BHARAT INSTITUTE OF ENGGINEERING AND TECHNOLOGY

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PIN- 760002

LECTURE NOTES

ON

GEOTECHNICAL ENGINEERING

CIVIL, 3RD SEMESTER

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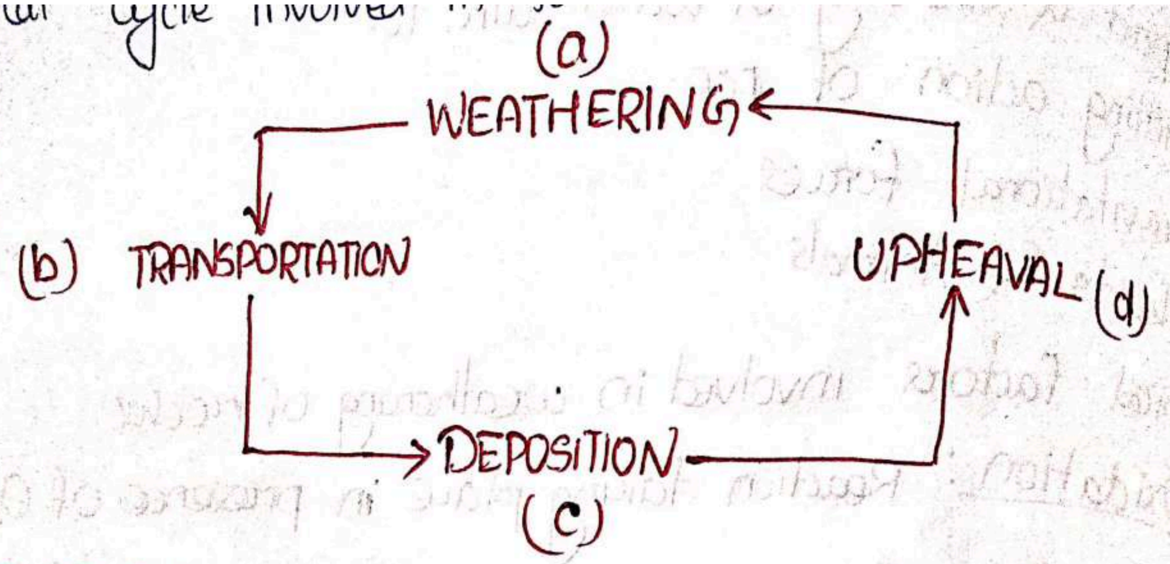
SOIL MECHANICS

- Soil is an unconsolidated material composed of solid particles formed by disintegration of rock & void spaces of which is filled with either water or air or both.
- The process of formation of soil is termed as "PEDOGENESIS".
- Soil is formed due to weathering / disintegration / wear & tear / erosion of rocks.
- Weathering of rocks can be done either by Physical/Mechanical/Chemical agencies.
- Physical factors involved in weathering of rocks.
  (a) Impact & Grinding of water, air, Ice.
  (b) Splitting action of Ice
  (c) Gravitational forces
  (d) Plants & Animals
- Chemical factors involved in weathering of rocks
  (a) Oxidation: Reaction taking place in presence of O_2
  (b) Reduction: Reaction taking place in absence of O_2
  (c) Carbonation: Reaction taking place in presence of CO_2
  (d) Hydration: Reaction taking place in presence of H_2O.
  (e) Leaching by organic acids or water.

Leaching:
It is the process of extracting the substances from the solid that is soluble in liquid.

- If soil is formed by physical weathering, mineral constituents of soil is same as that of parent rock but if it is formed by chemical weathering the mineral constituents of the soil differ from the parent rock.
- If weathered soil mass is retained over the parent rock it is termed as Residual soil & if it is carried away from parent rock it is termed as Transported soil.
- The properties of soil like size, shape (roundness), surface texture, degree of sorting depends upon the mode of transportation of soil particles.

...eral cycle involved ...



TYPE OF SOIL:-

Different types of soil found are as follows

(a) ALLUVIAL SOIL:-

It is the type of soil which is deposited from suspension fr... running water.

...) LACUSTRINE SOIL:-

It is the type of soil which is deposited from suspension in fresh s... water of lake.

...) MARINE SOIL:-

It is the type of soil which is deposited from suspension in sea water.

...) AEOLINE SOIL / SAND DUNES:-

It is the soil transported by blowing wind.

...) GLACIAL SOIL:-

It is the soil which is transported by Ice.

...) TALUS / COLLUVIAL SOIL:-

It is the soil transported by gravity

...) LOOES SOIL:-

It is the uniformly graded wind blown silt slightly cemented by calcium compound or Montmorillonite.

-It is also termed as COLLAPSABLE SOIL.

(h) MARL SOIL:-

It is finely grained calcium carbonated soil of marine origin which is formed due to decomposition of plants & animals (aquatic life)

(i) TUFF SOIL:-

A fine grained slightly cemented volcanic ash transported either by wind or water.

(j) BENTONITE SOIL:-

- It is chemically weathered volcanic ash.
- It consist of high % of montmorillonite, hence possess high plasticity, high shrinkage & swelling characteristics & low shear strength.
- It is used as lubricant for drilling operation.

(k) BLACK COTTON SOIL:-

- It is a residual soil formed from Basalt & have excess of montmorillonite in it.
- It is dark in colour & is suitable for growing cotton.

(l) LATERITE SOIL:-

It is the type of soil formed due to leaching out of silicious compound & deposition of Fe_2O_3 & Al_2O_3.
- It is found in hilly areas.

(M) MUCK SOIL:-

It is the mixture of fine particled organic soil (formed due to black decomposed organic matter) & inorganic soil.
- It is found in marshy/swampy/after the overflow of river.

(N) PEAT SOIL:-

- It is highly organic soil which is almost entirely consists of organic /decomposed vegetative matter in different stages.
- It is highly fibrous, compressible.

NOTE -

MUCK SOIL + PEAT SOIL ⟶ CUMULOSE SOIL

(O) LOAM SOIL:-

It is the mixture of clay, silt & sand

(P) GUMBO SOIL:-

It is black coloured highly plastic soil which is formed either by physical or chemical weathering.

(Q) VARVED SOIL/CLAY:-

It is a sedimentary soil formed in glaciers lakes (generally) with visible layering.
- It is composed of 2 periodically repeated layers

dark (silty-clayey) & bright (silty sandy) ones is formed in sum. & other is formed in winter.

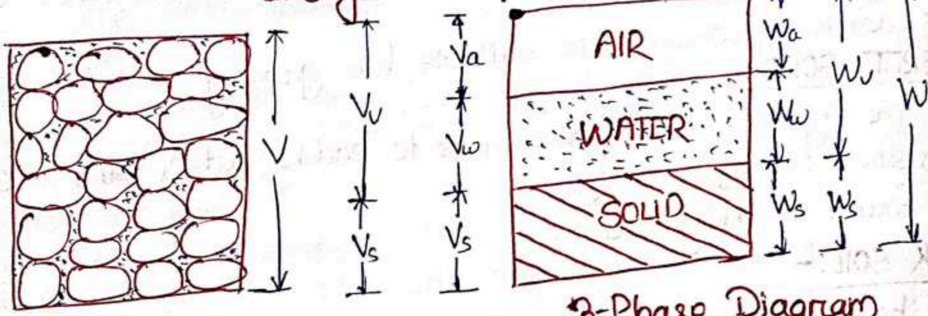
(R) FISSURED SOIL/CLAY:-

It is the type of soil that is formed when dry at depth, but is intercepted by developement of cracks through which water may easily seep into it.

PROPERTIES OF SOIL:-

- Soil is 3 phase system which consist of solids, liquids & gases they do not occupy separate spaces but are blended with eachother in definite proportion which in turn governs the property of soil

Solids → Organic, Inorganic; Liquid → Water, Gases → Air



3-Phase Diagram

$V = V_v + V_s$ — V = Volume of Soil

$V_v = V_a + V_w$ — V_v = Volume of voids

$\boxed{V = V_a + V_w + V_s}$ — V_s = Vol. of solids

V_a = Vol. of Air

V_w = Vol. of Water

also $W = W_v + W_s$ — W = Weight of Soil

$W_v = W_a + W_w$ — W_v = Weight of void

$\boxed{W = W_a + W_w + W_s}$ — W_s = Weight of solid

Now $\rho_{air} = 1.2\ kg/m^3$

$\rho_{water} = 1000\ kg/m^3$

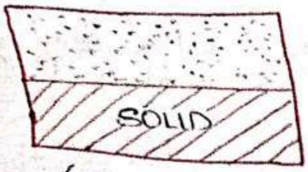
Since $\rho_{air} <<< \rho_{water} < \rho_{solid}$

Hence $W_a \simeq 0$

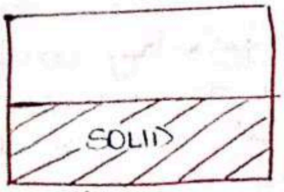
$W_v = W_w$

$\boxed{W = W_w + W_s}$

NOTE-
In some limiting case soil can also be represented as 2-Phase s



(Case-I)
SATURATED SOIL
Solids + Water



(Case-II)
DRY SOIL
Solids + Air

(i) WATER CONTENT : —(w)

- It is defined as the % ratio of weight of water to the wight of solids in the given soil mass.

