20).

TABLE 4.1. HRB-CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

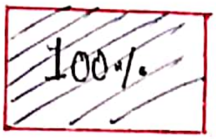
General Description	*Granular materials (35% or less passing 75 micron IS sieve)*							*Silt clay materials (more than 35% passing 75 micron IS sieve)*			
Group Classification	A–1		A–3	A–2				A–4	A–5	A–6	A–7
	A–1–a	A–1–b		A–2–4	A–2–5	A–2–6	A–2–7				A–7–5, A–7–6
Sieve analysis, percent passing											
2.0 mim IS sieve	50 max										
425 micron sieve	30 max	50 max	51 min								
75 micron sieve	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 425 micron sieve											
Liquid Limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		NP	10 max	10 max	11 min	11 max	10 max	10 max	11 min	11 min
Group Index	Zero					4 max		8 max	12 max	16 max	20 max
Usual type of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

(4). Unified Soil Classification and Indian Standard classification system :-

⇒ Based on the airfield classification system that was developed by A. Casagrande in 1940.

⇒ The Indian Standard Institution adopted the Unified classification system in 1954.

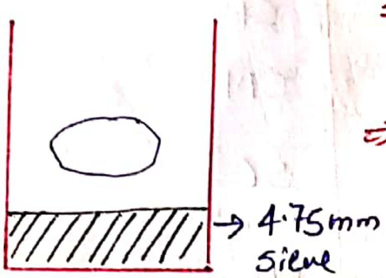
⇒ This classification system is based on both grain size and palasticity property of soil and is therefore applicable to any use.



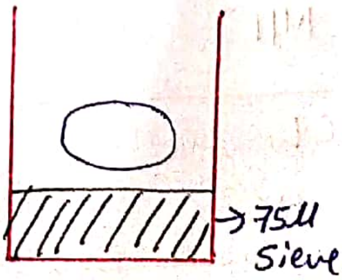
⇒ If >50% Retained above 4.75mm sieve [Gravel]

⇒ If >50% passed from 4.75mm sieve [Sand]

⇒ If passed from 75μ sieve [clay & silt]



⇒ If >50% of the soil is clay and silt [Fine grained soil]



⇒ If >50% of the soil is retained above 75μ sieve [Coarse-grained soil]

⇒ If 50% retained and 50% passed (Dual symbol)

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⇒ The soil classified into 15 groups

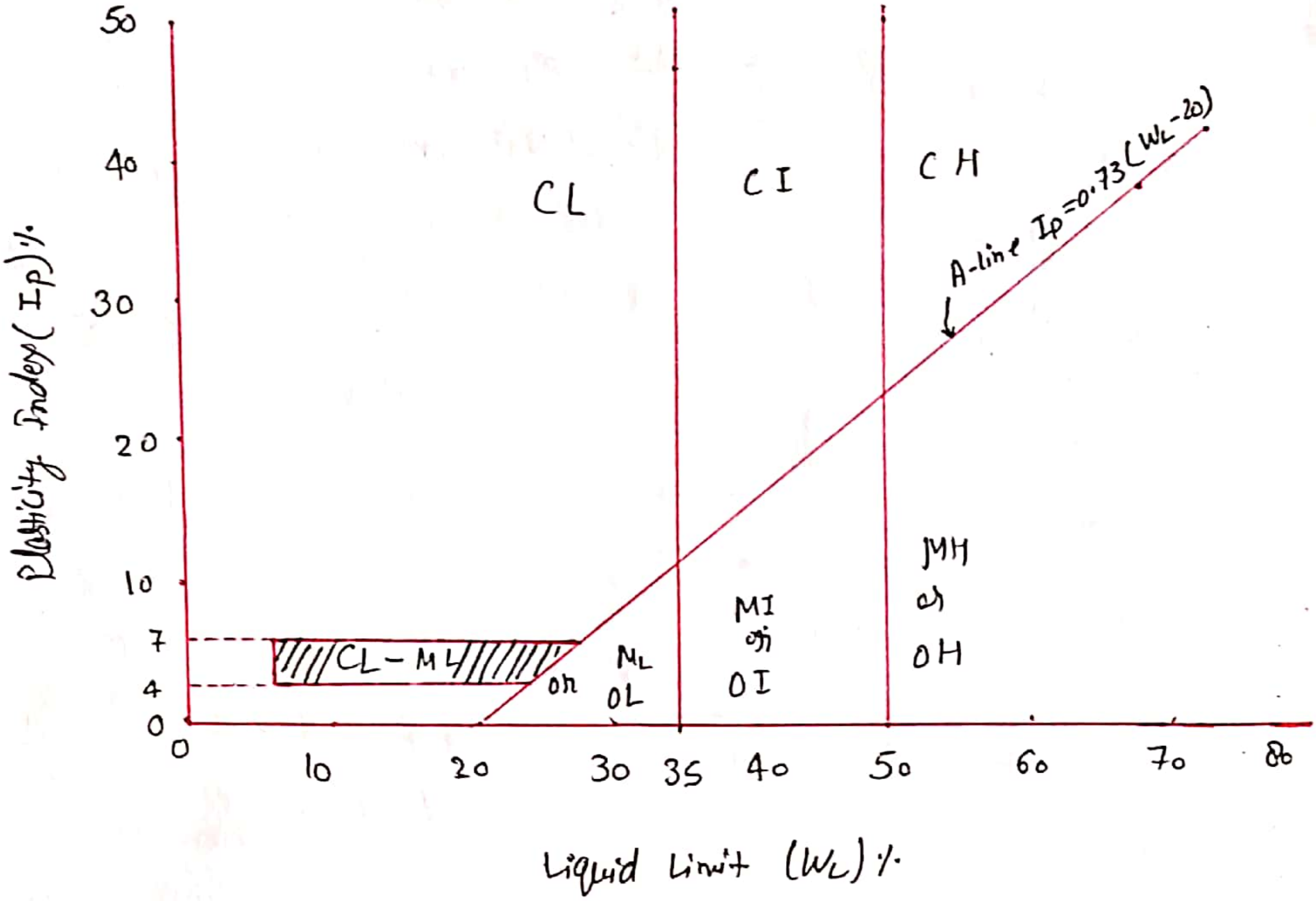
⇒ Each groups is designated a symbol consist of two Capital letters

