CIE: 40
SEE: 60
(L:T:B - 3:0:0)

Basic GeoTechnical Engineering.
(18CV54)

M-1-P-1.

MODULE - 1.

Introduction:- Origin & Formation of soil, Regional soil deposits in India, Phase diagram, phase relationships, definitions and their inter relationships.

Determination of Index properties: Specific gravity, water content, in-situ density, relative density, particle size analysis (sieve and Hydrometer analysis).

Atterberg's Limits, consistency indices. Activity of clay, Field identification tests, Plasticity chart, BIS soil classification (IS: 1498 - 1970)

1.1 Geotechnical Engineering may be considered as the branch of engineering involving the study of soil, its behaviours and application as an engineering material. Concepts of physics, solid mechanics, earth science and geology are considered in the geotechnical Engg.

1.2 Origin and Formation of soil:- * "Soil is porous, particulate, heterogeneous, anisotropic and undergoes volume change under shear. Hence it is considered as complex material".

The material constituting the earth crust may be broadly classified into SOIL & ROCK. Soil is considered to includes all naturally occurring loose or soft deposit overlying the solid bed rock crust. The soil is produced by the physical & chemical disintegration (weathering - periodical temp change, impact & abrasive actions of flowing water, ice & wind, splitting action of ice, plant & animals - physical agency; oxidation, hydration, carbonation and leaching by an acid/water - chemical ") of rocks and which may or may not contain organic matter.

The term rock refers ~~to~~ only to the natural soil part of earth crust known as Bed Rock OR ~~to~~ hard fragments of rocks.

Soils are formed from rocks due to weathering action (disintegration). Igneous rock is the basic rock formed from crystallization of molten magma ~~and~~ which is formed inside the earth (plutonic rocks) OR on the surface (volcanic rock). Igneous rock undergo metamorphism under high temperature & pressure to form metamorphic rocks. Both igneous & metamorphic rocks are converted into sedimentary rocks due to transportation to different locations by agencies such as wind, water etc.,

Weathering is the process of breaking down rocks into smaller pieces called grains. This process ~~may be~~ is due to agencies like.

a) Physical → periodical Temperature change, impact & abrasive actions of flowing waters, ice & wind, splitting action of ice, plants & animals

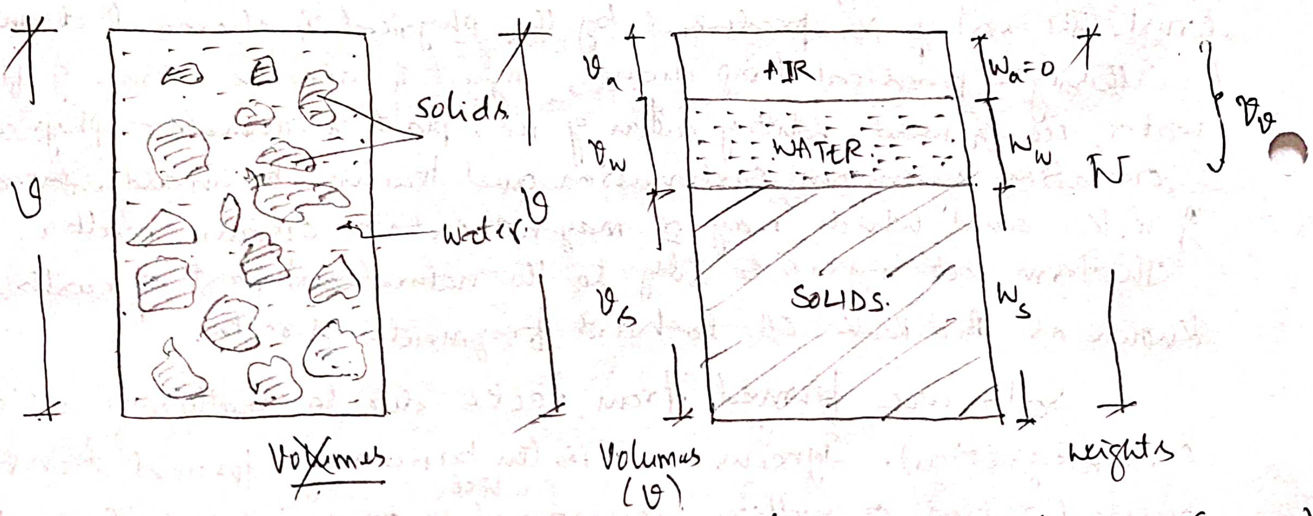
b) ~~Chemical~~ Mechanical → This is caused by the expansion & contraction of rocks from continuous gain or loss of heat resulting in disintegration

c) Chemical → oxidation, hydration, carbonation and leaching by an acid or water.

* The size of individual soil particle (grains) varies over a wide range. Many of physical properties of soil are dictated by the size, shape & chemical composition of grains.

<u>Soil as a Construction Material</u>:- It is the oldest & cheapest construction material available. It is used to manufacture bricks, tiles or earthware. It is used as foundation material and to construct dams & embankment. Used as filler material for retaining walls.

<u>Phase Diagram</u>:- A soil mass is a "THREE PHASE SYSTEM" consisting of solid particles (i.e., soil grains), water and air. The voids b/w soil grains is filled partly with water and partly with air. (In case of dry soil, the voids are filled with air only). as shown in figure.



Element of Natural soil.

Element separated into Three phases

$V_v = (V_a + V_w)$

Where: V = Total volume of the soil mass.

V_a = Vol. of air

V_w = Vol. of water

V_s = Vol. of solids

W = Total weight of soil mass

W_a = Weight of air = 0

W_w = weight of water.

W_s = weight of solids

$\therefore W = W_a + W_w + W_s = (W_w + W_s)$

1) **Water Content:- (w).:** It is defined as the ratio of weight of water (W_w) to the weight of solid soils (W_s), expressed in percentage. It is also referred as moisture content. Water content of soil mass varies with season (summer, rainy). While substituting in the eqn, it is expressed in decimal. It can be calculated in the laboratory.

$$w = (W_w/W_s) \times 100.$$

2) **Void ratio:- (e)** It is defined as the ratio of volume of voids (V_v) to the volume of solids (V_s), and is expressed in decimal. It is not possible to find the void ratio in the laboratory. It is calculated by using the other properties.

$$e = (V_v/V_s)$$

3) **Porosity:- (n):** It is defined as the ratio of volume of voids (V_v) to the total volume of soil mass $n = (V_v/V)$ and expressed in percentage. It is not possible to determine the porosity in lab. It is computed from other properties.

4) **Degree of saturation:- (S or Sr):** It is defined as the ratio of volume of water (V_w) to volume of voids (V_v), expressed as percentage.

$$S = S_r = \left(\frac{V_w}{V_v}\right) \times 100.$$

For dry soil S=0 and for fully saturated soil S=1 (or 100%). It is not possible to determine the degree of saturation in the laboratory. Hence it is computed.

5) **Air content (a_c):** It is defined as the ratio of volume of air (V_a) to volume of voids (V_v), expressed as percentage. $a_c = (V_a/V_v) \times 100.$

For dry soil $a_c = 1$ (100%) and fully saturated soil $a_c = 0$. Air content is computed.

6) **Percentage of air voids (n_a):** It is defined as the ratio of volume of air (V_a) to the total volume of mass (V) expressed as percentage.

$$n_a = (V_a/V) \times 100.$$

Percentage air voids is computed. It is always less than air content ($n_a < a_c$).

7) **Bulk unit weight:** It is defined as the ratio of total weight (W) of soil mass to total volume of soil mass (V) $\gamma_b = W/V$. In SI units it is expressed as kN/m^3. Its value normally ranges from 12 to 24 kN/m^3.

8) **Dry unit weight: (γ_d)** It is defined as the ratio of weight of soil solids (W_s) to the volume of soil ~~solids~~ mass $\gamma_d = (W_s/V)$. It cannot be determined in the laboratory and hence computed from the other properties using relation $\gamma_d = \frac{\gamma_b}{(1+w)}$

9) **Saturated unit weight:-** It is defined as the ratio of weight of saturated soil mass (W_{sat}) to the total volume of soil mass (V).

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

***

9) Unit weight of soil solids (γ_s): It is defined as the ratio of weight of soil solids (W_s) to the volume of soil solids (V_s)

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

It cannot be determined in the laboratory and hence computed from other parameter.

(11) Unit weight of water (γ_w): It is defined as the ratio of weight of water to volume of water. Its value is generally taken as $9.81\ kN/m^3$

(12) Submerged unit weight (γ' OR γ_{sub}): It is defined as the ratio of submerged weight of ~~solids~~ soil solids $(W_s)_{sub}$ to the total volume of soil mass V.

$$\gamma' = \gamma_{sub} = \frac{(W_s)_{sub}}{V}$$

*** When the soil mass is submerged, the weight of soil solids (W_s) is reduced due to ~~buoy~~ buoyancy. The submerged weight $(W_s)_{sub}$ is equal to the weight of soil solids in air minus the weight of water displaced by soil solids

$$(W_s)_{sub} = (W_s) - (\text{vol of water displaced} \times \gamma_w).$$

$\because$ a submerged soil is invariably saturated, $W_s = (W_{sat} - W_w)$

$$\therefore (W_s)_{sub} = (W_{sat} - W_w) - (\text{vol of water displaced} \times \gamma_w)$$

$$(W_s)_{sub} = (W_{sat} - W_w) - (V_s \times \gamma_w)$$

$$= (W_{sat}) - (V_w \gamma_w) - (V_s \gamma_w)$$

$$= (W_{sat}) - \gamma_w(V_w + V_s)$$

But for saturated soil. $V_w + V_s = V$.

$$\therefore (W_s)_{sub} = (W_{sat}) - (\gamma_w)(V) \div V.$$

$$\frac{(W_s)_{sub}}{V} = \frac{W_{sat}}{V} - \frac{(\gamma_w)(V)}{V} \Rightarrow \boxed{\gamma_{sub} = \gamma_{sat} - \gamma_w}$$

NOTE:- 1. In the definitions of above unit weights, if weight is replaced by mass (M), the terms are correspondingly called. Bulk density, Dry density, Density of soil solids, saturated density, Density of water and submerged density.

2. It is usually expressed as g/cc. For water, the density is 1 gm/cc

3. Inter conversion b/w density & unit weight.

$$1\ g/cc = \left[\left(\frac{1}{1000} \times 9.81\right)(100)^3\right] N/m^3 = 9810\ N/m^3 = \frac{9810}{1000} = 9.81\ kN/m^3$$

$$\gamma_{(kN/m^3)} = (\rho)_{(g/cc)} \times 9.81.$$

12) Submerged unit weight (γ' or γ_{sub})

It is defined as the ratio of submerged weight of soil solids $(W_s)_{sub}$ to the total volume of soil mass (V).

$$\therefore \gamma' = \gamma_{sub} = \frac{(W_s)_{sub.}}{(V)}$$

{ *** When the soil mass is submerged, the weight of soil solids (W_s) is reduced due to BUOYANCY.

∴ Submerged weight of soil solids $(W_s)_{sub}$ = (Wt. of soil solids in air) − (wt. of water displaced by soil solids.)

$$\therefore (W_s)_{sub} = (W_s) - (\text{Vol. of water displaced} \times \gamma_w) \quad \text{--- (1)}$$

As the soil is submerged, invariably the soil is saturated.

$$\therefore (W_s) = (W_{sat} - W_w)$$

wt = (vol) (γ)

$$(1) \Rightarrow (W_s)_{sub} = (W_{sat} - W_w) - (\text{Vol of water displaced} \times \gamma_w) \quad [V_w = V_s]$$

$$\Rightarrow (W_{sat} - W_w) - (V_s \times \gamma_w)$$

$W_w = V_w \gamma_w$.

$$(W_s)_{sub.} \Rightarrow (W_{sat}) - (V_w \gamma_w) - (V_s \gamma_w)$$

$$= (W_{sat}) - (\gamma_w)(V_s + V_w)$$

→ But for saturated soil $V_s + V_w = V$

$$(W_s)_{sub} = (W_{sat}) - (\gamma_w)(V) \quad \div V.$$

$$(W_s)_{sub}/V = (W_{sat})/V - (\gamma_w)(V)/V \Rightarrow \boxed{\gamma_{sub} = \gamma_{sat} - \gamma_w.}$$

13) Specific gravity of soil solids (G):

14) Bulk specific gravity (G_m):

15) Density Index (I_D):

Interrelationships:- ①, ②, ③, ④, ⑤ ... ⑬ γ_{sat}, γ_b, γ_d & S.