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

$$w \geq 0\%.$$

NOTE

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

$$1+w = 1+\frac{W_w}{W_s}$$

$$1+w = \frac{W_w+W_s}{W_s}$$

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

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

NOTE

Water content can also be expressed in terms of weight of soil

$$w' = \frac{\text{Wt. of water}}{\text{Wt of soil}} \times 100$$

$$w' = \frac{W_w}{W} \times 100$$

$$0 \leq w' < 100\%.$$

$$w' = \frac{W_w}{W}$$

$$w' = \frac{W_w}{W_w+W_s}$$

$$w' = \frac{W_w/W_s}{\frac{W_w}{W_s}+\frac{W_s}{W_s}}$$

$$\boxed{w' = \frac{w}{w+1}} \quad \text{or} \quad \boxed{w = \frac{w'}{1-w'}}$$

NOTE :-
Weight of solids is ~~comparatively~~ comparatively stable than wt. of soil as it does not depends on weight of water. Hence engg. significance of w is more than w'.

(II) VOID RATIO (e) :-

- It is defined as the ratio of volume of voids to the volume of solids in the given soil mass.

$$e = \frac{V_v}{V_s}$$, $e > 0$

NOTE :

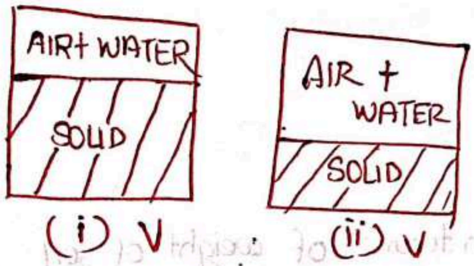
$$e = \frac{V_v}{V_s} \Rightarrow 1+e = 1 + \frac{V_v}{V_s}$$

$$\Rightarrow 1+e = \frac{V_s + V_v}{V_s}$$

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

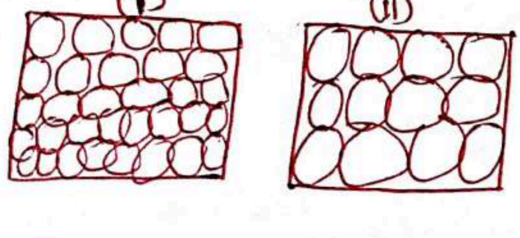
$$V_s = \frac{V}{1+e}$$

NOTE
Void ratio can also be used to represent degree of denseness of soil.



$V_s(i) > V_s(ii)$
$V_v(i) < V_v(ii)$
$e(i) < e(ii)$
Denseness (ii) < Denseness (i)
Denseness $\propto \frac{1}{e}$

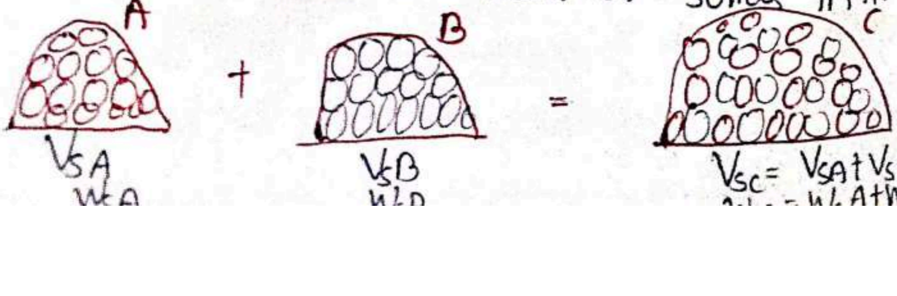
NOTE Though volume of one void is more for coarse grained soil, total of voids in fine grained soil is more, due to which total volume of voids in fine grained soil is more hence its void ratio & water content is more than coarse grained soil.



Properties	Fine grained	Coarse grained
Size of Voids	↓	↑
Vol. of one void	↓	↑
no. of voids	↑	↓
Total vol. of voids	↑	↓

NOTE :-

When 2 or more soil sample are mixed with each other, the resultant sample would have same amount of solids in it.



(iii) POROSITY (η) :-

- It is defined as the ratio of volume of voids to the volume of soil present in the soil mass.

$$\boxed{\eta = \frac{V_v}{V} \times 100}$$

$$0\% < \eta < 100\%$$

NOTE :-

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

$$\Rightarrow \eta = \frac{V_v}{V_v + V_s} = \frac{V_v/V_s}{\frac{V_v}{V_s} + \frac{V_s}{V_s}}$$

$$\Rightarrow \boxed{\eta = \frac{e}{e+1}} \quad \text{or} \quad \boxed{e = \frac{\eta}{1-\eta}}$$

NOTE: Both e & η signifies the water storage capacity of the soil as they represent vol. of voids in it.

NOTE: Since volume of solid is comparatively stable than vol. of voids, as it doesnot depend upon volume of voids, engg. significance of "e" is more than "η".

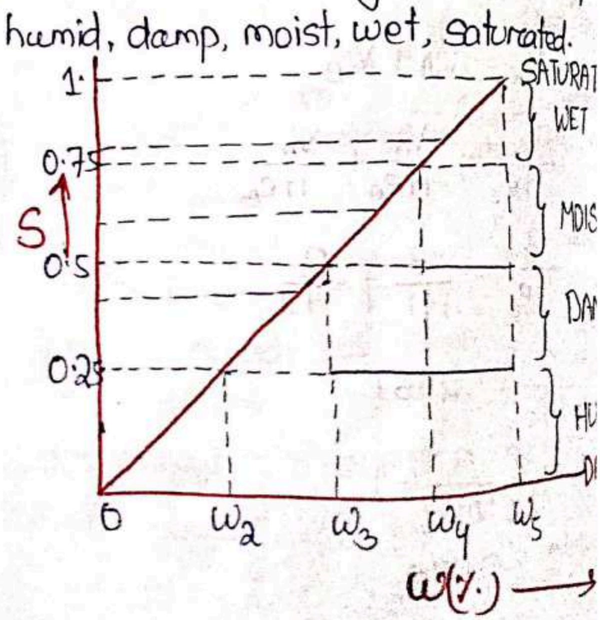
(IV) DEGREE OF SATURATION:-

- It is defined as the ratio of vol. of water to the volume of voids present in sample of soil.

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

$$0\% \leq S \leq 100\%$$

- Depending upon the degree of saturation in given soil sample can be classified as dry, humid, damp, moist, wet, saturated.



(V) AIR CONTENT (a_c) :-

- It is defined as the ratio of volume of air to the volume of voids present in the given sample of soil mass.

$$a_c = \frac{V_a}{V_v} \times 100 \qquad 0\% \le a_c \le 100\%$$

NOTE

$$V_v = V_a + V_w \Rightarrow \frac{V_v}{V_v} = \frac{V_a}{V_v} + \frac{V_w}{V_v}$$

$$\Rightarrow 1 = a_c + S$$

(VI) PERCENTAGE AIR VOIDS :- (η_a).

It is defined as the ratio of volume of air to the volume of soil present in the given sample of soil mass.

$$\eta_a = \frac{V_a}{V} \times 100 \qquad 0\% \le \eta_a < 100\%$$

NOTE

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

$$\eta_a = a_c \cdot \eta$$

(VII) UNIT WEIGHT (OR) UNIT DENSITY :-

(a) BULK UNIT WEIGHT / BULK DENSITY :-

It is the ratio of wt/mass of soil in existing condition to the total volume of soil mass.

$$\gamma_b \text{ or } \gamma = \frac{\text{wt. of soil in existing condition}}{\text{Volume of soil}} = \frac{W}{V}$$

$$\rho_b / \rho = \frac{\text{Mass of soil in existing Condition}}{\text{Volume of soil}} = \frac{M}{V}$$

Since $W = Mg$

$$\Rightarrow \gamma = \rho g$$

(b) DRY UNIT WEIGHT / DRY DENSITY :-

- It is the ratio of weight / mass of soil in dry state to the volume of soil.

$$\gamma_d = \frac{W_d}{V} = \frac{W_s}{V} \qquad \rho_d = \frac{M_d}{V} = \frac{M_s}{V}$$

It can also be used to represent the denseness of the soil.

Denseness of soil $\propto \gamma_d$

NOTE :- Also denseness of the soil $\propto \frac{1}{e}$

Hence $\gamma_d \propto \frac{1}{e}$

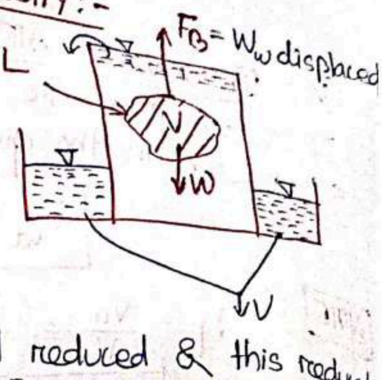
(c) SATURATED UNIT WT / ...