⇒ 1st Letter based on main soil type.

⇒ 2nd Letter based on gradation and plasticity.

Main soil Type	Prefix	Subgroup	Suffix	Classification Group symbols
Gravel	G	Well-graded	W	GW
		Poorly-graded	P	GP
		Silty	M	GM
		Clayey	C	GC
Sand	S	Well-graded	W	SW
		Poorly-graded	P	SP
		Silty	M	SM
		clayey	C	SC
Silt	M	LL < 50%	L	ML
		LL > 50%	H	MH
clay	C	LL < 50%	L	CL
		LL > 50%	H	CH
organic	O	LL < 50%	L	OL
		LL > 50%	H	OH
Peat	Pt			Pt.

Plasticity chart :-



⇒ Silts and clay of low compressibility having liquid limit less than 35%. [L]

⇒ Silts and clay medium compressibility having a liquid limit greater than 35% and less than 50% [I]

⇒ Silts and clay of high compressibility having a liquid limit greater than 50% [H].

Sensitivity of Clay:-

The consistency of an undisturbed sample of clay is altered, even at the same water content, if it is remoulded. It is because the original structure of clay is altered by reworking or remoulding. Since the strength of a clay soil is related to its structure, remoulding results in decrease of its strength.

The degree of disturbance of undisturbed clay sample due to remoulding is expressed by sensitivity (S_i) which is defined as the ratio of its unconfined compression strength in the natural or undisturbed state to that in the remoulded state, without change in the water content.