① e & n
② e, S, w & G
③ e, S & n_a
④ a_c, S & n_a
⑤ γ_d, γ_b & w
⑥ γ_d, G, γ_w & e
⑦ γ_b, G, S & e
⑧ γ', G, e & γ_w
⑨ γ', G, n & γ_w
⑩ γ_d, G, w & S
⑪ γ_d, G, w & n_a
⑫ n_a, n, w & γ_d.

13) **Specific gravity of Soil solids (G):** It is defined as the ratio of weight of a given volume of soil solids @ a given temperature to the weight of equal volume of distilled water at that temperature, both being taken in air.

(OR). It is defined as the ratio of unit weight of soil solids (γ_s) (OR density of soil solids, ρ_s) to the unit weight of (OR density) of water @ the standard temperature. Thus $G = \frac{\gamma_s}{\gamma_w} = \frac{\rho_s}{\rho_w}$

Specific gravity of soil solids is also known as "absolute specific gravity". Normally G of most soils varies from 2.6 to 2.75 (organic soils may have G upto 2). Since G has a relatively constant value, it is commonly used in the field of geotechnical engineering.

14) **Bulk Specific Gravity (G_m):** It is defined as the ratio of bulk unit weight (γ_b) (OR bulk density ρ_b) to the unit weight of water (γ_w) (OR density of water ρ_w)

$$G_m = \frac{\gamma_b}{\gamma_w} = \frac{\rho_b}{\rho_w}$$

*** This is also known as apparent specific gravity OR mass specific gravity.

15) **Density Index (I_D):** It is defined as the ratio of the difference between void ratio of the soil mass in the loosest state (e_{max}) and its void ratio in the natural state to the difference between void ratios of the soil mass in the loosest (e_{max}) and densest (e_{min}) state, expressed as percentage i.e. $I_D = \left(\frac{e_{max} - e}{e_{max} - e_{min}}\right) \times 100$.

It is also called "Relative Density". Higher the value, higher will be the load carrying capacity and lesser will be the settlement.

Interrelationships:

1) Void Ratio and porosity (e & n):

From def^n Void ratio $e = \frac{V_v}{V_s}$ as $V = V_v + V_s$ ∴ $V_s = (V - V_v)$

$$\therefore e = \frac{V_v}{(V - V_v)} \Rightarrow e = \frac{V_v/V}{\left(\frac{V - V_v}{V}\right)} = \frac{(V_v/V)}{1 - (V_v/V)} \quad \because n = \frac{V_v}{V}$$

$$e = \frac{n}{1-n} \text{ ——— (I-a)}$$

$$\text{OR } n = \frac{e}{1+e} \text{ ——— (I-b)}$$

2) Void ratio, Degree of Saturation, water content & Specific gravity (e, S, w & G)

W.K.T. $e = V_v/V_s$ $\quad S = V_w/V_v$ $\quad \therefore (e)(S) = (V_v/V_s)(V_w/V_v) = V_w/V_s$ —— (a)

$w = \frac{W_w}{W_s} = \frac{V_w \gamma_w}{V_s \gamma_s}$ $\quad$ But from (a) $\frac{V_w}{V_s} = (e)S$ & W.K.T. $G = \gamma_s/\gamma_w$ —— (II)

$\therefore (w) = (eS)(1/G)$ OR $(eS) = (w)(G)$

③ Void ratio, Degree of Saturation & percentage air voids (e, S & n_a)

W.K.T. $n_a = \frac{V_a}{V}$ & ~~$V = V_a + V_w$~~ $\Rightarrow V_v = V_a + V_w$ $\therefore V_a = (V_v - V_w)$
& $V = (V_v + V_s)$

$\therefore n_a = \frac{(V_v - V_w)}{(V_v + V_s)}$ $\div V_s \Rightarrow \frac{(V_v - V_w)/V_s}{(V_v + V_s)/V_s} = \frac{(V_v/V_s - V_w/V_s)}{(V_v/V_s + V_s/V_s)} \Rightarrow$

But $(e)(S) = \left(\frac{V_v}{V_s}\right)\left(\frac{V_w}{V_v}\right) = \frac{V_w}{V_s}$

$\Rightarrow \therefore n_a = \frac{(e - eS)}{(e+1)} \Rightarrow n_a = \frac{e(1-S)}{1+e}$ — III (a)

But $n = \frac{e}{(1+e)}$ $\therefore n_a \Rightarrow n(1-S)$ — III (b)

④ Air content, Degree of Saturation and percentage air voids (a_c, S & n_a).

W.K.T. $a_c = \frac{V_a}{V_v}$ and $S = \frac{V_w}{V_v}$ $\therefore a_c + S = \frac{V_a}{V_v} + \frac{V_w}{V_v} \Rightarrow \left(\frac{V_a + V_w}{V_v}\right) = \frac{V_v}{V_v} = 1$

$\therefore a_c + S = 1$ — IV (a)

Also we have $n_a = n(1-S)$ — from III (b) OR $\frac{n_a}{n} = (1-S)$.

But from IV (a) $1 - S = a_c$

$\therefore \frac{n_a}{n} = a_c$ OR $n_a = n a_c$ — IV (b)

⑤ γ_d, γ_b & w:- (Dry, Bulk → unit wt / density & water content)

W.K.T. $\gamma_d = \frac{W_s}{V}$ & $w = \frac{W_w}{W_s} \Rightarrow (1+w) = (1) + \left(\frac{W_w}{W_s}\right) \Rightarrow (1+w) = \left(\frac{W_s + W_w}{W_s}\right)$

But $W_s + W_w = W$ as $W_a = 0$.

$\therefore (1+w) = \left(\frac{W}{W_s}\right)$ OR $W_s = \frac{W}{(1+w)}$

Substituting in γ_d eq^n we get $\gamma_d = \frac{W/(1+w)}{V} = \frac{W}{(1+w)} \times \frac{1}{V}$ But $\gamma_b = \frac{W}{V}$

$\therefore \gamma_d = \frac{\gamma_b}{(1+w)}$ — V

⑦ γ_b, G, S, e & γ_w:- (Bulk, Specific gravity, Degree saturation, Void ratio, Density of water)

W.K.T. $\gamma_b = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{V_s\gamma_s + V_w\gamma_w}{V_s + V_v}$ $\div V_s \Rightarrow \frac{(V_s\gamma_s + V_w\gamma_w)/V_s}{(V_s + V_v)/V_s}$

$\Rightarrow \frac{\gamma_s + \gamma_w(V_w/V_s)}{(1 + V_v/V_s)}$ $\Rightarrow$ But $\frac{V_w}{V_s} = (e)(S)$ & $V_v/V_s = e$

$\gamma_b \Rightarrow \frac{\gamma_s + \gamma_w(S)(e)}{(1+e)}$ But $G = \frac{\gamma_s}{\gamma_w}$ $\therefore \gamma_s = (G)(\gamma_w)$

$\therefore \gamma_b = \frac{G\gamma_w + \gamma_w(S)(e)}{(1+e)} \Rightarrow \gamma_b = \frac{\gamma_w(G + Se)}{(1+e)}$ — VII — a.

When soil is fully saturated, $S = 1$ & $\gamma_b = \gamma_{sat}$.

$\therefore \gamma_{sat} = \frac{\gamma_w(G+e)}{(1+e)}$ — VII — b.

⑥ γ_d, G, γ_w & e (dry density, specific gravity, Density of water & Void ratio)

W.K.T. $\gamma_d = \frac{W_s}{V} = \frac{(V_s \gamma_s)}{(V_s + V_v)} \div V_s \quad \frac{(V_s \gamma_s)/V_s}{(V_s+V_v)/V_s} = \frac{\gamma_s}{(1+V_v/V_s)} = \frac{\gamma_s}{(1+e)}$

But $\gamma_s = G\gamma_w \quad \therefore \gamma_d = \frac{G\gamma_w}{(1+e)}$ — (VI)

⑧ γ', G, e & γ_w :- (Submerged unit wt, sp. gr., void ratio & unit wt. of water)

W.K.T. $\gamma' = \gamma_{sat} - \gamma_w$ $\quad \left[\gamma' = \gamma_{sub} = \frac{(W_s)_{sub}}{V}\right.$

$\left. \text{But } (W_s)_{sub} = (W_s - V_s\gamma_w)\right]$

Since a submerged is always a saturated one., $W_s = (W_{sat} - W_w)$

$(W_s)_{sub} = (W_{sat} - W_w) - V_s\gamma_w \Rightarrow W_{sat} - V_w\gamma_w - V_s\gamma_w$

$\therefore (W_s)_{sub} = W_{sat} - \gamma_w(V_v + V_s) \Rightarrow W_{sat} - (\gamma_w)(V)$

$\div V$ or $\frac{(W_s)_{sub}}{V} = \frac{(W_{sat}) - (\gamma_w)(V)}{V} \Rightarrow \gamma' = \gamma_{sat} - \gamma_w$.

But $\gamma_{sat} = \frac{\gamma_w(G+e)}{(1+e)} \quad \therefore \gamma' = \frac{\gamma_w(G+e)}{(1+e)} - \gamma_w$

OR ~~$\gamma' = \gamma_w(G+e$~~ $\gamma' = \frac{\gamma_w(G-1)}{(1+e)}$ — (VIII) — a.

⑨ γ', γ_d, n & n_a (Submerged unit wt, dry unit wt, porosity & % air voids)

Above eqn can be written as $\gamma' = \frac{G\gamma_w}{(1+e)} - \frac{\gamma_w}{(1+e)}$ But $\frac{G\gamma_w}{(1+e)} = \gamma_d$.

& W.K.T. $n = \frac{e}{(1+e)}$ & $e = \frac{n}{(1-n)}$ OR $n = e(1-n)$.

$\therefore \frac{e}{(1+e)} = e(1-n)$ OR $\frac{1}{(1+e)} = (1-n)$

$\therefore \gamma' = \gamma_d - (1-n)(\gamma_w)$ — (VIII) — b

⑩ γ_d, ~~G~~, w and s (Dry unit wt, sp. gr. water content & D.O.S.)

From (IV) W.K.T. $\gamma_d = \frac{G\gamma_w}{(1+e)}$ But $e = \frac{wG}{s} \longrightarrow (es) = (wG)$

$\therefore \gamma_d = \frac{G\gamma_w}{1+\left(\frac{wG}{s}\right)}$ — (IX) — ⓐ when sys/mass is saturated $s = 1$. & $w = w_{sat}$

$\gamma_d = \frac{G\gamma_w}{1+(w_{sat})(G)}$ — (IX) — ⓑ

(11) Dry Density, Specific gravity, water content & % air voids (γ_d, G, ω & n_a)

$$V = V_a + V_w + V_s \Rightarrow V = V_a + \left(\frac{W_w}{\gamma_w}\right) + \left(\frac{W_s}{\gamma_s}\right)$$

$\div V$

$$1 = \frac{V_a}{V} + \frac{W_w}{\gamma_w V} + \frac{W_s}{\gamma_s \cdot V} \Rightarrow 1 = n_a + \frac{\omega \times (W_s)}{\gamma_w \cdot (V)} + \frac{W_s}{\gamma_s (V)} \quad \left[\because \frac{V_a}{V} = n_a \text{ \& } \omega = W_w/W_s\right]$$

$$(1-n_a) = \frac{W_s}{V}\left(\frac{\omega}{\gamma_w} + \frac{1}{\gamma_s}\right) = \frac{W_s}{V}\left[\frac{\omega}{\gamma_w} + \frac{1}{G(\gamma_w)}\right] \quad \left[G = \frac{\gamma_s}{\gamma_w} \text{ \& } \gamma_d = \frac{W_s}{V}\right]$$

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

$$\therefore (1-n_a) = \frac{\gamma_d}{\gamma_w}\left(\frac{\omega G + 1}{G}\right) \quad \text{OR} \quad \gamma_d = \frac{(1-n_a)G(\gamma_w)}{(1+\omega G)} \quad \text{— (X)}$$

(12) % air voids, porosity, water content & Dry Density: (n_a, n, ω & γ_d)

From (X) W.K.T. $\gamma_d = \frac{(1-n_a)G(\gamma_w)}{(1+\omega G)} \Rightarrow (1-n_a) = \frac{(\gamma_d)(1+\omega G)}{G(\gamma_w)}$

$$\therefore n_a = 1 - \frac{\gamma_d(1+\omega G)}{G(\gamma_w)} \Rightarrow 1 - \frac{\gamma_d}{G(\gamma_w)} - \frac{\gamma_d \omega G}{G(\gamma_w)} = 1 - \frac{\gamma_d}{G(\gamma_w)} - \frac{\gamma_d \omega}{\gamma_w}$$