It is the ratio of wt./mass of soil in saturated state to the volume of soil.

$$\gamma_{sat} = \frac{W_{sat}}{V} \qquad \rho_{sat} = \frac{M_{sat}}{V}$$

NOTE If soil is in dry state i.e. $S=0$, $\gamma_b = \gamma_d$
If soil is in saturated state i.e. $S=1$, $\gamma_b = \gamma_{sat}$

(d) SUBMERGED UNIT WT./ SUBMERGED DENSITY:-

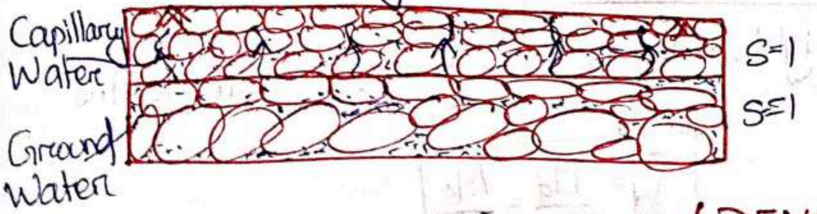


- If the soil mass is submerged below the water table level, it is subjected to force of buoyancy in vertically upward direction.
- The magnitude of this buoyancy force is equal to the wt of water displaced
- Due to this buoyancy force wt. of soil reduced & this reduced wt of soil is termed as SUBMERGED / BOUYANT/ APPARENT/ EFFECTIVE WT. of the soil.

$$\gamma_{sub} \text{ or } \gamma' = \frac{W_{sub}}{V}$$
$$= \frac{W_{SAT} - F_B}{V} = \frac{W_{SAT} - W_{WD}}{V} = \frac{W_{SAT} - (V_w \gamma_w)_D}{V}$$
$$= \frac{W_{SAT} - V\gamma_w}{V} = \frac{W_{SAT}}{V} - \frac{V\gamma_w}{V}$$
$$\gamma' = \gamma_{SAT} - \gamma_w \qquad \rho' = \rho_{SAT} - \rho_w$$

- A submerged soil will always be saturated but it is not necessary that saturated soil is always submerged.

For eg. Soil below WT. is submerged & saturated but soil above WT in capillary fringe is saturated but not submerged.



(e) UNIT WEIGHT OF SOLID / DENSITY OF SOLID:-

It is the ratio of wt/mass of solid to the volume of solid

$$\gamma_s = \frac{W_s}{V_s} \qquad \rho_s = \frac{M_s}{V_s}$$

NOTE $\gamma' \approx \gamma_w = \frac{\gamma_{SAT}}{2}$

$$(KN/m^3) \quad \underset{26-29}{\gamma_s} > \underset{20-21}{\gamma_{SAT}} > \underset{18-20}{\gamma_b} > \underset{16-18}{\gamma_d} > \underset{10}{\gamma'}$$

(viii) SPECIFIC GRAVITY:-

(a) TRUE/ ABSOLUTE SPECIFIC GRAVITY:-

It is defined as the ratio of wt. of solid of given volume to wt. of standard liquid (water) of same volume.

$$\boxed{G = \frac{W_s}{W_w}} \quad (V_s = V_w)$$

$$G = \frac{W_s \cdot V_s}{V_s W_w}$$

$$= \left(\frac{W_s}{V_s}\right)\left(\frac{V_w}{W_w}\right)$$

$$\boxed{G = \frac{\gamma_s}{\gamma_w}}$$

(b) MASS / BULK / APPARENT SPECIFIC GRAVITY:-

It is the ratio of wt/mass of soil of given volume to the wt/mass of standard liquid (water) of same volume

$$G_m = \frac{W}{W_w} \quad (V = V_w)$$

$$= \frac{W}{V} \cdot \frac{V}{W_w} = \left(\frac{W}{V}\right) \cdot \left(\frac{V_w}{W_w}\right) = \frac{\gamma}{\gamma_w}$$

$$\boxed{G_m = \frac{\gamma}{\gamma_w}} \quad \text{or} \quad \boxed{G_m = \frac{\rho}{\rho_w}}$$

NOTE $\boxed{G > G_m}$

SOIL TYPE	SPECIFIC GRAVITY
- Sand & Gravel	2.65 - 2.68
- Silt & Silty sand	2.66 - 2.70
- Inorganic Clay	2.7 - 2.8
- Soil with high iron & mica	2.75 - 2.85
- Organic Soil	1 - 2

- Specific Gravity of fine grained soil is generally more than coarse grained soil.
- Specific Gravity of Inorganic soil is generally more than Organic soil.
- With increase in presence of minerals in soil its specific gravity increases.
- As per Indian Standards "G" is reported at 27°c & at any other temp. it can be computed as

(IX) DENSITY INDEX/ RELATIVE DENSITY/ DEGREE OF DENSITY: (I_D)

- Density Index is used to represent the relative degree of density or Compactness of the soil in absolute terms unlike void ratio & dry density.
- It is defined as the ratio of difference of void ratio of the soil in loosest state & void ratio in natural state to the difference of void ratio of soil in loosest state & densest state.

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

e_{max} = Void Ratio in loosest state

e = Void Ratio in Natural state

e_{min} = Void Ratio in densest state

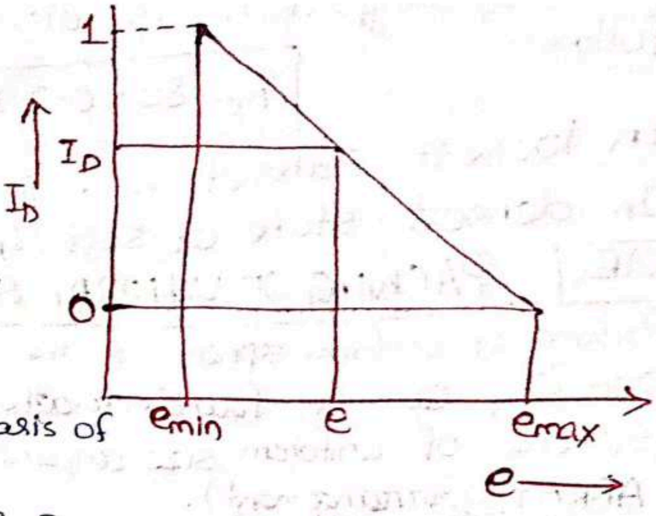
- If $e = e_{max}$, soil is in loosest state, $I_D = 0\%$.
- If $e = e_{min}$, soil is in densest state, $I_D = 100\%$.

NOTE]

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

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

$$\Rightarrow I_D = \frac{\frac{1}{\gamma_{d_{min}}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{d_{min}}} - \frac{1}{\gamma_{d_{max}}}} \times 100$$



⇒ Degree of denseness on the basis of density index is as follows.

I_d (%)	Degree of Denseness
0 - 15	Very loose
15 - 35	Loose
35 - 65	Medium Dense
65 - 85	Dense
85 - 100	Very dense

- Id is not used for the analysis of cohesive soil as there are large uncertainities involved in finding the void ratio of cohesive soil in its loosest state in laboratory.
- Two sand deposits having same shape & size can exhibit different properties if they possess different density index (I_D).
- Here sand having more I_D is more compact, dense, stable, less compressible, has highere sheare strength.

(X) RELATIVE COMPACTION:- (R_c)

- It is used to indicate the degree of denseness or compactness of soil in absolute terms as density Index but it can be used for both cohessive & cohesionless soil.
- It is defined as the ratio of dry unit weight of the soil in natural state & dry unit wt. of soil in densest state

$$R_c = \frac{\gamma_d}{\gamma_{d_{max}}} \times 100$$

γ_d = Dry unit wt. of soil in existing/natural state

$\gamma_{d_{max}}$ = dry unit wt of soil densest state

also $\gamma_d \propto \frac{1}{e}$ $\left[\gamma_d = \frac{G\gamma_w}{1+e}\right]$

Hence $R_c = \frac{G\gamma_w}{1+e} \cdot \frac{1+e_{min}}{G\gamma_w} \Rightarrow$ $R_c = \frac{1+e_{min}}{1+e} \times 100$

- Relative compaction is also linked with density Index as follows.

$$R_C = 80 + 0.2\, I_D$$

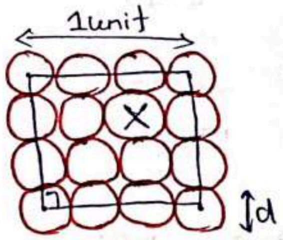
In loosest state of soil, $I_D = 0\% \Rightarrow R_C = 80\%$

In densest state of soil, $I_D = 100\% \Rightarrow R_C = 100\%$

NOTE | PACKING OF UNIFORM SPHERE :-

- Packing of uniform sphere is the only system, where void ratio & porosity can be found mathematically.
- Sphere of uniform size attains stable loosest packing in "CUBICAL ARRAY" (Arrangement).
- Sphere of uniform size attains stable densest packing: "ROMBOHEDRAL ARRAY".

(a) LOOSEST STATE :-



Here each particle is in contact with 6 other particles.