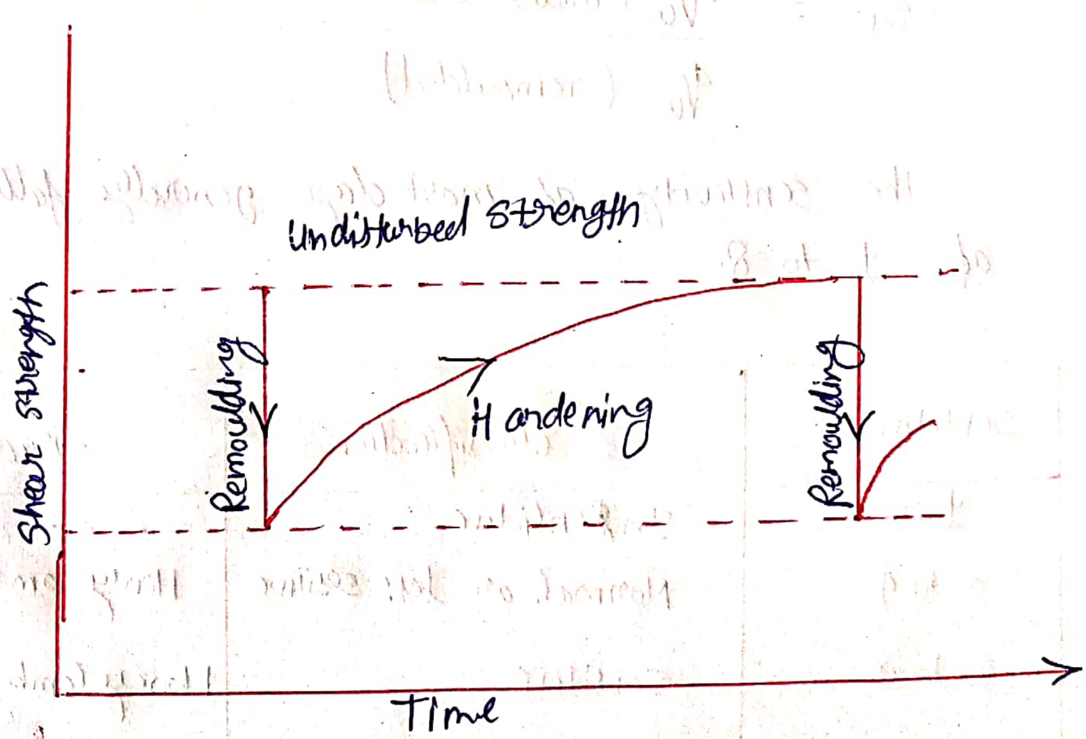
$$S_i = \frac{q_u \text{ (undisturbed)}}{q_u \text{ (remoulded)}}$$

The sensitivity of most clay generally falls in a range of 1 to 8.

Sensitivity	Classification	Structure
1	Insensitive	—
2 to 4	Normal or less sensitive	Honey comb
4 to 8	Sensitive	Honey comb or Flocculent
8 to 16	Extra sensitive	Flocculent
> 16	Quick	Unstable

Thixotropy of clays :- When sensitive clay are used in construction, they loose strength due to remoulding during construction operation. However with passage of time, the strength again increase, though not to the same original level. This phenomenon of 'strength loss-strength gain' with no change in volume or water content is called 'Thixotrophy'.

The Loss of strength due to remoulded is partly due to (i). permanent destruction of the structure due to in-situ layers and
(ii). reorientation of molecules in the absorbed layer.



Thixotrophy of clay

5.9. CLAY MINERALS

There are two fundamental *building blocks* for the clay mineral structures. One is a *silica tetrahedral unit* [Fig. 5.14 (*a*] in which four oxygen or hydroxyls having the configuration of a tetrahedron enclose a silicon atom. The tetrahedra are combined in a sheet structure so the oxygens of the bases of all the tetrahedra are in a common plane,

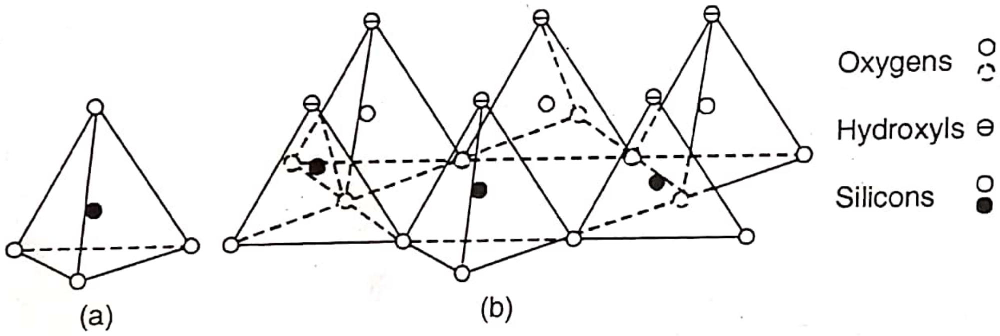
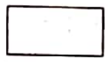


FIG. 5.14. BASIC STRUCTURAL UNITS IN THE SILICASHEET (GRIM, 1959).

and each oxygen belongs to two tetrahedra [Fig. 5.14 (*b*)]. The silica tetrahedral sheet alone may be reviewed as a layer of silicon atom between a layer of oxygens and a layer of hydroxyls (tips of the tetrahedra). The silicon sheet is represented by the symbol,  representing the oxygen basal layer and the hydroxyl apex layer.

The second building block is an octahedral unit in which an aluminium, iron or magnesium atom is enclosed in six hydroxyls having the configuration of an octahedron [Fig. 5.15 (*a*)]. The octahedral units are put together into a sheet structure [Fig. 5.15 (*b*)] which may be viewed as two layers of densely packed hydroxyls with cation between the sheets in octahedral co-ordination (Grim, 1959). This unit is symbolised by  and is known as *gibbsite*.