From (IV) But $\gamma_d = \frac{G\gamma_w}{(1+e)} = \frac{G\gamma_w}{(1+e)}$

$$\therefore n_a = 1 - \frac{G\gamma_w}{(1+e)(G)(\gamma_w)} - \frac{\omega\gamma_d}{\gamma_w} \Rightarrow n_a = 1 - \frac{1}{(1+e)} - \frac{\omega\gamma_d}{\gamma_w}$$

$$\therefore n_a = 1 - \frac{1}{(1+e)} - \frac{\omega\gamma_d}{\gamma_w}$$

$$\therefore n_a = n - \frac{\omega\gamma_d}{\gamma_w} \quad \text{— (XI)}$$

W.K.T. $e = \frac{n}{(1-n)}$ OR $n = e(1-n)$

also $n = \frac{e}{(1+e)}$

$\therefore \frac{e}{(1+e)} = e(1-n)$

$\therefore n = 1 - \frac{1}{(1+e)}$

(13) Saturated Density, Bulk Density, Dry Density & Degree of Saturation: (γ_{sat}, γ_b, γ_d & S)

From VII (a) W.K.T. $\gamma_b = \frac{\gamma_w(G+eS)}{(1+e)} \Rightarrow \frac{G\gamma_w}{(1+e)} + S\frac{e\gamma_w}{(1+e)}$

$$\gamma_b = \frac{G\gamma_w}{(1+e)} + S\left[\frac{(G+e)\gamma_w}{(1+e)} - \frac{G\gamma_w}{(1+e)}\right]$$

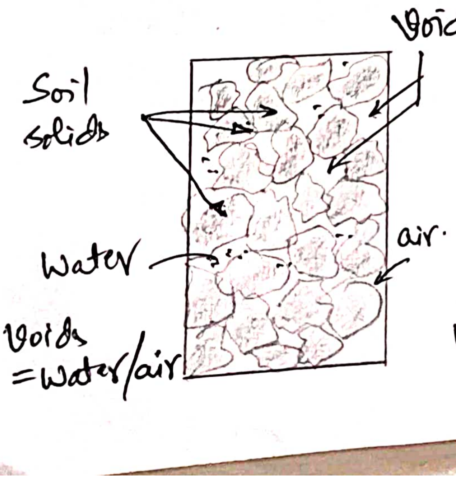
$$\left\{\because \frac{G\gamma_w}{(1+e)} = \gamma_d \text{ \& } \frac{(G+e)\gamma_w}{(1+e)} = \gamma_{sat}\right\}$$

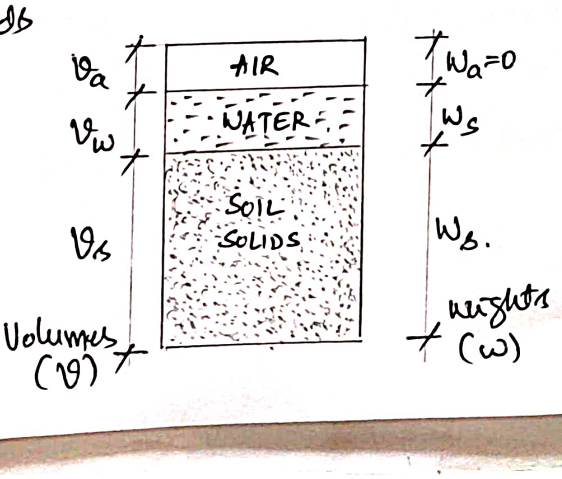
$$\gamma_b = \gamma_d + S[\gamma_{sat} - \gamma_d] \quad \text{— (XII)}$$

Basic eqn for Definitions. with notation. M-1-P-5
(with reference Three-Phase Diagram)

Sl.No.	Terms	notation	eqn	Remarks
1	Water Content / Moisture content	ω	$\omega = \frac{W_w}{W_s} \times 100$	or $\frac{m_w}{m_s} \times 100$ — percentage Decimals
2.	Void Ratio	e	$e = (V_v)/(V_s)$	Decimals.
3.	Porosity	n	$n = (V_v)/(V) \times 100$	percentage.
4.	Degree of Saturation	S (or) S_r	$S = S_r = (V_w)/(V_v) \times 100$	percentage.
5.	Air Content	a_c	$a_c = (V_a)/(V_v) \times 100$	percentage.
6.	Percentage air voids &	n_a	$n_a = (V_a)/(V) \times 100$	percentage.
7.	Bulk unit weight (For mass — Bulk Density) — ρ_b	γ_b	$\gamma_b = (W)/(V)$	$\rho_b = (M)/V$ kN/m3 Range - 12 - 24
8.	Dry unit weight. (Bulk density) — ρ_d	γ_d	$\gamma_d = (W_s)/(V)$ $\gamma_d = (\gamma_b)/(1+\omega)$	$\rho_d = (m)_s/V$
9.	Unit weight of soil solids (Density of soil solids) ρ_s	γ_s	$\gamma_s = (W_s)/(V_s)$	$\rho_s = (M_s)/(V_s)$
10.	Saturated unit weight (Density) ρ_{sat}	γ_{sat}	$\gamma_{sat} = (W_{sat})/(V)$	—do—
11.	Unit weight of water (Density) ρ_w	γ_w	$\gamma_w = (W)_w/(V)_w$	9.81 kN/m^3
12.	Submerged unit weight. (Density) $\rho' = \rho_{sub}$.	γ' (or) γ_{sub}	$\gamma' = \gamma_{sub} = \frac{(W_s)_{sub}}{(V)}$ $\gamma_{sub} = (\gamma_{sat} - \gamma_w)$	
13.	Specific gravity of soil solids $G = \gamma_s/\gamma_w = \rho_s/\rho_w$	G	$G = (W)_s/(V_w)$ $= (Wt)_s/(Wt)_{of\ w}$	Same Temperature, Distilled water. 2.6 to 2.75
14.	Density Index (I_D) (Relative Density)	I_D	$I_D = \frac{(e_{max} - e)}{(e_{max} - e_{min})} \times 100$	percentage.

NOTE:- W_w = Weight of water ; W_s = Weight of soil solids; V_v = Volume of voids
V_s = Volume of soil solids; V = Total volume of soil mass $= (V_a + V_w + V_s)$
V_a = Volume of air ; W – Total wt. of soil mass $= W_a^0 + W_w + W_s = (W_w + W_s)$





Expressions for INTERRELATIONSHIPS

Sl No	TERMS	Notations	Interrelationship	Remarks
1.	Void Ratio & Porosity	e, n	$e = (n)/(1-n)$ & $n = (e)/(1+e)$	I-(a) I-(b)
2.	Void Ratio, Degree of Saturation (D.O.S.), water Content & Specific gravity.	e, S, w & G.	$(e)(S) = (w)(G)$	II
3.	Void Ratio, D.O.S. & % air voids	e, S, n_a	$n_a = \frac{e(1-S)}{(1+e)}$ & $n_a = n(1-S)$	III-(a) III-(b)
4.	Air content, D.O.S., % air voids, porosity.	e, S, n_a, n	$a_c = (1-S)$ & $n_a = n a_c$	IV-(a) IV-(b)
5.	Dry Density, Bulk density & water Content -(also unit wt.)	γ_d, γ_b & w	$\rho_d = \gamma_d = (\gamma_b)/(1+w)$	V
6.	Dry Density, Specific Gravity, unit wt. of water & void ratio	γ_d, G, γ_w & e	$\rho_d = \gamma_d = G\gamma_w/(1+e)$	VI
7.	Bulk Density, sp. Gravity, D.O.S., Void ratio & unit wt. of water.	γ_b, G, S, e, γ_w	$\rho_b = \gamma_b = \gamma_w(G+eS)/(1+e)$ $\rho_{sat} = \gamma_{sat} = \gamma_w(G+e)/(1+e)$	VII-(a) VII-(b)
8. 9.	Submerged unit wt, sp. gravity, & Void ratio & unit wt. of water. Porosity, Dry Density,	γ', G, e & γ_w n, γ_d	$\gamma' = \gamma_w(G-1)/(1+e) = \rho'$ $\gamma' = \gamma_d - (1-n)\gamma_w = \rho'$	VIII-(a). VIII-(b).
10.	Dry density, sp. gravity, D.O.S. & water Content.	γ_d, G, S & w	$\gamma_d = G\gamma_w/\{1+\frac{(wG)}{S}\} = \rho_d$ $\gamma_d = G\gamma_w/(1+w_{sat}.G) = \rho_d$	IX-(a) IX-(b)
11.	Dry density, sp. gravity, water content & % air voids	γ_d, G, & n_a.	$\gamma_d = \rho_d = (1-n_a)G\gamma_w/(1+wG)$	X
12.	% air voids, porosity, water content & Dry Density.	n_a, n, w & γ_d.	$n_a = n - (w\gamma_d)/(\gamma_w)$	XI
13.	Saturated Density, Bulk Density, Dry Density & D.O.S	γ_{sat}, γ_b, γ_d & S	$\gamma_b = \gamma_d + S[\gamma_{sat} - \gamma_d]$ or $\rho_b = \rho_d + S[\rho_{sat} - \rho_d]$.	XII

① The mass of moist sample of soil is 25 kg and its volume is $0.014 m^3$. After drying in oven, the mass of the soil reduces to 20.6 kg. Find water content, density of moist soil, dry density, void ratio and degree of saturation. Take $G = 2.68$.

Given Data:- Mass of moist soil $= M_{wet} = 25 kg$; Volume $= 0.014 m^3$

— " — Dry soil $= M_d = 20.6 kg$. $G = 2.68$

To find:- $w, \rho_b, \rho_d, e, S, \& n$

i) $w = \frac{M_{wet} - M_d}{M_d} = \frac{25 - 20.6}{20.6} = 0.214$ or 21.4%

ii) $\rho_b = \frac{M_{wet}}{V} = \frac{25}{0.014} = 1785.1 kg/m^3$

iii) $\rho_d = \frac{M_{dry}}{V} = \frac{20.6}{0.014} = 1471 kg/m^3$ [OR $\rho_d = \frac{\rho_b}{(1+w)} = \frac{1785.1}{(1+0.214)} = 1470 kg/m^3$]

iv) $\rho_d = \frac{G\rho_w}{(1+e)}$ $\therefore (1+e) = \frac{G\rho_w}{\rho_d}$ or $e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.68 \times 1000}{1470.0} - 1 = 0.82$

v) $n = \frac{e}{1+e} = \frac{0.82}{1+0.82} = 0.45$ or 45%.

vi) $S = \frac{wG}{e} = \frac{0.214 \times 2.68}{0.82} = 0.699$ or 69.9%.

② One cubic meter of wet soil weighs 19.80 kN. If $G = 2.7$ & $w = 11\%$ find void ratio, dry density & D.O.S.

Given Data:- $\gamma_b = 19.8 kN/m^3$ $G = 2.7$ & $w = 0.11$

To find:- $e, \gamma_d \& S$.

W.K.T. $\gamma_d = \frac{\gamma_b}{(1+w)} = \frac{19.8}{1+0.11} = 17.84 kN/m^3$

$\gamma_d = \frac{G\gamma_w}{(1+e)} \Rightarrow 17.84 = \frac{(2.7)(9.81)}{(1+e)}$ $\therefore e = 0.485$

$S = wG/e = (0.11)(2.7)/(0.485) = 0.612$ (or 61.2%)

③ A soil sample has a porosity of 40%. The specific gravity of soil solids is 2.70. Calculate void ratio, dry density, bulk density for 50% saturation and density of saturation.

Given Data: $n = 40\% = \frac{40}{100} = 0.40$ $G = 2.70$

To find e, ρ_d, γ_b for 50% saturation & γ_{sat}.

W.K.T. $e = \frac{n}{1-n} = \frac{0.4}{1-0.4} = 0.667$ & $\rho_d = \frac{G\rho_w}{(1+e)} = \frac{2.70 \times 1000}{1+0.667} = 1619.2 kg/m^3$

γ_b(50% saturation) $= \frac{(G+eS)}{(1+e)}\gamma_w = \frac{2.70 + (0.667)(0.5)}{(1+0.667)} \times 9.81 = 17.85 kN/m^3$

$(S=1)$ $\rho_{sat} = \frac{2.70 + (0.667)(100/100)}{(1+0.667)} \times 9.81 = 19.81 kN/m^3$

(4) Determine water content, bulk density, dry density and D.O.S from the following data. Sample size = 3.81 cm diameter × 7.62 cm height. wet weight = 1.64 N, oven dry weight = 1.37 N G = 2.70.

Given data: diameter = 3.81 cm = 3.81/100 m L = 7.62 cm = 7.62/100 m.