Volume of soils $V = 1 \times 1 \times 1 = 1 m^3$

no. of solids in soil $n = \frac{1}{d} \cdot \frac{1}{d} \cdot \frac{1}{d} = \frac{1}{d^3}$

Volume of one solid $V_{S1} = \frac{\pi d^3}{6}$

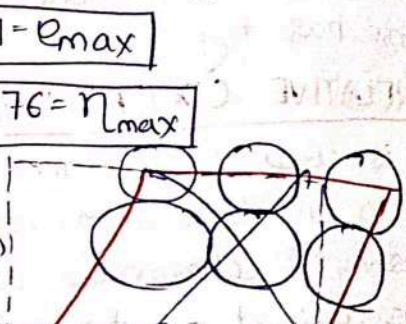
Total volume of solids in soil $= V_S = n V_{S1} = \frac{1}{d^3} \times \frac{\pi d^3}{6} = \frac{\pi}{6}$

Volume of voids in Soil $= V_v = V - V_s = 1 - \frac{\pi}{6} = 0.476 m^3$

$e_{max} = \frac{V_v}{V_s} = \frac{0.476}{\pi/6} =$ $\boxed{0.91 = e_{max}}$

$\eta_{max} = \frac{V_v}{V} = \frac{0.476}{1} =$ $\boxed{0.476 = \eta_{max}}$

(b) DENSEST STATE :-



Here each particle is in contact with 12 other particles

Volume of Rombohedral (V)

$V = \sqrt{1 + 2\cos\alpha}\ (1 - \cos\alpha)$

Volume of soil $V = \sqrt{1 + 2\cos 60^\circ}\ (1 - \cos 60^\circ)$
$= 0.707 m^3$.

Volume of solids $V_s = \frac{\pi}{6} m^3$

Volume of voids $= V_v = V - V_s$
$= 0.707 - \frac{\pi}{6} = 0.18 m^3$

$e_{min} = \frac{V_v}{V_s} = \frac{0.18}{\pi/6} = 0.35$ $\boxed{e_{min} = 0.35}$

$\eta_{min} = \frac{V_v}{V} = \frac{0.18}{0.707} =$ $\boxed{\eta_{min} = 0.26}$

$0.41 - 0.35$

$= 53.57\%$ (Medium dense soil)

INTER RELATIONSHIP B/W THE PROPERTIES OF SOIL:-

(a) e, w, G, S

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

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

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

$$e = \frac{1}{S} \cdot \frac{V_w}{V_s}$$

$\therefore \gamma_w = \frac{W_w}{V_w}$ $\quad G = \frac{\gamma_s}{\gamma_w}$ $\quad \gamma_s = G\gamma_w$

$V_w =$ $\quad G = \frac{W_s}{V_s \gamma_w}$

$$= \frac{1}{S} \cdot \frac{W_w}{\gamma_w} \cdot \frac{G\gamma_w}{W_s}$$

$$= \frac{1}{S} \cdot \frac{W_w}{W_s} \cdot \frac{G\gamma_w}{\gamma_w}$$

$$= \frac{1}{S} \cdot w \cdot G$$

$$eS = w \cdot G$$

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

(b) $\gamma, G, e, S, \gamma_w$

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_v + V_s}$$

$$= \frac{G V_s \gamma_w + \gamma_w V_w}{V_s(1+e)}$$

$$= \frac{G\gamma_w + \frac{V_w}{V_s} \cdot \gamma_w}{(1+e)}$$

$$= \frac{G\gamma_w + \frac{V_w}{V_v} \cdot \frac{V_v}{V_s} \cdot \gamma_w}{(1+e)} \Rightarrow \gamma = \frac{G\gamma_w + eS\gamma_w}{1+e}$$

$$\Rightarrow \boxed{\gamma = \frac{(G+eS)}{1+e}\gamma_w}$$

NOTE 1. For dry soil $\gamma = \gamma_d$, $S = 0$

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

2. For Saturated soil $\gamma = \gamma_{sat}$, $S = 1$

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

also $\gamma_{sat} = \frac{G\gamma_w}{1+e} + \frac{e\gamma_w}{1+e}$ $\quad e = \frac{wG}{S}$

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

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

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

$$\boxed{\gamma_{sat} = \gamma_d(1+w)}$$

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

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

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

also $\gamma' = \frac{G\gamma_w}{1+e} - \frac{\gamma_w}{1+e}$

$$\boxed{\gamma' = \gamma_d - (1-\eta)\gamma_w}$$

(c) γ_d, γ, w

$\gamma_d = \frac{W_d}{V} = \frac{W_s}{V} = \frac{W}{(1+w)V} = \frac{\gamma}{1+w}$ $\quad \because \boxed{W_s = \frac{W}{1+w}}$

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

(d) γ_d, G, γ_w, w

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

$$\left(e = \frac{wG}{S}\right)$$

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

If $S=1$, $e = wG$ (Here w represents water content at which soil is saturated)

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

NOTE The above relationship is significant to understand the compaction of soil.

(e) $\gamma_d, \eta_a, G, w, \gamma_w$

$$V = V_v + V_s = V_a + V_w + V_s$$

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

$$1 = \eta_a + \frac{W_w}{\gamma_w \cdot V} + \frac{W_s}{G\gamma_w \cdot V}$$

$$1-\eta_a = \frac{W_w}{\gamma_w \cdot V} + \frac{W_s}{G\gamma_w V}$$

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

$$1-\eta_a = \frac{W_s}{\gamma_w V}\left[w + \frac{1}{G}\right]$$

$$1-\eta_a = \frac{W_d}{\gamma_w V}\left[w + \frac{1}{G}\right] = \frac{\gamma_d}{\gamma_w}\left[w + \frac{1}{G}\right]$$

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

NOTE This relationship is also significant to understand the compaction

INDEX PROPERTIES OF SOIL :-

These are the properties of the soil which helps in identification & classification of soil

(a) WATER CONTENT (ω)

- SOIL WATER

(i) Ground/ Free/Gravity Water :-

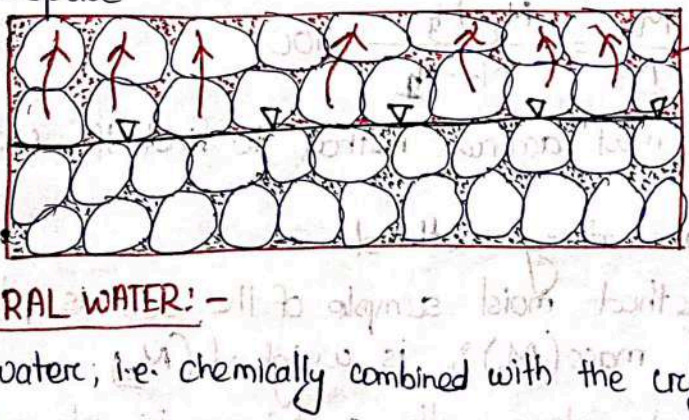
It is subsurface water that fills the void continuously upto ground water table level. This water is subjected to no force other than its own weight. It obeys all the laws of hydraulics & is capable of moving under hydrodynamic forces.

(ii) CAPILLARY WATER :-

- It is the water which is lifted above the ground water table level by capillary force.
- It remains in suspension in the voids of the soil.
- It also obeys laws of hydraulic & moves under hydrodynamic forces.

NOTE

1. Gravity & Capillary water is also termed as PORE (VOID) WATER
2. If Gravity water is present then capillary water do not exist in same space.



(iii) STRUCTURAL WATER :-

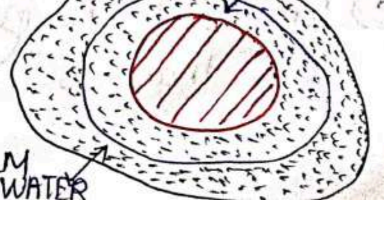
It is the water, i.e. chemically combined with the crystal structure of soil solids

- Under normal loading condition found in engg. this water can not be removed.
- It even does not get removed by heating the soil upto 105-110°c.

(iv) ADSORBED WATER / PELLICULAR WATER :

(i) HYGROSCOPIC WATER :-

It is the water which is adsorbed by the soil solids from the atmosphere by physical force of attraction & is held over the surface by adhesion.



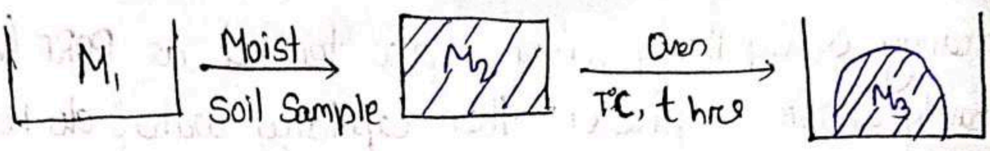
(2) FILM WATER :-

It is the water that is present as a film over the layer of hygroscopic water.

- It is held by soil solids, but also has lower adhesion than hygroscopic water.

Measurement of water content can be done by any of the following method.

(a) OVEN DRYING METHOD :-



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

- It is the most accurate method to find the water content soil.
- It is a laboratory method.
- In this method moist sample of the soil is placed in a container of mass (M_1) & is weighed (M_2).
- Moist sample along with container is placed in oven heated as per the conditions.

(a) For inorganic soil temp. is maintained at 105-110

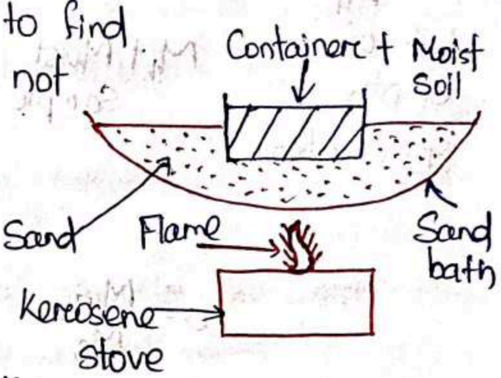
(b) For organic soil temp is obtained less than 60°c avoid oxidation of organic matter.