About 15 minerals are ordinarily classified as clay minerals, and these belong to four main groups ; kaolin, montmorillonite, illite and palygorskite. Out of these, the first three groups are the most common, and will be described here.

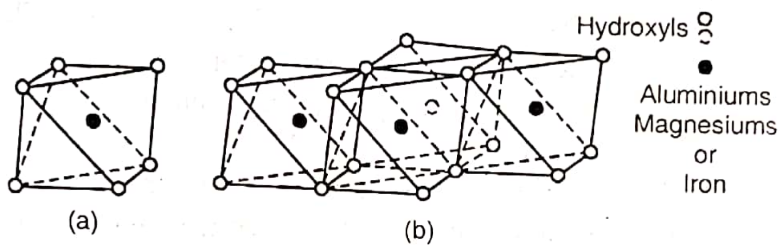
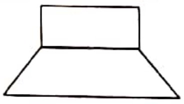


FIG. 5.15. BASIC STRUCTURAL UNITS IN THE OCTAHEDRAL SHEET (GRIM, 1959).

Kaolinite. Kaolinite is the most common mineral of the kaolin group. The kaolinite structural unit is made up of gibbsite sheets (with aluminium atoms at their centres) joined to silica sheets through the unbalanced oxygen atoms at the apexes of the silicas, (*i.e.*, the apexes of the silica layer and one of the gibbsite form a combined layer). This structural unit is symbolised by  which is about 7 Å (one angstrom, Å= 10^{-7} mm= 10^{-10} m) thick.

The *Kaolinite mineral or crystal,* is stacking of such 7 Å thick sheets symbolised as shown in Fig. 5.16 (*a*). The structure is like that of a book with each leaf of the book 7Å thick. Successive 7 Å layers are held together with *hydrogen bonds* (Fig. 5.16 *b*). A kaolinite crystal may be made up of often 100 or more such stackings. The kaolinite particles occur in clay as platelets from 1000 Å to 20,000 Å wide by 100 Å to 1000 Å thick. Since the hydrogen bond is fairly strong, it is extremely difficult to separate the layers, and as a result kaolinite is relatively stable and water is unable to penetrate between the layers, Kaolinite consequently shows relatively little *swell* on wetting. The platelets carry negative electromagnetic charges on their flat surface which attract thick layers of adsorbed water thereby producing plasticity when the kaolinite is mixed with water. China clay is almost pure kaolinite.

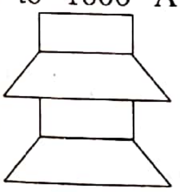


FIG. 5.16 (*a*)

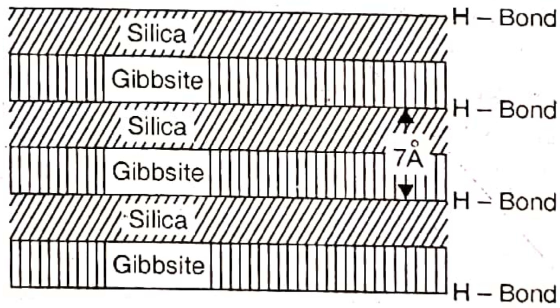
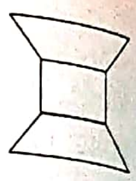
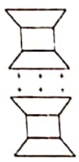


FIG. 5.16 (*b*). STRUCTURE OF KAOLINITE.

Montmorillonite. This is the most common of all the clay minerals in expansive clay soils. The mineral is made up of sheet like units. The basic structure of each unit is made up of gibbsite sheet (*i.e.* the octahedral sheet) sandwiched between two silica sheets, and is symbolised as shown in Fig. The thickness of each unit (or sheet) is about 10 Å and the dimensions in the other two directions are indefinite. The gibbsite layer may include atoms of aluminium, iron, magnesium or a combination of these. In addition, the silicon atoms of tetrahedra may interchange with aluminium atoms. These structural changes are called *amorphous changes* and result in a net negative charge on the clay mineral. Cations which are in soil water (i.e., Na^+, Ca^{++}, K^+ etc.) are attracted to the negatively charged clay plates, and exist in a continuous state of interchange.