$\therefore V = \frac{\pi d^2}{4}(L) = \frac{\pi}{4}\left(\frac{3.81}{100}\right)^2\left(\frac{7.62}{100}\right) = 8.69 \times 10^{-5}\ m^3$

Water content = $\frac{(wt)\ wt. - (Dry)\ wt}{Dry.\ wt} = \frac{1.64 - 1.37}{1.37} = 0.197$ (19.7%)

W.K.T. $\gamma_b = \left(\frac{W}{V}\right)_{wet} = \frac{1.64 \times 10^{-3}}{8.69 \times 10^{-5}} = 18.87\ kN/m^3$

$\gamma_d = \left(\frac{W}{V}\right)_{Dry} = \frac{1.37 \times 10^{-3}}{8.69 \times 10^{-5}} = 15.77\ kN/m^3$

also $\gamma_d = \frac{G\gamma_w}{(1+e)}$ or $e = \frac{G\gamma_w}{\gamma_d} - 1 = 0.68$

$(S)(e) = (w)(G) \Rightarrow (S)(0.68) = (0.197)(2.7)$

$\therefore S = S_r = 0.782$ (or 78.2%)

(5) A soil mass has a bulk weight density of 20.6 kN/m³ and water content of 16%. Calculate the water content, if the soil partially dries to a density of 19.2 kN/m³ and the void ratio remain unchanged.

Given data: $(\gamma_b)_1 = 20.6\ kN/m^3$ $\gamma_{b_2} = 19.2\ kN/m^3$ $w_1 = 0.16$ $w_2 = ?$

NOTE:- For the void ratio to remain same, Dry density γ_d for both the cases must be same.

& W.K.T $\gamma_d = \left(\frac{\gamma_b}{1+w}\right)$ $(\gamma_d)_1 = (\gamma_d)_2 \Rightarrow \frac{\gamma_{b_1}}{(1+w_1)} = \frac{\gamma_{b_2}}{(1+w_2)}$ $\therefore w_2 = 0.0811$ or 8.11%

(6) A sample of saturated soil has a water content of 35%. The specific gravity of solids is 2.65. Determine its void ratio, porosity, saturated unit weight and dry unit weight.

Given Data:- $w = w_{sat} = 0.35$; $S = 1$ & $G = 2.65$

$(e)(S) = (w)(G) \Rightarrow (e)(1) = (0.35)(2.65)$ $\therefore e = 0.93$

$n = \frac{e}{1+e} = \frac{0.93}{1+0.93} = 0.48$

$\gamma_{sat} = \frac{(G+e)\gamma_w}{(1+e)} = \frac{(2.65+0.93)}{(1+0.93)} \times 9.81 = 18.2\ kN/m^3$

$\gamma_d = \frac{G\gamma_w}{(1+e)} = \frac{(2.65)(9.81)}{(1+0.93)} = 13.47\ kN/m^3$

(7). The mass of a dry soil sample is 78gm. Find the volume of voids if the total volume of the sample is 45ml and the specific gravity is 2.65. Also determine the voids ratio. $1 ml = 1cc = 1 cm^3$

W.K.T $\rho_d = \frac{W_s}{V} = \frac{M_s}{V} = \frac{78}{45} = 1.73\ g/cc$

& $G = \frac{\rho_s}{\rho_w}$ ∴ $\rho_s = (\rho_w)(G)$ But $\rho_s = \left(\frac{M_s}{V_s}\right)$

∴ $\left(\frac{M_s}{V_s}\right) = (\rho_w)(G)$ ∴ $V_s = (M_s)/(\rho_w)(G) = \frac{78}{2.65 \times 1} = 29.43\ cc$

as $V = V_v + V_s$ ∴ $V_v = V - V_s = 45 - 29.43 = 15.57\ cc.$

∴ void ratio $e = \frac{V_v}{V_s} = 15.57/29.43 = 0.53.$ or 53%

(8) A sample of dry soil has a void ratio of 0.65 and its grain specific gravity is 2.75. what is unit weight?

Water is added to the sample so that its degree of saturation is 60% without any change in void ratio. Determine the water content and bulk unit weight.

The sample is next placed under water. Determine the bulk unit weight (neglecting buoyancy) if the degree of saturation is 95% & 100% respectively.

Given Data: $G = 2.75$ & $e = 0.65$ $\gamma_d = ?$

a) $\gamma_d = \frac{G\gamma_w}{(1+e)} = \frac{(2.75)(9.81)}{(1+0.65)} = 16.35\ kN/m^3$

ii) $S = 60\% = 0.6$ & $e = 0.65$

b) $(eS) = (wG)$ $(0.65)(0.6) = (w)(2.75)$ ∴ $w = 0.142$ (14.2%)

$\gamma_d = \frac{\gamma_b}{(1+w)}$ ∴ $\gamma_b = (\gamma_d)(1+w) = (16.35)(1+0.142) \Rightarrow \gamma_b = 18.67\ kN/m^3$

$S = 0.95$ & $S = 1.$

c) $\gamma_b = \frac{(G+eS)\gamma_w}{(1+e)} = \frac{(2.75+0.65\times0.95)\times 9.81}{(1+0.65)} = 20.02\ kN/m^3$

$\gamma_{sat} = \frac{(2.75+0.65\times1)\,9.81}{(1.65)} = 20.22\ kN/m^3$

(9) A saturated clay has a water content 39.8% and bulk specific gravity as 1.84. Determine the void ratio & specific gravity of particles.

Given Data: $S = 1$; $w = 0.398$ $G_m = 1.84$ Reqd.? - e & G.

$G_m = \gamma_b/\gamma_w \Rightarrow 1.84 = \gamma_b/9.81$ ∴ $\gamma_b = 1.84 \times 9.81 = 18.05\ kN/m^3$

$eS = wG$

$e = (0.398)(G)$

For fully saturated soil $\gamma_b = \gamma_{sat} = 18.05\ kN/m^3$ ∴ $\gamma_{sat} = \frac{(G+e)\gamma_w}{(1+e)}$

$18.05 = \frac{(G+0.398G)(9.81)}{(1+0.398G)}$ ∴ $G = 2.764$ & $e = (w)(G) = 0.398 \times 2.764$
$= 1.10$

[Let Bulk sp.gr. or Mass sp.gr be $= G_m$]

(10) The mass of wet soil when compacted in a mould was 1.955 kg. The water content of the soil was 16%. If the volume of mould was 0.945 litres. Determine i) Dry density ii) void ratio iii) Degree of saturation & iv) percent air voids. Take G = 2.68.

Soln. Bulk density ρ_b is given by = $\frac{wt.}{vol} = \frac{1.955}{(9.45\times10^{-4})} = 2068.8\ kg/m^3$

{1000 ltrs = 1 m³; 0.945 ltr = 9.45×10⁻⁴ m³ = 9.45×(10⁻⁴) m³}

$\rho_d = \frac{\rho_b}{(1+w)}$ $w = 0.16$ $\therefore \rho_d = \frac{2068.8}{(1+0.16)} = 1783.5\ kg/m^3$

also $\rho_d = \frac{G\rho_w}{(1+e)}$ $\therefore e = \frac{G\rho_w}{\rho_d} - 1 = \frac{(2.68)(1000)}{1783.5} - 1 = 0.503.$

$(es) = (wG) \Rightarrow (0.503)(s) = (0.16)(2.68)$ $\therefore S = 0.853\ (85.3\%)$

$\rho_d = \frac{(1-n_a)G\rho_w}{(1+wG)}$ $1783.5 = \frac{(1-n_a)(2.68)(1000)}{[1+(0.16)(2.68)]}$ $\therefore n_a = 0.0492\ (4.92\%)$

(11) A compacted sample of soil with a bulk density of 2.0 g/cc has a water content of 15%. What are its dry density, degree of saturation and air content? Take G = 2.65

$\rho_d = \frac{\rho_b}{(1+w)} \Rightarrow \frac{2.0}{(1+0.15)} = 1.74\ gm/cc.$ also $\rho_d = \frac{G\rho_w}{(1+e)} \Rightarrow 1.74 = \frac{(2.65)(1)}{(1+e)}$

$\therefore e = 0.52$

$(e)(s) = (w)(G) \Rightarrow (0.52)(S) = (0.15)(2.65)$

$\therefore S = 0.76\ (76\%)$

W.K.T. $a_c = (1-S) \Rightarrow a_c = (1-0.76) = 0.24$ or 24%.

(12) A moist sample of soil has a mass of 633g and a volume of 300 cm³ @ water content of 11%. Taking G = 2.68, determine void ratio, D.O.S. and % of air voids. Also determine the water content @ which the soil gets fully saturated, without increase in the volume. What will be unit wt. @ saturation.

Given:- Wet mass of soil = M_{wet} = 633 gm, V = 300 cc (cm³), $w = 0.11$, $G = 2.68$.

To find:- e, S, n_a & w_{sat} & γ_{sat}.

W.K.T. Bulk density $\rho_b = M_{wet}/(V) = 633/300 = 2.11\ g/cc.$

$\rho_d = \frac{\rho_b}{(1+w)} = 2.11/(1+0.11) = 1.9\ g/cc.$ also $\rho_d = \frac{G\rho_w}{(1+e)}$ $\rho_w = 1$

$\therefore 1.9 = \frac{(2.68)(1)}{(1+e)}$ $\therefore e = 0.41.$

W.K.T. $(e)(S) = (w)(G) \Rightarrow (0.41)(S) = (0.11)(2.68)$ $\therefore S = 0.719\ (71.9\%)$

also $n_a = n(1-S)$ $\therefore n = \frac{e}{1+e} = \frac{0.41}{1+0.41} = 0.29$ $\therefore n_a = 0.29(1-0.719) = 0.082\ (8.2\%)$

Water content @ full saturation $(e)(S) = (w)(G) \Rightarrow (e)(S) = (w)_{sat}(G)$ $\therefore w_{sat} = \frac{0.41}{2.68} = 0.153$

Bulk unit wt. @ full saturation $\gamma_{sat} = \frac{(G+e)(\gamma_w)}{(1+e)} = \frac{(2.68+0.41)(9.81)}{(1+0.41)} = 21.50\ kN/m^3$

(13) A saturated sample of soil has a water content of 35%. Adopting $G=2.70$, Calculate dry unit wt, saturated unit weight & submerged unit weight. Given: $S=1$ $\omega=0.35$ $G=2.70$.

To find: γ_d, γ_{sat} & $\gamma'=\gamma_{sub}$. W.K.T. $(e)(S)=(\omega)(G)$ $\therefore e=0.945$.

$$\gamma_d=\frac{G\gamma_w}{(1+e)}=\frac{2.70\times 9.81}{(1+0.945)}=13.02\ kN/m^3;\quad \gamma_{sat}=\frac{(G+e)\gamma_w}{(1+e)}=18.38\ kN/m^3$$

$$\gamma_{sub}=\gamma'=\gamma_{sat}-\gamma_w=18.38-9.81=8.57\ kN/m^3$$

(14) An undisturbed specimen of clay was tested in the laboratory and the following results were obtained.

wt of soil $=2.1N$; oven dry weight $=1.75N$: specific gravity of soil solids $=2.7$. What was the total volume of original undisturbed soil specimen. Assuming the D.O.S. of specimen as 50% find bulk weight, saturated unit wt, void ratio, porosity and water content.