(c) For soil having high Gypsum content temp is less than 80°c to avoid loss of water of cry

For sand & Gravel drying is required for 4-6 hrs.
For clay & silt drying is required for 16-20 hrs.
- However it is done for 24 hrs to ensure Complete loss of water.
- In no case temp. must be increased beyond 110°C as it would lead to loss of structural water also.
- In this method all types of soil water is removed, i.e. ground, Capillary, Adsorbed, except structural water.

(b) SAND BATH METHOD:-

- It is a quick field method i.e. used to find water content when facility of oven is not available.
- In this method, moist sample of soil along with container is placed in sand bath & is heated over Kerosene stove.



- As there is no control over temp in this case it is not suitable for high organic soil & soil having high Gypsum content, moreover it gives inaccurate result due to possibility of loss of structural water.
- Steps of observation are same as that of oven drying method.

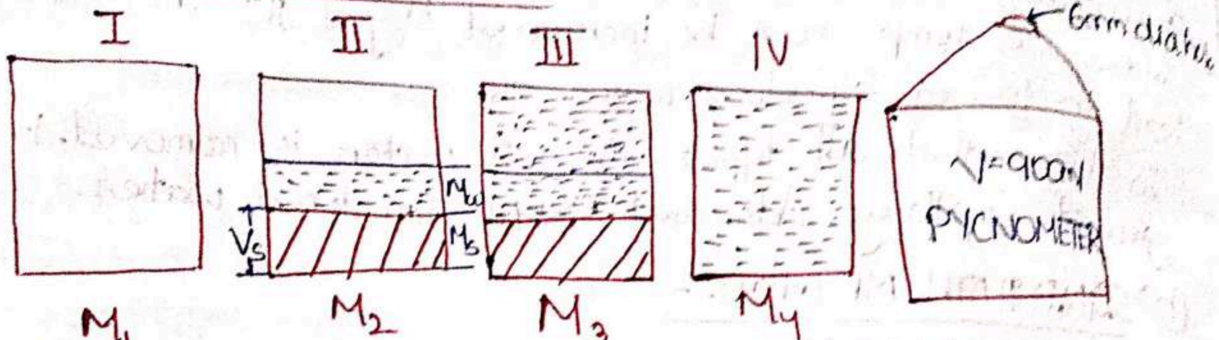
$$\omega = \frac{M_2 - M_3}{M_3 - M_1} \times 100$$

(C) ALCOHOL METHOD:-

- It is also a quick field method, in this method Alcohol i.e. Methylated Spirit is added in the sample as it increases the rate of drying & is ignited to note the water content.
- Here also there is no control over the temp.
- Hence it is not suitable for organic soil & soil having high Gypsum content.
- It also give inaccurate result due to possibility of loss of structural water.
- Series of observation is same as Oven drying Method.

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

(d) PYCNOMETER METHOD: -



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

Mass of water in soil sample $M_w = M_2 - M_1 - M_s$

$M_4 = M_3 - M_s + M_w$ (having vol same as solid)

$M_4 = M_3 - M_s + V_w \rho_w$

$M_4 = M_3 - M_s + V_s \rho_w$

$M_4 = M_3 - M_s + \frac{M_s}{G \rho_w} \rho_w$

$M_4 = M_3 - M_s \left[1 - \frac{1}{G}\right]$

$$M_s = \frac{(M_3 - M_4) G}{(G-1)}$$

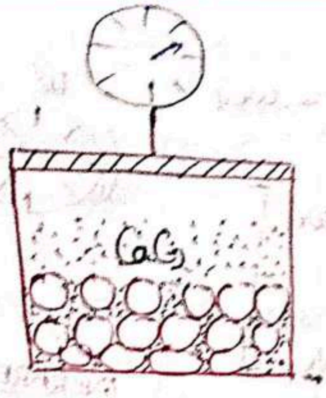
$$w = \frac{M_w}{M_s} = \frac{M_2 - M_1 - M_s}{M_s}$$

$$w = \frac{M_2 - M_1}{M_s} - 1$$

$$\boxed{w = \frac{M_2 - M_1}{M_3 - M_4}\left(\frac{G-1}{G}\right) - 1}$$

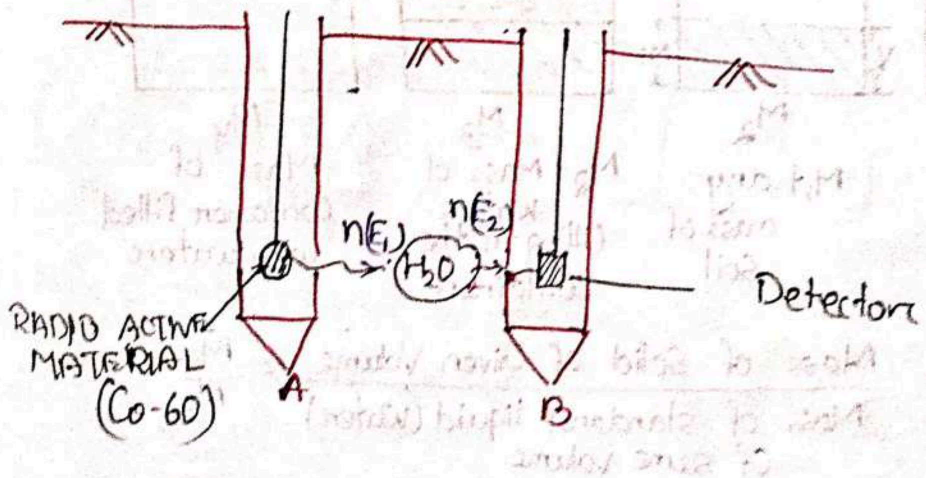
- It is a quick method which gives the result in 10-20min.
- It is suitable for those soils whose specific Gravity known.
- This is used /preferred for cohesionless soil as in case of cohesive soil it is difficult to removed the entrapped air from the soil
- Pycnometer is 900ml flask having conical top with 6mm dia hole at top to remove the air from the sample.

(e) CALCIUM CARBIDE METHOD/MOISTURE METER METHOD:-



- It is one of the quickest method available to find the water content (w') of soil in 5-7min
- It is a field method
- In this method 4-6gm (5gm) of sample is taken (fixed wt due to Calibration) which is then placed in moisture meter & is mixed with CaC_2.
- This CaC_2 reacts with water present in soil sample & releases Acetylene Gas (C_2H_2) that exerts the pressure over the gauge. It is Calibrated to give water content of soil in terms of total wt of soil (w').

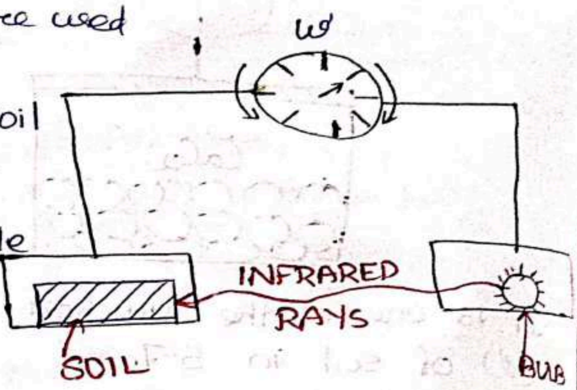
(f) RADIATION METHOD:-



... method in which 2 steel casings are lowered in the soil mass to be tested

- In first casing, a radioactive material (Co 60) is placed & in another casing detector is lowered.
- When Radioactive material is activated it emitts neutrons which strikes with the hydrogen atom of water & looses its energy i.e further detected by detector & is calibrated with the water content of soil.

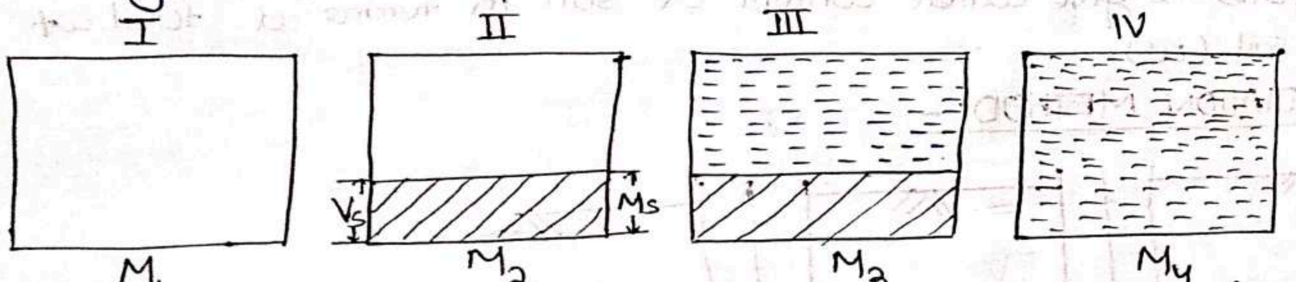
(g) TORSIONAL BALANCE METHOD:-



- In this method infrared rays are used for drying of the soil sample.
- This method is suitable for those soil which quickly absorbs the moisture from the atmosphere, as in this case drying & weighing of the soil sample is done simultaneously.
- Infrared rays are generated by 250W, 230V, 50Hz frequency bulb.
- It gives the water content in terms of wt of soil.