The basic 10 Å thick units are stacked one above the other like the leaves of a book and symbolised as shown in Fig. 5.17 (*a*). There is very weak bonding between the successive sheets and water may enter between the sheets causing the minerals to swell (Fig. 5.17 *b*). The spacing between the elemental silica-gibbsite-silica sheets depends upon the amount of available water to occupy the space. For this reason, montmorillonite is said to have an expanding lattice. Each thin platelet has a power to attract to each flat surface a layer of adsorbed water approximately 200 Å thick, thus separating platelets a distance of 400 Å under zero pressure. In the presence of abundance of water, the mineral can, in some cases, split up into about an individual unit layers of 10 Å thick. Soils containing montmorillonite minerals exhibit high shrinkage and swelling charactersitics, depending upon the nature of exchangeable cations present.



5.17 (*a*).

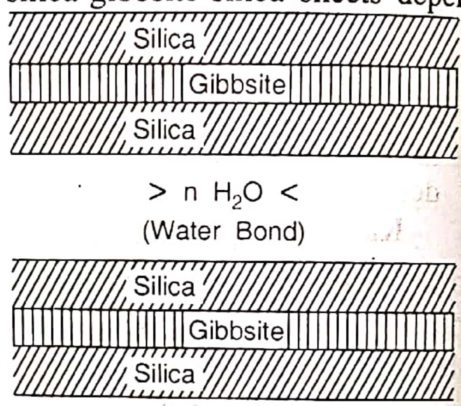


FIG. 5.17 (*b*). STRUCTURE OF MONTMORILLONITE.

Illite. The structure of illite is similar to that of montmorillonite except that there is always substantial (20% $\pm$) replacement of silicons by aluminium in the tetrahedral layers and potassiums are between the layers serving to balance the charge resulting from the replacement and to tie the sheet units together. The basic unit is symbolically represented as shown in Fig. 5.18 (*a*). The cation bond of illite is weaker than the hydrogen bond of kaolinite, but is stronger than the water bond of montmorilllonite. Due to this, the illite crystal (Fig. 5.18 *b*) has a greater tendency to split into ultimate platelets consisting of gibbsite layer between two silica layers, than that in kaolinite. However, illite structure does not swell because of movement of water between the sheets, as in the case of montmorillonite. Illite clay particle may be 50 Å to 500 Å thick and 1000 Å to 5000 Å in lateral dimensions.

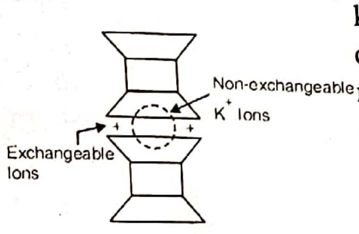


FIG. 5.18 (*a*)

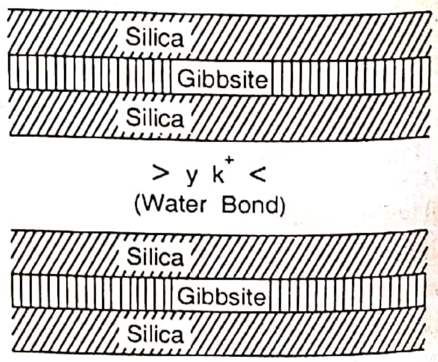


FIG. 5.18(*b*). STRUCTURE OF ILLITE.

Density of water = 1000 Kg/m³

$\rho_w = 1 \, gm/cm^3$ to $\gamma_w = 9.81 \, KN/m^3$

*
$F = m \cdot a$
$N = Kg \cdot m/s^2$

we know that, -

$W = m \times g$

$= 1000 \, Kg \, 9.81 \, m/s^2$

$= 1000 \times 9.81 \, Kg \times m/s^2$ $(1N = Kg \, m/s^2)$

$= 9810 \, N$

$W = \frac{9810}{1000} KN = 9.81 \, KN$

Then, $\gamma = \frac{W}{V} = \frac{9.81 \, KN}{m^3} = 9.81 \, KN/m^3$

$\gamma_w = 9.81 \, KN/m^3$ $\rho_w = 1 \, gm/cm^3$

$\gamma_w = 9.81\ KN/m^3$ to $\rho_w = 1\ gm/cm^3$

We know that

$1\ kg = 9.81\ N$

$9.81\ N = 1\ kg$

$9.81\ N = 1000\ gm$

$1N = \frac{10^3}{9.81}\ gm$

$\frac{1}{10^3}\ KN = \frac{10^3}{9.8}\ gm$

$1\ KN = \frac{10^3 \times 10^3}{9.81}\ gm$

$1\ KN = \frac{10^6}{9.81}\ gm$

$\gamma_w = 9.81 \times \frac{10^6}{9.81}\ gm/m^3$

$\rho_w = \frac{10^6\ gm}{10^6\ cm^3}$

$\rho_w = 1\ gm/cm^3$