Given: W_{wet} = wt of wet soil $=2.1N$ wt of dry soil $=W_{dry}=1.75$ $G=2.70$ $S=50\%=0.5$

To find: 'V', γ_b, γ_{sat}, e, n, & ω water content $=\frac{W_{wet}-W_{dry}}{W_{dry}}=0.2\ (20\%)$

$(e)(S)=(\omega)(G) \Rightarrow (e)(0.5)=(0.2)(2.7)$ $\therefore e=1.08$

$$\gamma_d=\frac{G\gamma_w}{(1+e)}=\frac{2.7\times 9.81}{(1+1.08)}=12.73\ kN/m^3 \quad \text{also } \gamma_d=\frac{W_d}{V}\ \therefore V=\frac{W_d}{\gamma_d}=\frac{1.75\times 10^{-3}}{12.73}$$

$$\gamma_b=\frac{(G+eS)\gamma_w}{1+e} \rightarrow \gamma_b=\frac{(2.7+1.08\times 0.5)(9.81)}{(2.08)} \quad \therefore V=1.375\times 10^{-4}\ m^3$$

$$\gamma_{sat}=\frac{(G+e)\gamma_w}{(1+e)}=\frac{(2.7+1.08)}{(2.08)}\times 9.81=17.83\ kN/m^3 \quad \rightarrow \gamma_b=15.28\ kN/m^3$$

$$n=\frac{e}{(1+e)}=\frac{(1.08)}{(2.08)}=0.52\ (52\%)$$

Relative Density or Density Index: (For Cohesionless soils only)

It is defined as the ratio of the difference between the void ratio of cohesionless soil in the loosest state and void ratio in natural state to the difference between its void ratios in the loosest and densest state and is expressed in percentage.

$$\therefore I_D=D_r=\frac{(e_{max}-e)}{(e_{max}-e_{min})}\times 100.$$

Where e_{max} = void ratio in the loosest state. e_{min} = V.R. in the densest state

e = V.R. for the soil in the field of natural state

In the loosest state $D_r=0$ & in the densest state $D_r=100\%$. On the basis of relative density, granular soils are grouped qualitatively as follows

D_r: $<15\rightarrow$ Very loose; $15\text{-}35\rightarrow$ loose; $35\text{-}65\rightarrow$ Medium; $65\text{-}85\rightarrow$ Dense; $>85\rightarrow$ Very dense

Using the relation, $e=\frac{G\gamma_w}{\gamma_d}-1$, the eqn of relative density can be expressed as follows.

$$D_r=I_D=\frac{(\gamma_d)_{max}}{(\gamma_d)}\times\frac{(\gamma_d)-(\gamma_d)_{min}}{(\gamma_d)_{max}-(\gamma_d)_{min}}\times 100$$

R.D. is a better indicator of denseness of an in-situ coarse grained soil deposits than V.

(15) A sample of sandy soil was found to have moisture content of 25% and unit weight of 18 kN/m³. Laboratory tests with the same material indicated that the void ratio in the loosest & densest states were 0.9 & 0.5 respectively. If G = 2.7, compute e, S & I_D

Given Data: $\gamma_b = 18\ kN/m^3$ $w = 0.25$ $e_{max} = 0.9$ $e_{min} = 0.5$ $G = 2.7$

$e, S \& I_D$ — ? WKT $\gamma_d = \frac{G\gamma_w}{(1+e)}$ (2) & $\gamma_d = \frac{\gamma_b}{(1+w)}$ (1) $= \frac{18}{(1+0.25)} = 14.4\ kN/m^3$

$\therefore e = 0.84$. $(e)(S) = (w)(G)$ $\therefore S = 0.804\ (80.4\%)$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 = \frac{0.9 - 0.84}{0.9 - 0.5} \times 100 = 15\%.$$

(16) A sample of sand above water table was found to have natural water content of 16% and a unit weight of 18.5 kN/m³. During laboratory tests in a dried sample gives dry density @ densest and loosest state respectively 19.85 kN/m³ & 14.28 kN/m³. Determine D.O.S. & Density Index. G = 2.66

Given Data: $w = 0.16$ $\gamma_b = 18.15\ kN/m^3$ $(\gamma_d)_{max} = 19.85$ & $(\gamma_d)_{min} = 14.28$

find S_r & I_D W.K.T. $\gamma_d = \frac{G\gamma_w}{(1+e)}$ (2) & $\gamma_d = \frac{\gamma_b}{1+w} = \frac{18.8}{(1+0.16)} = 15.65\ kN/m^3$

$\gamma_w = 9.81$. $\therefore e = 0.67$. $(e)(S) = (w)(G)$ $\therefore S = S_r = 0.635\ (63.5\%)$

W.K.T. $I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$. $(\gamma_d)_{loosest} = \frac{G\gamma_w}{(1+e_{max})} \Rightarrow 14.28 = \frac{(2.66)(9.81)}{(1+e_{max})}$ $\therefore e_{max} = 0.83$

lly $(\gamma_d)_{densest} = \frac{G\gamma_w}{(1+e_{min})} \Rightarrow 19.85 = \frac{(2.66)(9.81)}{(1+e_{min})} = 0.32$

$$\therefore I_D = \frac{0.83 - 0.67}{0.83 - 0.32} \times 100 = 31.4\%.$$

$\left[\text{OR } I_D = \frac{(\gamma_d)_{max}}{\gamma_d} \times \frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}}\right] \times 100$

OR

$$I_D = \frac{19.85}{15.65} \times \left(\frac{15.65 - 14.28}{19.85 - 14.28}\right) \times 100 = 31.2\%.$$

(17) At a site the dry density of the soil is 16 kN/m³. The wt of the soil filled in a container of 1 litre in its loosest & densest possible states are 15N & 17N respectively. Determine density Index.

Given $\gamma_d = 16\ kN/m^3$ $V = 1000\ cm^3 = \frac{1000}{(100 \times 100 \times 100)} m^3 = 1 \times 10^{-3}\ m^3$

$W_{loosest} = \frac{15}{1000} kN = 15 \times 10^{-3}$ & $W_{densest} = 17 \times 10^{-3} kN$. To find I_D → ?

$(\gamma_d)_{max} = \frac{17 \times 10^{-3}}{1 \times 10^{-3}} = 17\ kN/m^3$ $(\gamma_d)_{min} = \frac{15 \times 10^{-3}}{1 \times 10^{-3}} = \left(\frac{W}{V}\right) = 15\ kN/m^3$

$$I_D = \frac{(\gamma_d)_{max}}{\gamma_d} \times \frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}} \Rightarrow \left(\frac{17}{16}\right) \times \left(\frac{16 - 15}{17 - 15}\right) \times 100 = 53.13\%.$$

INDEX PROPERTIES OF SOIL:-

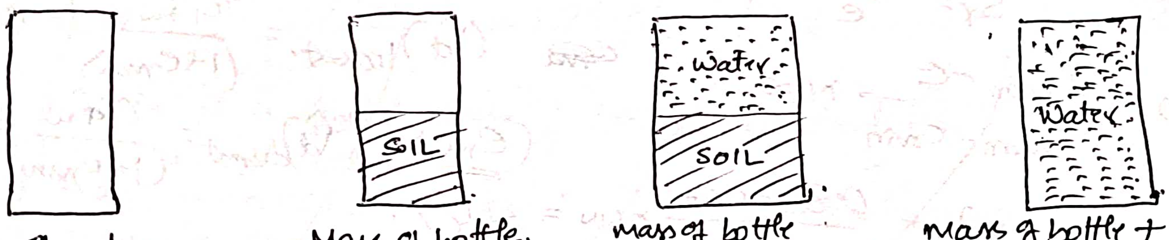
Index properties of soils are those which are mainly used in the identification and classification of soils and help in predicting the suitability of soils as foundation OR construction material. Following are the index properties.

1) Specific gravity of soil particles.
2) Particle size Distribution
3) Consistency Limits & indices
4) Relative Density.

Some times field density & water content are also included as they are required in computations relating to other properties.

SPECIFIC GRAVITY:- Specific gravity of soil solids is useful in several computations like void ratio, degree of saturation & unit weights

The sp. gr. of soil solids is determined using 50ml/100ml density bottle OR a 500ml pycnometer (PYCNOMETER). Generally density bottle is suitable for all types of soils & the pycnometer method is used in case of grained soils only. Both the methods involve the sequential operations. (Ref. fig)



Mass of clean & empty bottle (m_1) — Mass of bottle + soil (m_2) — mass of bottle + soil + distilled water (m_3) — mass of bottle + distilled water (m_4)

Specific gravity = $\dfrac{\text{Mass of given volume of soil}}{\text{mass of equal vol of distilled water}}$ } @ 27°C

i.e. $G = \dfrac{(M_2 - m_1)}{(M_2 - M_1) - (M_3 - M_4)} = G_{27}$ { If sp. gr. is determined @ any other temperature $t°C$, say G_t, then it is converted to a value @ standard temperature 27°C say G_{27} by following relation

$$G_{27} = (G_t) \times \frac{(\text{sp. gr. of water @ } t°C)}{(\text{sp. gr. of water @ } 27°C)}$$

NOTE:- In case of clays, kerosene which has better wetting capacity is preferred to distilled water in the density bottle method & is calculated using the eqn

$$G = \frac{(M_2 - m_1)}{(M_2 - M_1) - (M_3 - M_4)} \times (G_k)$$

(18) An Ovendried soil sample having mass of 195g was put inside a pycnometer which was then completely filled with water. The mass of pycnometer with soil and water was found to be 1584 g. The mass of pycnometer filled with water alone was 1465g. Calculate the specific gravity of solids.

Given Data:- Mass of soil = M_{dry} = 195g $(M_2 - M_1)$

Mass of pyc + soil + water = M_3 = 1584 g

Mass of pycnometer + water = M_4 = 1465 g

Reqd: G;

W.K.T. $G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} = \frac{M_d}{M_d - (M_3 - M_4)} = \frac{195}{195 - (1584 - 1465)} = 2.566$

(19) The specific gravity of soil solids for a given soil sample was determined by density bottle method using kerosene. Following observations were recorded. Compute the G at test temperature which was at 27°C. Also report the value @ 4°C

Given: $w = 0.16$, $\gamma_b = 18.15$, $(\gamma_d)_{max} = 19.85$, $(\gamma_d)_{min} = 14.28$, $G = 2.66$

Find: S_r & I_D

$\gamma_d = \frac{G\gamma_w}{(1+e)}$ ∴ $\gamma_d = \frac{\gamma_b}{1+w} = \frac{18.15}{1+0.16} = 15.65$ kN/m³

∴ $e = 0.67$

$S_r = \frac{wG}{e}$ ⟹ $(e)(S) = (w)(G)$ $S_r = 0.635$

$(\gamma_d)_{loosest} = \frac{G\gamma_w}{(1+e_{max})} = 0.83$

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

(e_{min}) $(\gamma_d)_{densest} = \frac{G\gamma_w}{(1+e_{min})} = 0.32$

∴ $I_D = \frac{0.83 - 0.67}{0.83 - 0.32} \times 100 = 31.4\%$.

or $I_D = \left(\frac{19.85}{15.65}\right)\left(\frac{15.65 - 14.28}{19.85 - 14.28}\right) \times 100 = 31.2\%$

Soln: Mass of density bottle = 61.45g; Mass of bottle + soil = 82.24g

Mass of bottle + soil + kerosene = 261.12g. (—"—) + kerosene = 246.49 g

Take G of kerosene @ 27°C as 0.773; G of water @ 27°C as 0.995

G of water @ 4°C as 1.000

Given:- $M_1 = 61.45g$; $M_2 = 82.24g$; $M_3 = 261.12g$; $M_4 = 246.49g$

$(G_k)_{27} = 0.773$; $(G_w)_{27} = 0.9965$; $(G_w)_4 = 1.000$ To find: G_{27} & G_4

$G_{27} = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} \times G_k = \frac{(82.24 - 61.45)}{(82.24 - 61.45) - (261.12 - 246.49)} \times 0.773 = 2.61$

∴ $G_4 = \frac{(G_w)_{27}}{(G_w)_4} \times G_{27} = \frac{0.9965}{1.000} \times 2.61 = 2.60$

Water Content:-
a) Oven-drying method.
b) Pycnometer method.
c) Rapid methods → i) Infrared lamp & torsion balance method. ii) Calcium Carbide method.

Field Density:-
a) Core cutter method — cohesive soil
b) Sand replacement method — noncohesive soil
} Refer soft copy.

(20) Field density test by core cutter method gave following results.
Mass of core cutter + soil = 3200g. (m_2)
— " — = 1500g. (m_1)
Internal volume of core cutter = 1000cc. (V).
water content = 12%. (w)
Specific gravity of soil solids = 2.67 (G).
Calculate a) In-situ dry density ρ_d b) Degree of saturation S c) Saturated density ρ_{sat}.

Soln:- In-place bulk density $\rho_b = \frac{M}{V} = \frac{(3200-1500)}{1000} = 1.7\ g/cc$

— " — dry density $\rho_d = \frac{\rho_b}{(1+w)} = \frac{1.7}{(1+0.12)} = 1.52\ g/cc$.

$(S)(e) = (w)(G)$

W.K.T. $\rho_d = \frac{G\rho_w}{(1+e)}$ (ρ_w = 1 g/cc) ∴ $e = 0.76$.

$(S)(0.76) = (0.12)(2.67)$ ∴ $S = 0.42\ (42\%)$

$\rho_{sat} = \frac{(G+e)\rho_w}{(1+e)} = 1.95\ g/cc$

(21). The results of a field density test conducted using sand replacement method are as follows.
i) Mass of excavated soil = 923 g. — (M_{soil})
ii) Mass of SPC + sand before pouring into pit = 5330g
iii) Mass of SPC + sand after pouring into pit = 4152g.
Earlier the mass of sand filling the calibrating container of 1000ml was found to be 1540g. The mass of sand filling the cone portion was found to be 430g. If in-situ water content is 9%, calculate in-situ dry density.