(ii) SPECIFIC GRAVITY (G):-

- Specific Gravity of soil can be measured by
  - (a) 50 ml density bottle
  - (b) 500 ml flask
  - (c) Pycnometer



$$G = \frac{\text{Mass of Solid of Given Volume}}{\text{Mass of standard liquid (water) of same volume}} = \frac{M_s}{M_w}$$

Mass of Solid M_s = Mass of dry soil $M_d = M_2 - M_1$

Mass of water in stage III = $M_3 - M_2$

Mass of water in stage IV = $M_4 - M_1$

Mass of water having vol. same as that of solids = Mass of Water in stage IV − Mass of water in stage-III

$$M_w = M_4 - M_1 - (M_3 - M_2)$$
$$= M_4 - M_1 - M_3 + M_2$$
$$= M_4 - M_3 + M_2 - M_1$$
$$M_w = M_4 - M_3 + M_d$$

$$G = \frac{M_s}{M_w}$$
$$= \frac{M_2 - M_1}{M_4 - M_3 + M_2 - M_1}$$

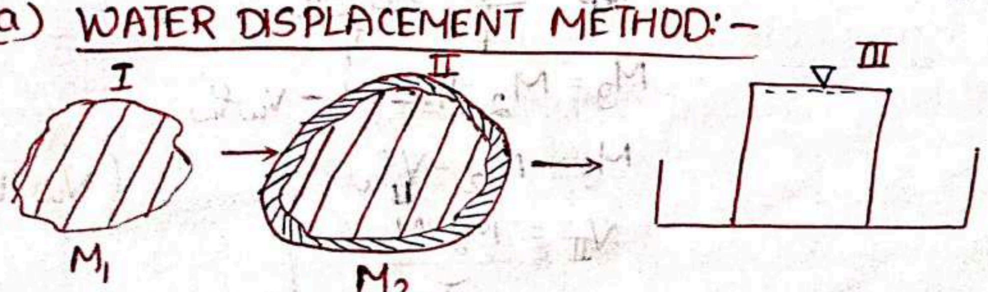
$$\boxed{G = \frac{M_d}{M_4 - M_3 + M_d} = \frac{M_2 - M_1}{M_4 - M_3 + M_2 - M_1}}$$

- Density bottle method is the most accurate amongst all & is suitable for all types of soil (but is preffered for fine grained soil)
- Flask & Pycnometer is suitable to be used for coarse grained soil & if it is used for fine grained soil then KEROSENE is used instead of water as it is better wetting reagent. (it helps effectively in removing air voids)
- In density bottle only Kerosene is used.
- Steps of observation is same for all

(III) UNIT WEIGHT :-

Unit wt of the soil can be measured by any of following method.

(a) WATER DISPLACEMENT METHOD:-



Mass of paraffin wax = $M_p = M_2 - M_1$

Volume of paraffin wax = $V_p = \frac{M_p}{\rho_p} = \frac{M_2 - M_1}{\rho_p}$ $[\rho_p = 0.9089/ml]$

Volume of water displaced V_w = Vol. of soil + Vol. of paraffin wax

$$V_\omega = V + V_p$$

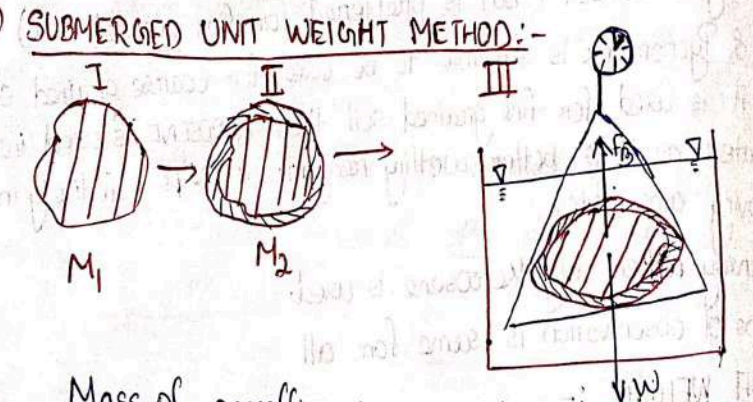
$$V = V_\omega - V_p$$

$$\rho = \frac{\text{Mass of soil}}{\text{Volume of soil}}$$

$$= \frac{M_1}{V} = \boxed{\frac{M_1}{V_\omega - \frac{(M_2 - M_1)}{\rho_p}} = \rho}$$

- This method is suitable for cohesive soil which is highly sticky in nature.
- In this method, sample of soil is trimed into more or less uniform shape & size & weighed (M_1)
- The sample is then coated with paraffin wax to prevent the entry of water into the soil (used in next stage) & is again weighed (M_2).
- The coated specimen is then immersed in container full of water that displace water from the container in equal volume (V_ω).

) SUBMERGED UNIT WEIGHT METHOD :-



Mass of paraffin wax = $M_p = M_2 - M_1$

Vol of " " $= V_p = \frac{M_p}{\rho_p} = \frac{M_2 - M_1}{\rho_p}$

$$M_3 = M_2 - F_B = M_2 - V_\omega \rho_\omega$$

$$M_3 = M_2 - V_{II} \rho_\omega \quad (V_\omega = V)$$

$$V_{II} = \frac{M_2 - M_3}{\rho_w}$$

$$V_{II} = V + V_p$$

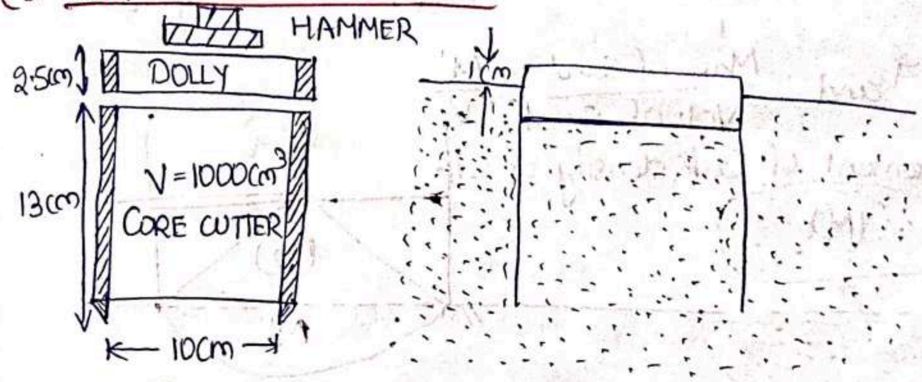
$$V = V_{II} - V_p$$

$$V = \frac{M_2 - M_3}{\rho_w} - \frac{M_2 - M_1}{\rho_p}$$

$$\rho = \frac{M_1}{V} = \frac{M_1}{\frac{M_2 - M_3}{\rho_w} - \frac{M_2 - M_1}{\rho_p}}$$

- It is suitable for cohesive soil which is sticky in nature.
- First 2 sequence of observation is same as before.
- In this method, coated specimen is immersed in water & its reduced/effective/apparent/buoyant/submerged unit wt. is noted.

(C) CORE CUTTER METHOD:-



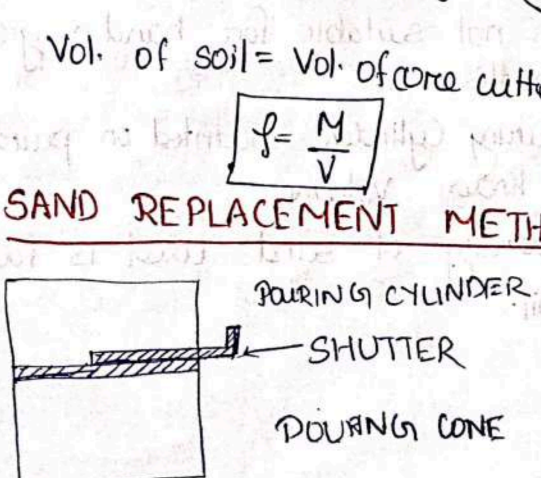
- It is a field method which is suitable to be used for cohessive soil.
- This method consist of a core cutter of volume $1000 cm^3$ [D=10cm, H=13cm] & dolly of height 2.5cm & a hammer. [wt = 9kg]
- In this test, core cutter is drilled in the soil mass, which is to be tested & cutter with the soil is taken out to note the mass of the soil in it.

The density of the soil is given by: $\rho = \frac{\text{Mass of Soil (M)}}{\text{Vol. of Soil (V)}}$

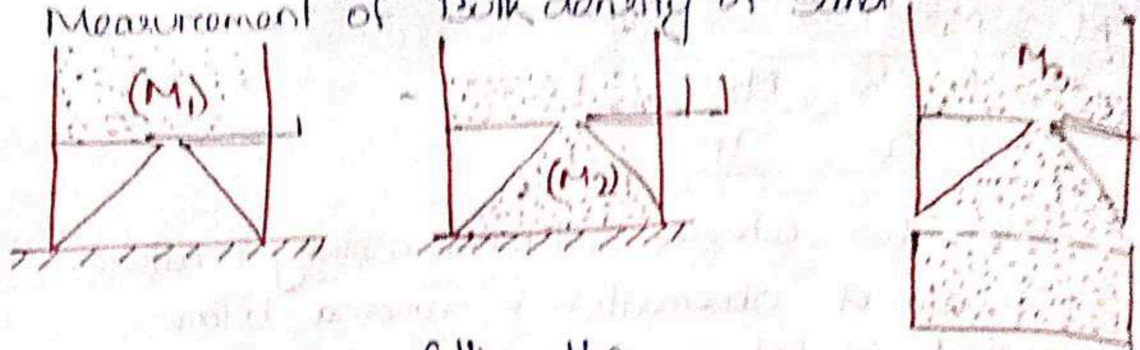
Vol. of soil = Vol. of core cutter (V)

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

(d) SAND REPLACEMENT METHOD:-



(a) Measurement of Bulk density of sand

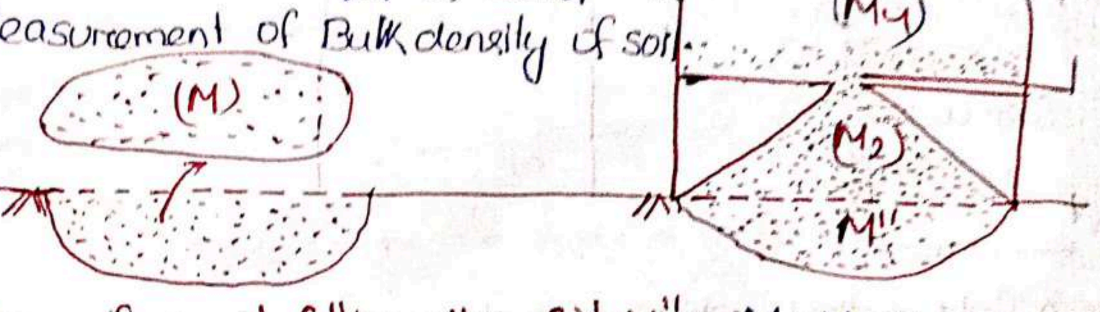


Mass of sand filling the calibrating cylinder $M' = M_1 - M_2 - M_3$

Vol. of sand filling the calibrating cylinder (V) = Vol. of calibrating cylinder

$$\rho_{sand} = \frac{\text{Mass of Sand}}{\text{Vol. of Sand}} = \frac{M'}{V}$$

(B) Measurement of Bulk density of soil



Mass of sand filling the pit $M'' = M_1 - M_2 - M_4$

Vol. of sand ~~filling~~ in the pit = $\dfrac{\text{Mass of sand in pit}}{\rho_{sand}} = \dfrac{M''}{\rho_{sand}} = \dfrac{M_1 - M_2 - M_4}{\rho_{sand}}$

Vol. of soil excavated from pit = Vol. of sand in pit = V

Hence $\rho_{soil} = \dfrac{\text{Mass of soil}}{\text{Volume of soil}} = \boxed{\dfrac{M}{V} = \rho_{soil}}$

- Since core cutter method is not suitable for hard & gravely soil, this method is used in this case.
- This method consists of pouring cylinder mounted on pouring cone & a calibrating cylinder of known volume.
- In this test, first bulk density of sand used is found followed by unit weight of soil.

(i) Bulk density of sand -

~~Sand~~ :

NOTE :- In both core cutter & sand replacement method, the sample of the soil is further tested for its water content.

(IV) PARTICLE SIZE DISTRIBUTION :-

- The % of various size of particles in a given dry soil sample is determined by the particle size distribution analysis, which is carried out in two stages

(a) SIEVE ANALYSIS
(b) Sedimention Analysis

Particle Size Analysis

- Sieve Analysis (For Coarse Graind Soil) $d \geq 75\mu$
  - Coarse Sieving (Gravel) $d = 4.75 - 80mm$
  - Fine Sieving (Sand) $d : 75\mu - 4.75mm$
- Sedimentation Analysis (For fine grained soil) $d < 75\mu$
  - Pipette Method
  - Hydrometer M.

(a) SIEVE ANALYSIS :-

- It is done for soil fraction having size greater than or equal to 0.075mm or 75μ.
- As per IS 460:1962, sieves are designated by the size of the square opening in mm or micron(μ).
- In this method, different sieves are placed one over another in decreasing order of their size & the dry sample of soil is to be tested is placed over top most sieve.
- Sieving is then done for atleast 10 min either manually or mechanically (in sieve shaker).
- Weight of the soil fraction retained over each sieve is then noted, to compute " % FINNER" (N) corresponding to given size of particle.

% FINNER (N) = 100 - cummulative % wt retained

- Sieve analysis is carried out in following 2 stages

(i) COARSE / GRAVEL SIEVING :-

- It is done for soil fraction having size in b/w (4.75mm - 80mm) [Gravel Fraction]
- Standard size of sieve used in this case includes 80mm, 40mm, 20mm, 10mm, 4.75 mm.

(ii) FINE / SAND SIEVING :-

- It is done for soil fraction having size in between (4.75mm - 75μ)
- Standard size of sieve used in this case includes 2mm, 1mm, 600μ, 425μ, 212μ, 150μ, 75μ.
- It is generally preferred to wash the soil fraction passing through 4.75mm sieve before carrying out fine sieving in order to remove silt & clay particle present over sand particles (thereby it is also termed as Wet sieving).

(b) SEDIMENTATION ANALYSIS :-

- It is done for those soil particles which passes through 75μ sieve.
- Particle having size smaller the 0.2μ cannot be analysed even by sedimentation analysis, as they undergo brownian motion.
- For them special technique like X-ray diffraction or electro microscopic is used.

- Sedimentation analysis is based on "STOKE's LAW" according to settling velocity of spherical particles undergoing discrete settling in an infinite medium / keeping all the factors to be constant depends upon shape, size & mass of the particles & is given by

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

G = Specific Gravity of Particle
γ_w = Unit wt of water
d = size of particle
μ = Viscocity of water

Q. At 20°C, μ = 0.01 poise. G = 2.65

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

$$= \frac{(2.65-1)\times 9810\times (d\times 10^{-3})^2}{18\times 0.01\times 0.1}$$

$$= 0.9 d^2 \ (m/s) \quad \because d \text{ in mm}$$

Q. At 27°C, μ = 0.00855 poise. G = 2.65 V_s = ?

Ans-

$$V_s = \frac{(2.65-1)\times 9810\times (d\times 10^{-3})^2}{18\times 0.00855\times 0.1}$$

$$= 1.05 d^2 \ (m/sec)$$

- Limitation of Stoke's Law:-

(a) Particle undergoing settlement is assumed to be Spherical but in actual fine grained soil particle are flaky.

(b) Medium in which settlement takesplace is assumed to be infinite but in actual sedimentation jar is of finite size.

(c) During settlement, discrete settlement is considered but in actual fine grained particle being sticky in nature combines with each other & undergo flocculent setteling.

(d) Stokes law is valid for the particle having size in range of 0.1mm - 0.2μ, as above 0.1mm gravity acceleration sets in & below 0.2μ particle undergo Brownian motion.

* General Procedure for Sedimentation Analysis:-

Sedimentation analysis can be carried out by following method:-

(a) PIPETTE METHOD (b) HYDROMETER METHOD

- Method of preparation of soil suspension is same for the method & is as follows

(1) PRE-TREATMENT:-

Before preparing soil suspension, Organic Matter (OM) & Calcium compounds present in the soil sample is removed to avoid agglomeration (combine) of soil particles.

- To remove OM, oxidizing reagents like H_2O_2 is added.
- To Calcium compounds 0.2N HCl acid is added.

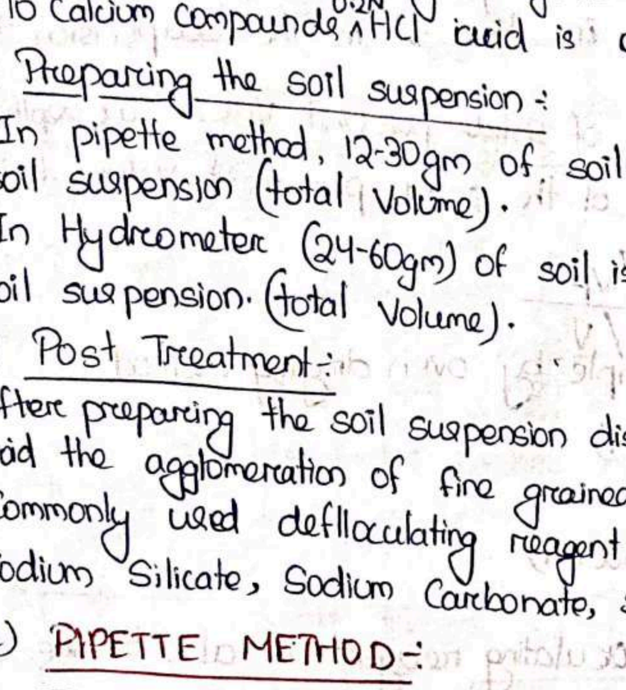
(2) Preparing the soil suspension:-

- In pipette method, 12-30gm of soil is added to make 500ml of soil suspension (total volume).
- In Hydrometer (24-60gm) of soil is added to make 1000ml of soil suspension. (total volume).