Soln Density of sand $\rho_{sand} = \frac{M}{V} = 1540/1000 = 1.54\ g/cc$

Mass of sand in the pit = 5330 − 4152 = 748 g.

∴ vol. of sand = vol. of pit = $V = \frac{748}{1.54} = 485.7\ cc$. → $\rho = \left(\frac{M}{V}\right)$

In-situ bulk density = $\rho_b = \frac{M}{V} = 923/485.7 = 1.9\ g/cc$.

— " — dry density = $\rho_d = \frac{\rho_b}{(1+w)} = 1.9/(1+0.09) = 1.74\ g/cc$

Particle size Distribution:-

Particle size distribution for a given soil sample indicates the percentage by mass of different soil particles like gravel, sand, silt and clay. IS size classification chart is shown in following Tabular column.

2μ	75μ	425μ	2.00	4.75	20	80	300	Boulder
Clay	Silt	Fine	Medium	Coarse	Fine	Coarse	Cobble	Boulder
		Sand			Gravel			

IS Size classification chart.

Particle size distribution is determined by conducting grain size analysis, also known as mechanical analysis. This Consists of two parts.

a) Sieve Analysis

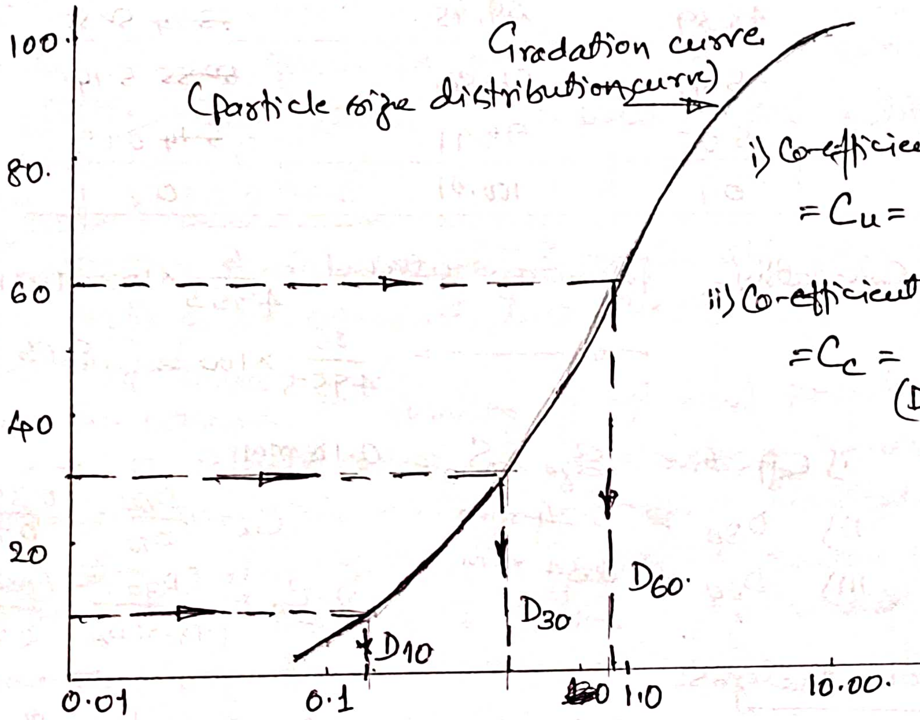
b) Sedimentation Analysis.

a) Sieve Analysis: The soil sample to be analysed is thoroughly dried with lumps being ~~pulveris~~ ~~pulverised~~ Pulverised by a Mallet (wooden hammer). Suitable quantity of soil sample is taken and seived through a set of sieves arranged from ~~bottom to~~ top to bottom in decreasing aperture opening. The results of the sieve are tabulated as shown in Table. Let 'M' g be the initial mass of soil sample taken.

Sl. No. (1)	Sieve Designation (2)	Particle size (mm) (3)	Mass of soil retained (g) (4)	Percentage mass retained (%) (5)	Cumulative % retained (6)	Percent fine (7)
				(4)/M) ×100.	(4) − (5) + 0.	N = 100 − (6)
1.	4.75 MM	4.75			~~(4) − (4)~~ + 0.	(1) − (5)
2.	2.00 MM	2.00			{(2) − (5)} + {(1) − (5)}	(2) − (5)
3.	⋮	⋮			{(3 − 5)} + {(2 − 5)}	
⋮	⋮	⋮				
	600μ	0.600				
	⋮	⋮				
	75μ	0.075				

(1) – (5) : first line fourth column
(2) – (5) : Second line Fifty coloumn

Particle size distribution curve is obtained by plotting percentage finer 'N' as ordinate (y-axis) on natural scale against particle size D, mm as abscissa (x-axis) on logarithmic scale.



i) Coefficient of uniformity $= C_u = \frac{D_{60}}{D_{10}}$.

ii) Co-efficient of curvature $= C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})}$.

NOTE:- D_{10} is called Effective size of soil mass.

(22) Results obtained from the sieve analysis are given below. Draw the particle size distribution curve and determine the effective size, uniformity co-efficient & coefficient of curvature of soil.

Mesh opening in mm.	2.4	1.2	0.6	0.3	0.15	0.075	Pan @ the bottom
Mass retained g.	0.0	5.0	25.0	215	225	25	5

Soln:- Total mass of soil = (0+5+25+215+225+25+5) = 495.5g.

∴ percentage retained $= \frac{\text{Mass Retained bottom}}{\text{Total mass}} \times 100 = \frac{5}{495.5} \times 100 = \underline{1.01}$

$= \frac{\text{Mass Retained}}{M} \times 100$

Mesh opening mm	Mass retained g	Percentage retained %	Cumulate percentage retained %	Percent finer 'N' %
2.4	0	0	0	100
1.2	5	1.01	1.01	~~100~~ 98.99
0.6	25	5.05	6.06	~~98.99~~ 93.94
0.3	215	43.39	49.45	~~93.94~~ 50.55
0.150	225	45.41	94.86	~~50.55~~ 5.14
0.075	25	5.05	99.91	~~5.14~~ 0.09
Pan	0.5	0.1	100.01	0

Specimen Calculation:- Percentage retained $= \frac{5}{495.5} \times 100 = 1.01$

ily

——"—— $= \frac{25}{495.5} \times 100 = 5.05$

From Graph:- i) Effective Size $S_{10} = 0.18$ mm

ii) $D_{30} = 0.24$ mm

iii) $D_{60} = 0.34$ mm.

$\therefore C_u = \frac{D_{60}}{D_{10}} = \frac{0.34}{0.18} = 1.89$

$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(0.24)^2}{(0.18)(0.34)} = 0.94$

Sedimentation Analysis:

This analysis carried out on soil fraction finer than 75μ. (< 75μ), which is kept in suspension in a liquid medium, usually water. Sedimentation analysis is based Stoke's Law:

STOKE'S LAW STATES THAT "The terminal velocity (constant velocity attained during settlement) of sinking of a SPHERICAL particle in a still water medium of infinite extent is dependent upon SIZE OF PARTICLE, UNIT WEIGHT OF PARTICLE, UNIT WEIGHT of WATER and VELOCITY OF WATER."

In equation form, Stoke's law can be written as

$$v = \frac{2}{9}(r)^2\left(\frac{\gamma_s - \gamma_w}{\mu}\right)$$

v = Terminal velocity of particle m/sec
r = radius of spherical particle — m

γ_s = unit wt of soil particle N/m³ γ_w = unit wt. of water N/m³

μ = viscosity of water N-s/m² (POISE).

$$v = \frac{2}{9}(r)^2 \frac{[\gamma_s - \gamma_w]}{(\mu)}$$

$$v = \frac{2}{9}(r)^2\left(\frac{\gamma_s - \gamma_w}{\mu}\right)$$

The above equation can be written as

$$v = \frac{2}{9}(r)^2 \frac{(G-1)\gamma_w}{\mu}$$

W.K.T. $G = \frac{\gamma_s}{\gamma_w}$ $\therefore \gamma_s = G\gamma_w$.

If D is the diameter of particle

$$v = \frac{1}{18}(D)^2 \frac{(G-1)\gamma_w}{\mu}$$

NOTE!- If 'μ' is given in poise, it can be converted into Pa-s using following relation. 1 poise = 0.1 N-s/m²

Limitations of STOKE'S LAW:-

1) Sedimentation analysis is based on the assumption that the falling particle is spherical. But the finer particles are usually needle shaped.

2) Stoke's law consider the velocity of spherical particle in a suspension of infinite extent. But analysis is carried out in a glass jar in which extent of liquid is limited. (soil → 50g/ltr).

3) An average value of specific gravity of grains is used, though the G of some of the grains may be different from the average. (Insignificant)

Hydrometer Method:-

In this method, the weight of solids present at any time is calculated indirectly by reading the density of soil suspension with a hydrometer. The hydrometer reading R_H is corrected for meniscus, temperature and dispersing agent used deflocculation by the following equation.

$$R_c = R_H + C_m \pm C_t - C_d.$$

R_c = corrected hydrometer reading. R_H = observed hydrometer reading.

C_m = correction for meniscus, C_t = Temperature correction, supplied by manufacturer chart.

C_d = Dispersing agent correction.

= +ve if test temp is > 27°C

= -ve if test temp is < 27°C

The eqn used in the analysis.

$$D = \sqrt{\frac{18\mu v}{\gamma_s \gamma_w}}$$

where v = terminal velocity = $\frac{H_e}{60t}$

H_e = effective depth in m.

t = time in minutes

and N = Percentage finer = $\left(\frac{G}{G-1}\right)\left(\frac{R_c}{M_s}\right)\times 100$

Where M_s = Mass of dry soil sample in g.

(23) 50g of minus 75 microns oven dried soil was used in a hydrometer analysis. The corrected hydrometer reading after 2 minutes in a 1000 cc soil suspension was 25. The effective depth He for R_H of 25 is 12.13 cm. Taking G as 2.75 and viscosity of the ~~point of on the~~ water as 0.001 N-s/m² (0.01 poise) calculated the coordinates of the point on the grain size curve.

~~Cons~~ Given:- $R_c = 25$; $M_s = 50g$ $t = 2$ minutes ; $H_e = 12.13$ cm 'm' $= 0.1213$ m

$G = 2.75$ $\mu = 0.001$ N-s/m²

To find D & N:-

WKT $D = \sqrt{\frac{18 \mu v}{(\gamma_s - \gamma_w)}}$ $v = \frac{H_e}{60t} = \frac{0.1213}{60 \times 2} = 1.01 \times 10^{-3}$ m/sec

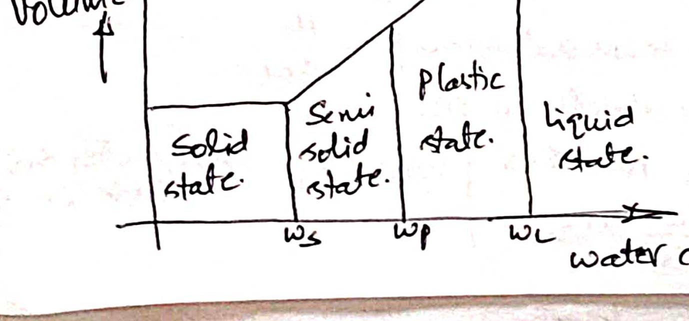
$\gamma_s - \gamma_w = G\gamma_w - \gamma_w = (G-1)\gamma_w$.

$$\therefore D = \sqrt{\frac{(18)(0.001)(1.01 \times 10^{-3})}{(2.75-1) \times 9810}} = 3.256 \times 10^{-5} m = 0.0325 mm$$

$$N = \left[\frac{G}{(G-1)}\right] \frac{R_c}{M_s} \times 100 = \frac{(2.75)}{(2.75-1)} \times \frac{25}{50} \times 100 = 78.57\%.$$

CONSISTENCY LIMITS:-

The term consistency is applicable only for fine grained soils (especially clays). Consistency indicates the relative ease with which a soil can be deformed. In other words it indicates the firmness of soil in terms of "soft", "firm", "stiff" and "hard". Consistency is related to a large extent to water content. Depending upon the water content, a fine grained soil may exist in the "liquid", "plastic", "semi-solid" and "solid" states. The water content @ which the soil passes from one state to next, are known as consistency limits. The significance of these limits was first demonstrated by ATTERBERG, a swedish scientist and hence consistency limits are also known as Atterberg limits. The relation of the limits to the states of consistency can be explained with the help of following diagram.



w_L = Liquid limit
w_P = Plastic limit
w_s = Shrinkage limit.