(3) Post Treatment:-

- After preparing the soil suspension dispersing/deflocculating reagent is added to avoid the agglomeration of fine grained soil
- Commonly used deflocculating reagent is Sodium Hexametaphosphate, Sodium Silicate, Sodium Carbonate, Sodium Oxilate etc.

(a) PIPETTE METHOD:-



(a) PIPETTE METHOD:-

In this method 10ml of sample is collected from soil suspension at fixed sampling depth (H_e) of 10cm. at different time intervals.

NOTE

Time interval considere is $\frac{1}{2}$, 1, 2, 4, 8, 15, 30 min, 1, 2, 4, 8, 16, 24 hr.

- The sample collected is further being tested for the mass of Solids ($M_s = M_d$) by oven drying method.

Size of particles that settled in soil suspension by sampling depth of "He" in time "t" is computed using "Stokes Law."

$$V_s = \frac{(G-1)\gamma_w d^2}{18\mu} = \frac{H_e}{t}$$

$$d = \sqrt{\frac{18\mu}{(G-1)\gamma_w} \times \frac{H_e}{t}}$$

$$d = K\sqrt{\frac{H_e}{t}} \quad \text{—(1)} \qquad K = \sqrt{\frac{18\mu}{(G-1)\gamma_w}}$$

- % finner corresponding to computed size of particles which settle by distance "He" in time "t" in the suspension is given by.

$$\%N = \frac{\text{Mass of Solids per Unit Volume at depth He}}{\text{Mass of the solids per unit volume Initially}}$$

$$= \frac{M_d/V_p}{M_D/V}$$

M_d = Mass of solids in sample by oven drying method

V_p = Volume of pipette (10ml)

M_D = 12-30gm

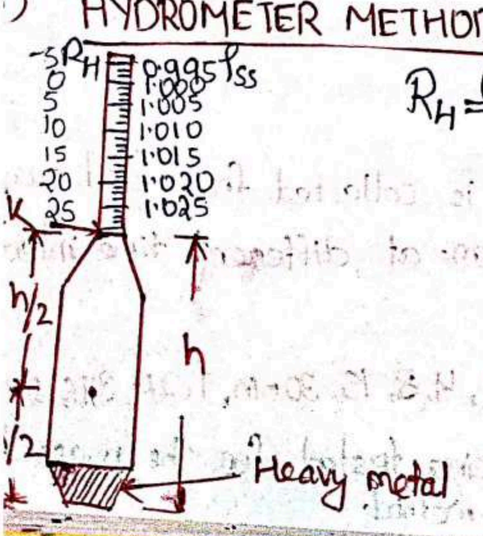
V = Vol. of Suspension (500ml)

If the effect of defllocculating reagent is also to be considered then

$$\%N = \frac{\frac{M_d}{V_p} - \frac{M}{V}}{M_D/V} \times 100 \quad \text{—(iii)}$$

M = Mass of defllaculating reagent.

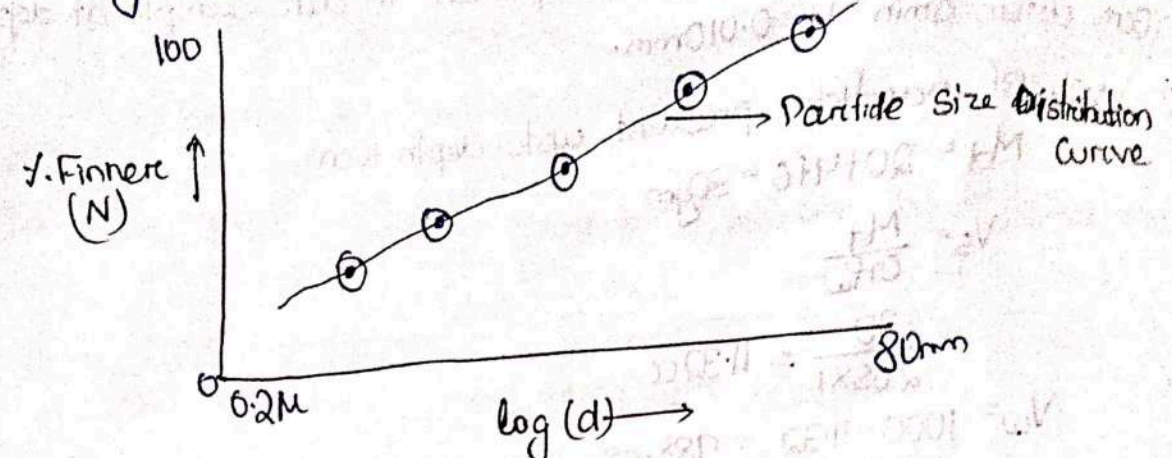
) HYDROMETER METHOD:-



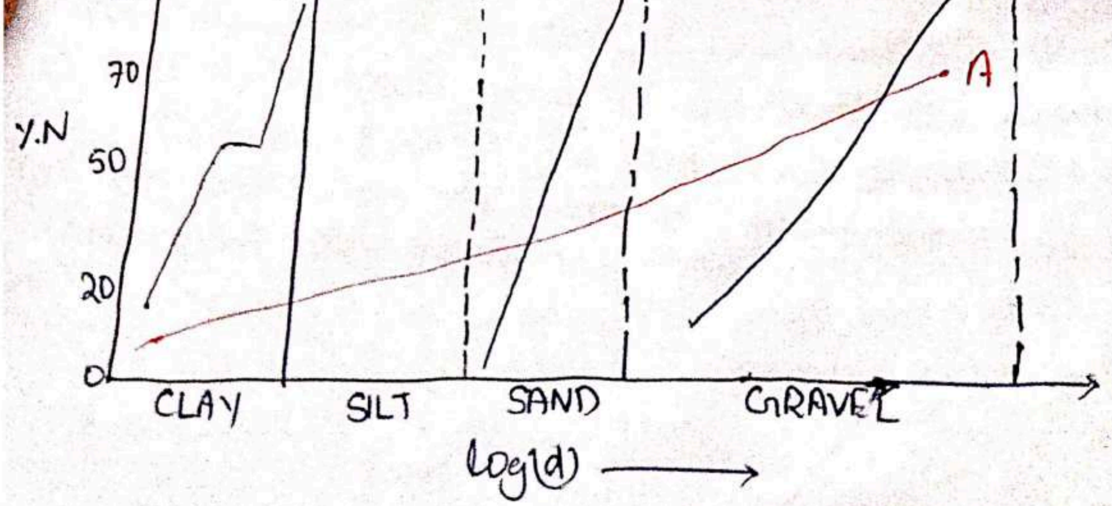
$$R_H = (\rho_{ss} - 1)\,1000 \qquad ss = \text{Soil suspension}$$

PARTICLE SIZE DISTRIBUTION CURVE :-

- The result of the particle size distribution analysis is reported in the form of a curve termed as particle size distribution curve in which % finner is expressed on Y-axis on arithmatic scale & corresponding size of particle is reported on X-axis on log scale.



- These curves helps in analysis the type of soil & its gradation.
- The soil may be termed as "WELL GRADED SOIL" if it has good [struck out]
- This curve helps in analysis the type of soil & its gradation.
- The soil may be termed as "WELL GRADED SOIL", if it has good representation of almost all size of particles
- If soil consists of excess of one size of particles & deficiency of another size particles or it consists of all particles of almost same size it is termed as "POORLY GRADED SOIL" & in later case it is termed as "UNIFORMLY GRADED SOIL"
- If certain size of particles are missing from soil, it is termed as "GAP GRADED / FLAT GRADED SOIL".



SOIL TYPE	GRADATION	TYPE OF SOIL
A	Well Graded Soil	÷
B	Gap graded soil	Fine grained soil
C	Well Graded soil	Coarse grained soil
D	Poorly graded soil	Coarse grained soil

For Coarse grained soil D_{10}, D_{30} & D_{60} size of particles holds higher than other size of particles as they help in analysing the gradation of coarse grained soil.

D_{10} = Size in mm, such that 10% of the particle are finner than this size.

D_{30} = Size in mm, such that 30% of the particle are finner than this size.

D_{60} = Size in mm, such that 60% of the particle are finner than this size.

These size (D_{10}, D_{30}, D_{60}) is found from particle size distribution curve only.

NOTE

D_{10} is also termed as "EFFECTIVE SIZE/ EFFECTIVE DIAMETER/ HAZEN" (named after Allen Hazen) size as it represent average size of particles in sample.

- Gradation of coarse grained soil expressed in terms of following parameters.

(A) COEFFICIENT OF UNIFORMITY (C_u):-

- It signifies the range of particle size distribution curve.
- Higher is the value of C_u, higher is the range of particle size hence better is the gradation.
- It is defined as ratio of D_{60} & D_{10}.

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

- For well graded sand, $C_u > 6$
- For well graded Gravel, $C_u > 4$

COEFFICIENT OF CURVATURE : (C_c)

It signifies the shape of the particle size distribution curve.

- It is defined as

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

Fore well graded soil $1 \le C_c \le 3$

Fore gap graded soil $C_c < 1$, $C_c > 3$