Fig:- ATTERBERG LIMITS

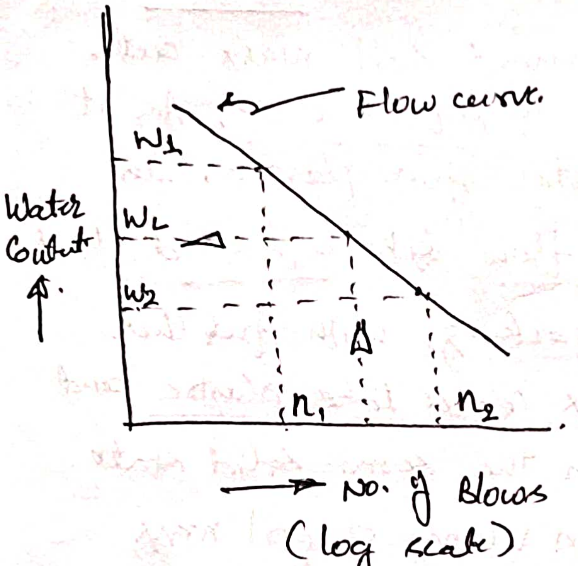
In a very wet condition, a fine grained soil mass acts like a viscous liquid and is said to be in liquid state. As it dries, the soil mass acquires the properties of a plastic. In the plastic state, the soil mass doesnot flow like a liquid, but it continues to be deformable without cracking. With further reduction in water content, the soil mass ceases to be plastic and becomes brittle. It is then said to be in the semi-solid state. Upto the semi solid state any reduction in volume of soil mass is very nearly equal to the volume of water lost. When the loss in water is not accompanied by a corresponding reduction in volume in soil mass, it is said to have entered the solid state.

The limiting water contents, when a soil mass passes from "liquid to plastic", "plastic to semi solid" and "semi solid to solid" states are respectively termed as 'Liquid limit', 'plastic limit' and 'Shrinkage limit'. Although the transition between each of the states is gradual, arbitrary tests have been adopted to precisely define these limits.

(1) LIQUID LIMIT (W_L). It is defined as the minimum water content @ which a part of soil cut by a groove (groove) of standard dimension will flow together for a distance of 12mm under the impact of 25 blows in a standard liquid apparatus. Liquid limit is the water content @ which the soil first shows a small but definite shearing resistance as the water content is reduced. From the definition of liquid limit, all soils possess the same value of shearing strength at liquid limit. It is about 27 g/cm².

In the laboratory the liquid limit is determined with the help of a standard liquid limit apparatus designed by "Casagrande". From the test data, flow curve shown in figure is drawn and the liquid limit is determined. The flow curve is a straight line having the following relation,

→ P.T.O.



W_1 = Water content for n_1 blows
W_2 = water content for n_2 blows.

Let I_f = Flow index (slope of the line)

$$\therefore W_1 - W_2 = (I_f) \log_{10}\left(\frac{n_2}{n_1}\right)$$

OR $$I_f = \frac{(W_1 - W_2)}{\log_{10}\left(\frac{n_2}{n_1}\right)}$$

NOTE: Higher I_f indicates lower shear strength.

(2) ~~Plas~~ **PLASTIC LIMIT** (W_P): It is defined as the minimum water content @ which a soil will just begin to crumble when rolled into a thread of approximately 3mm diameter.

(3) **plasticity Index** (I_P):- It is defined as the numerical difference between liquid limit (W_L) and plastic limit (W_P).

$$\therefore I_P = [W_L - W_P]$$

Plasticity Index indicates the range of water content within which the soil exhibits plastic properties. When plastic limit cannot be determined, the plasticity index is reported as NP (Non plastic)

(4) **Consistency Index** (I_C): It is defined as the ratio of difference between liquid limit (W_L) and natural water content (w) to the plasticity Index (I_P)

$$\therefore I_C = (W_L - w)/I_P$$

(5) **Liquidity Index** (I_L): It is defined as the ratio of difference between natural water content (w) and plastic limit (W_P) to the plasticity index (I_P).

$$\therefore I_L = (w - W_P)/I_P$$

(6) **Toughness Index** (I_T): It is defined as the ratio of plastic limit (W_P) to flow Index (I_f)

$$\therefore I_T = (W_P)/(I_f)$$

I_T, generally lies in the range of 0 to 3. When I_T is less than 1, FRIABLE (easily crushed) at the plastic limit.

Table - SOIL CLASSIFICATION RELATED TO PLASTICITY INDEX.

Plasticity Index, (I_p)	Soil description
0	Non-plastic
<7	Low-plastic
7-17	Medium-plastic
>17	Highly-plastic

TABLE:- CONSISTENCY OF COHESIVE SOILS

CONSISTENCY	Description	CONSISTENCY INDEX "I_c"	LIQUIDITY INDEX "I_L"
LIQUID	Liquid	<0	>1
PLASTIC	Very soft	0 - 0.25	0.75 - 1
	Soft.	0.25 - 0.50	0.50 - 0.75
	Medium Stiff.	0.50 - 0.75	0.25 - 0.50
	Stiff.	0.75 - 1	0 - 0.25
SEMI-SOLID	Very stiff OR Hard	>1	<0
SOLID	Very Hard.	>1	<0

7) ~~SHR~~ SHRINKAGE LIMIT (W_s).: It is defined as the maximum water content @ which a reduction in water content will not cause a decrease in the volume of a soil mass. It is the lowest water content @ which a soil can still be completely saturated.

The shrinkage limit is calculated as indicated below.

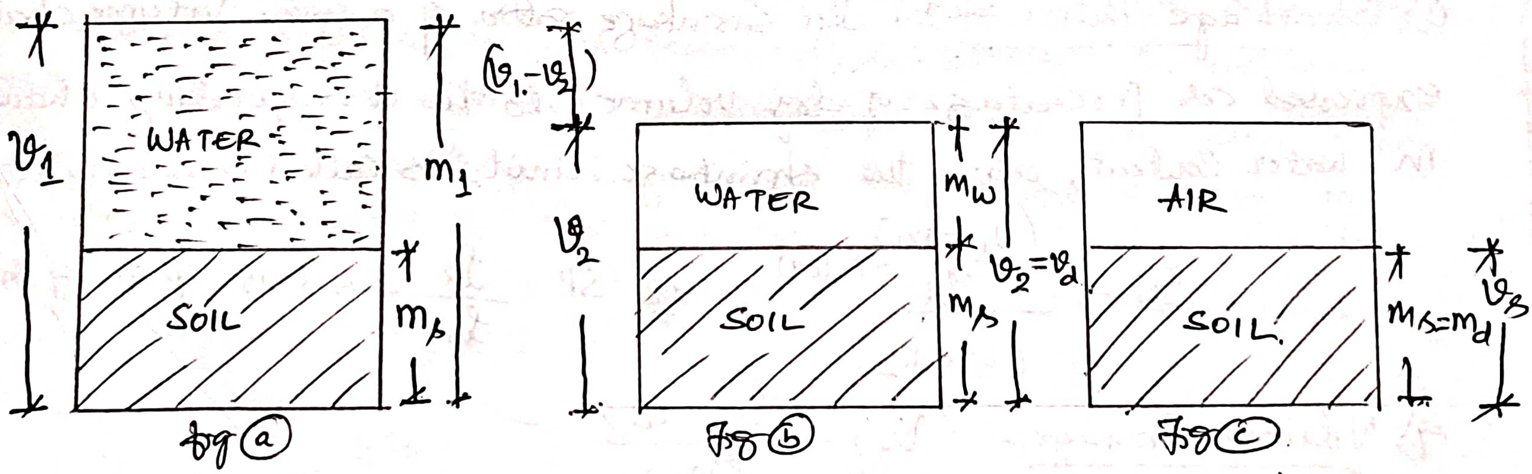


fig ⓐ Original soil pat

fig ⓑ Soil pat @ Shrinkage limit.

fig ⓒ Dry soil pat.

Fig ⓐ represents soil sample @ plastic state which fills with the container of known volume "V_1" with a mass of "m_1". As the sample is gradually dried, the water content @ a certain stage becomes equal to the shrinkage limit as in fig (b). At this point the volume decreases to "V_2" with the corresponding mass as m_2. The sample is still in a saturated state. Beyond the shrinkage limit, the sample continues to dry with no further volume decrease, until it reaches the dry state shown in fig (c). At this stage the mass of soil sample m_s and its volume "V_s" are measured.

Shrinkage limit is the (w_s) water content @ fig (b).

$$\therefore w_s = \frac{m_w}{m_s}$$ where m_w = mass of water (Refer fig b), m_s = mass of soil

$\therefore$ Mass of water in fig (b) = $(m_1 - m_s) - (V_1 - V_2)\rho_w = m_w$.

$$\therefore w_s = \frac{(m_1 - m_s) - (V_1 - V_2)\rho_w}{m_s} \quad \text{--- (1)}$$

OR

$$w_s = \left[w - \frac{(V_1 - V_d)\rho_w}{m_d}\right] \quad \text{--- (2)}$$

Alternatively if V_s is the volume of solids then

$$w_s = \frac{(V_2 - V_1)\rho_w}{m_d} \quad \text{--- (3)}$$

Shrinkage limit can also be determined by the following equation.

$$w_s = \left[\frac{\rho_w}{\rho_d} - \frac{1}{G}\right] \quad \text{--- (4)}$$

8) Shrinkage Ratio (SR):. The shrinkage ratio of a given volume change, expressed as percentage of dry volume, to the corresponding change in water content, above the shrinkage limit, is called shrinkage ratio.

$$SR = \frac{\frac{(V_1 - V_2)}{V_d} \times 100}{(w_1 - w_2)} \quad \text{OR} \quad SR = \frac{\rho_d}{\rho_w} \rightarrow \text{Mass sp. gr. of soil.}$$

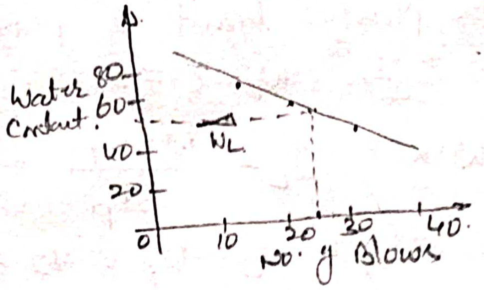
9) Volume Shrinkage (V_s) = $\frac{(V_1 - V_d)}{(V_d)}$

(24) The following data were obtained from a liquid limit test. Find the liquid limit.

No. of Blows :	20	28	34
w % :	68	60.1	54.3

$w_L =$ (from graph)

$I_f = \dfrac{w_1 - w_2}{\log_{10}\left(\frac{n_2}{n_1}\right)}$



(25). A soil has the following properties.

Natural water content = 20% ; Liquid limit = 25% ; (Also find void ratio @ liquid limit.)
plastic limit = 15% : Flow Index = 12.5% Take G = 2.70 &

Find plasticity Index (I_p), Consistency Index (I_c), Liquidity Index (I_L) & Toughness index (I_T)

Soln $I_p = w_L - w_p = 25 - 15 = 10\%$ (Medium plastic)

$I_c = \dfrac{w_L - w}{I_p} = \dfrac{(25-20)}{(10)} = 0.5$ (soft or medium stiff)

$I_L = \dfrac{w - w_p}{I_p} = \dfrac{20-15}{10} = 0.5$ (— do —)

$I_T = \dfrac{w_p}{I_f} = \dfrac{15}{12.5} = 1.2$ (Soil cannot be easily crushed @ plastic limit)

@ w_L = liquid limit $S = 1$. (D.O.S.) w_L (25%)

$(e)(S) = (w)(G) \Rightarrow (e)(1) = (0.25)(2.7) =$ i.e $e = 0.675$

(26) An undisturbed soil sample of clay brought from the field was noted have a volume of 18cc and mass 30.8g. On oven drying, the mass of the sample was reduced to 20.5g. The volume of dried sample as obtained by displacement of mercury was 12.5cc. Calculate the shrinkage limit and the specific gravity of soil solids. What is the shrinkage ratio.

Given volume $V_1 = 18cc$: mass $= m_1 = 30.8g$. (dried mass) $m_d = 20.5g$.
(when dried) vol $V_2 = 12.5cc$. $w_s = \dfrac{(m_1 - m_d) - (V_1 - V_2)\rho_w}{m_d}$

$$w_s = \frac{(30.8 - 20.5) - (18 - 12.5)\times 1}{20.5} = 0.234 \ (23.4\%)$$

also $w_s = \left[\dfrac{\rho_w}{\rho_d} - \dfrac{1}{G}\right]$ But $\rho_d = \dfrac{m_d}{V_s} = \dfrac{20.5}{12.5} = 1.64$ g/cc.

$\therefore$ $0.234 = \left[\dfrac{1}{1.64} - \dfrac{1}{G}\right]$ $\therefore G = 2.66$.

Shrinkage ratio $= \dfrac{\rho_d}{\rho_w} = \dfrac{1.64}{1} = 1.64$.

27) A sample of soil with a liquid limit of 72.8%. was found to have a liquidity Index of 1.21 and water content of 81.3%. What are its plastic limit & plasticity Index.

Sol^n Data: $w_L = 0.728$; $I_L = 1.21$ & $w = 0.813$

W.K.T $I_L = \frac{w - w_p}{I_p} = \frac{w - w_p}{w_L - w_p} \Rightarrow \frac{0.813 - w_p}{0.728 - w_p}$ $\therefore w_p = 0.323$ (32.3%)

$\therefore I_p = w_L - w_p = 72.8 - 32.3 = 40.5\%$.

Since $I_L = 1.21 > 1$ soil is in liquid state.

28) The oven dry wt. of pat of clay is 0.108N and wt. of mercury displaced on immersion is 0.842N. Taking G = 2.72, determine the shrinkage limit and shrinkage ratio.

Sol^n Data = $W_d = 0.108N$ wt. of mercury displaced $W_{mcy} = 0.842N$.

G = 2.70 Find: w_s & SR.

W.K.T $w_s = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G}\right]$ also $\gamma_w = 9810\ N/m^3$; $\gamma_d = \frac{W_d}{V_d}$.

$V_d = \frac{W_m}{\gamma_M} = \frac{0.842}{133416} = 6.31 \times 10^{-6}\ m^3$

[NOTE] $\gamma_{Mcy} = \frac{13.6}{1000} \times 9.81 \times (100)^3 = 133416\ N/m^3$]

$\therefore \gamma_d = \frac{0.108}{6.31 \times 10^{-6}} = 17115.7\ N/m^3$

$\therefore w_s = \left[\frac{9810}{17115.7} - \frac{1}{2.72}\right] = 0.2055$ (20.55%)

$SR = \frac{\gamma_d}{\gamma_w} = \frac{17115.7}{9810} = 1.745$.

29) A clay sample has a void ratio of 0.53 in dry state. What will be shrinkage limit if G = 2.7?. Find shrinkage ratio.

Given data: e = 0.53 G = 2.7 reqd. w_s = ? SR = ?

W.K.T. $\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow \frac{(2.7)(9810)}{(1+0.53)} = 17311.76\ N/mm^2$ Shrinkage Limit $w_s = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G}\right]$

$SR = \frac{\gamma_d}{\gamma_w} = \frac{17311.76}{9810} = 1.77$

$= \left(\frac{9810}{17311.76} - \frac{1}{2.7}\right) = 0.196$ (19.6%)

ACTIVITY of SOIL (A): (Activity of clay):- The ratio of plasticity Index (I_p) of the soil to the percentage of clay particles [Size < 2μ] present in the soil mass is called activity of soil. $\therefore A = \frac{I_p}{C}$ C = % of clay size particles in soil mass.

Table:- Soil classification related to Activity of SOIL.

ACTIVITY	SOIL TYPE
< 0.75	Inactive.
0.75 – 1.25	Normal
> 1.25	Active.

SOIL CLASSIFICATION:

M-1-P-16

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS).

Following symbols are used in the USCS.

I:- Based on grain size : Gravel (G), Sand (S), Silt (M), clay (C), and organic (O),

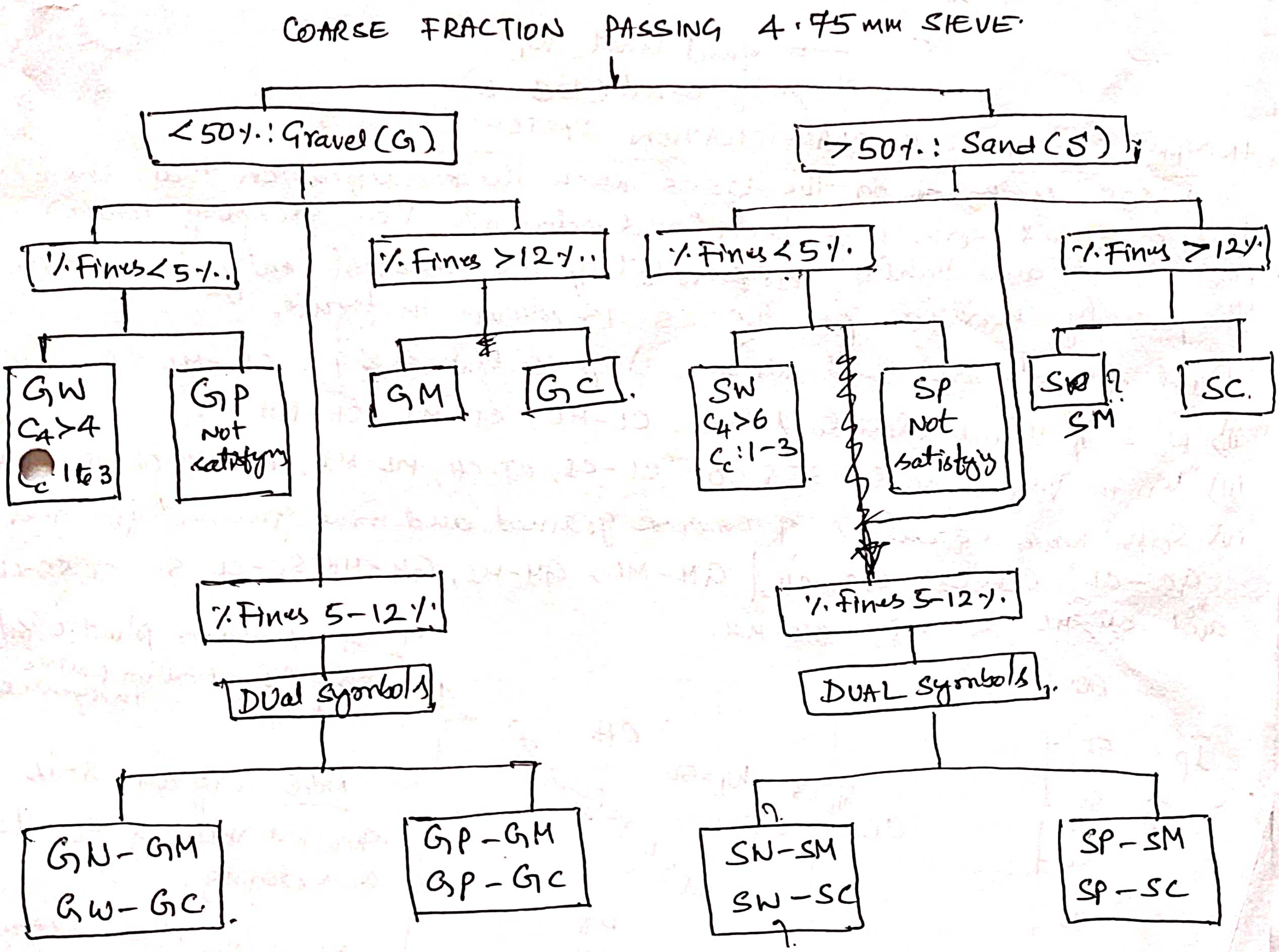
II:- Based on Grain size: Well graded (W) and Poorly graded (P).

III:- Based on Compressibility (plasticity): Low (L) and High (H).

PASSING 75μ sieve (0.075 mm).

Case I) < 50%. Coarse Grained. ←——→ Case II) > 50%. Fine Grained. ~~Sand (S)~~

Case I:- If Coarse Grained:-



Case - II) If Fine Grained.

↓

PLASTICITY CHART.

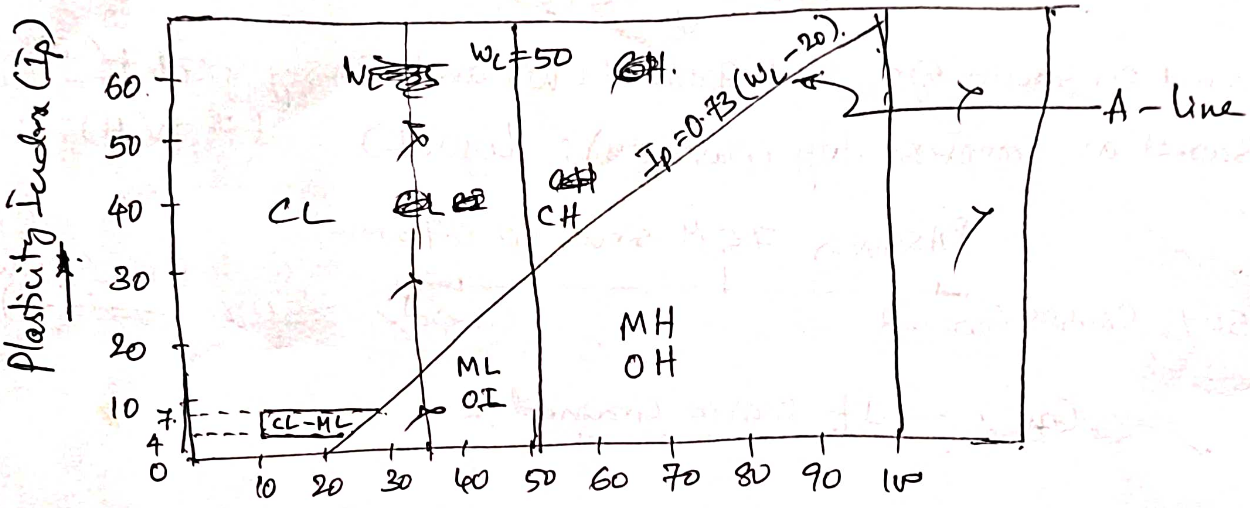


Fig: Plasticity chart (USCS).

INDIAN STANDARD SOIL CLASSIFICATION SYSTEM: (ISSCS)

ISSCS is based on the USCS with the modification that the fine grained soils have been subdivided into three groups of Low (L), Medium (M) and High (H), compressibility as against only two in USCS. The plasticity chart as per ISSCS is shown in figure.

Dual symbols are used when i) Ip is b/w 4 & 7 : CL-ML

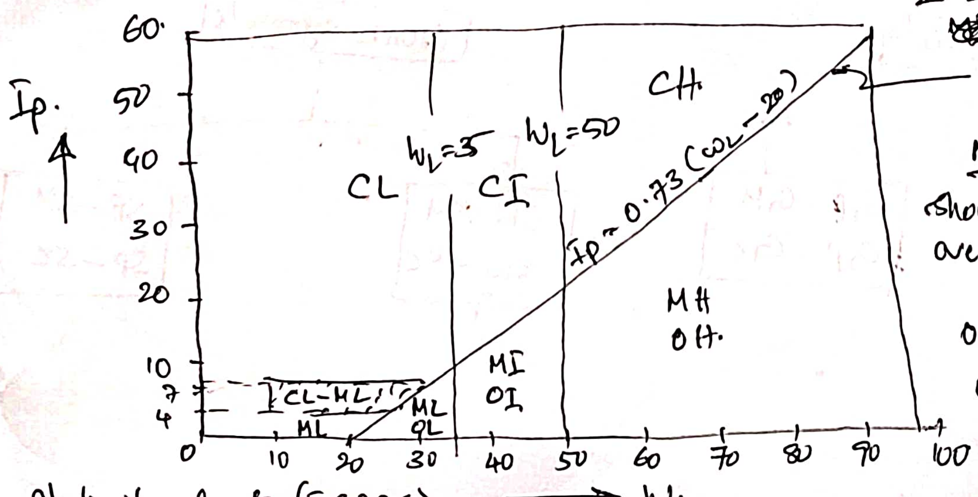
ii) WL & Ip values close to A-line : CL-ML, CI-MI, CH-MH

iii) WL is very close to 35 & 50 : CL-CI, CI-CH, ML-MI, MI-MH, OL-OI, OI-OH

iv) Soils have equal % of coarse grained and fine grained fractions: GC-CL; GC-CI; GC-CH; GM-ML, GM-MI, GM-MH, SC-CL, SC-CI, SC-CH and SM-ML; SM-MI; SM-MH.

MI → Medium plastic soils

CI - Medium plastic inorganic clay



Plasticity chart (ISSCS)

NOTE: Organic soils show less value of WL after oven drying.

OL → low plastic organic clay.

OI - Medium plastic organic soil.