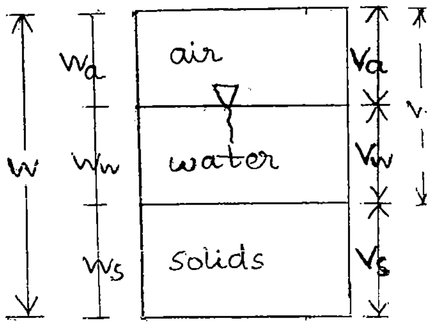
2. DEFINITIONS & PROPERTIES OF SOIL

* Partially saturated soil : Solids + water + air (3 phase syste
  Fully saturated soil : Solids + water. (2 phase system)
  Dry soil : Solids + air
* Frozen soil : Solids + water + ice + air. (4 phase system)



Phase Diagram
OR
Block Diagram

$V_s \rightarrow$ volume of solids.

$V \rightarrow$ volume of soil.

$V_v \rightarrow$ volume of voids.

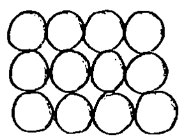
$$V_v = V_w + V_a.$$

$$V = V_s + V_w + V_a.$$

* Void Ratio, e

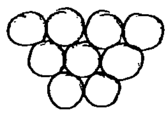
$$e = \frac{V_v}{V_s}$$

Range :- more than zero, it can have any value (no limit)
- For coarse grained soil, $e < 1$ generally.
- For fine grained soil, $e > 1$ generally
- The 'e' of FG soil is generally more than th of a coarse grained soil.



Cubical array
(loosest state)

$e_{max} = 0.91$



Diagonal array
(densest state)

$e_{max} = 0.35$

* Specific Gravity of Soil Solids, G

$$G = \frac{\gamma_s}{\gamma_w}$$; $\gamma_w \rightarrow$ distilled water (pure water).

Also called 'True Specific gravity of Soil'

For soils, G : 2.60 — 2.85 generally.
(inorganic).

* Mass Specific Gravity of Soil. (or) Bulk Sp. Gr. of soil (or) Apparent Specific Gravity of soil, G_m.

For a dry soil, $G_m = \frac{\gamma_d}{\gamma_w}$

For a partially saturated soil, $G_m = \frac{\gamma}{\gamma_w}$

For a fully saturated soil, $G_m = \frac{\gamma_{sat}}{\gamma_w}$.

$$\boxed{G_m < G}$$

For cement :-

True sp. gravity, G = 3.15

Apparent sp. gravity, $G_m = 1.44$

For cement, $\gamma_s = 3150 \ kgf/m^3$

$\gamma_d = 1440 \ kgf/m^3$

$n \approx 44\%$

Important Relationships:

1. $e = \frac{wG}{S_r}$

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

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

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

5. $\gamma_d = \frac{\gamma}{1+w}$

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

7. $\gamma = \gamma_d + S_r(\gamma_{sat} - \gamma_d)$

* Saturated unit weight of Soil, γ_{sat}.

It is the bulk unit weight of soil in a saturated condition. $\Rightarrow \gamma_{sat} > \gamma$

For partially saturated soil, ~~γ_{sat}~~ use γ

For fully saturated soil, use γ_{sat}.

* Dry unit weight of Soil, γ_d.

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

It can be used irrespective of saturation level of soil.

* Unit weight of Solids, γ_s

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

* Submerged Unit Weight of Soil, γ_{sub} or γ'

It is the submerged wt. of soil per unit volume of soil.

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

{ γ_{sat} ↓ - gravity force ; γ_w ↑ - buoyant force. }

7th Aug, MONDAY

Submerged weight of Soil is based on <u>Archimedes Principle</u>.

γ_w = unit weight of water
= 1 g/cc = 1 ton/m³ = 1000 kgf/m³.
= 9.81 kN/m³ ≈ 10 kN/m³.

$$\boxed{\gamma_s > \gamma_{sat} > \gamma_{bulk} > \gamma_{dry} > \gamma'}$$

For a given soil, γ_s remains a constant

* Porosity, n (also called 'Percentage voids')

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

Range: $0 < n < 100\%$ ($V_v \neq 0$ for soil, $\therefore n \neq 0$).

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

* Degree of Saturation, S_r

$$S_r = \frac{V_w}{V_v} \times 100.$$

For a dry soil, $S_r = \frac{0}{V_v} \times 100 = 0$ $(V_w = 0)$

For a saturated soil, $S_r = \frac{V_v}{V_v} \times 100 = 100$ $(V_w = V_v)$

Range: $0 \leq S_r \leq 100\ \%$

* Air content, a_c

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

For a saturated soil, $a_c = \frac{0}{V_v} = 0$ $(V_a = 0)$.

For a dry soil, $a_c = \frac{V_v}{V_v} = 1.$ $(V_a = V_v)$.

Range: $0 \leq a_c \leq 1$

* % air voids, n_a

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

For a saturated soil, $(V_a = 0)$, $n_a = 0$

For a dry soil, $n_a = n$ $(V_a = V_v)$.

Range: $0 \leq n_a \leq n$.

$$a_c + S_r = \frac{V_a}{V_v} + \frac{V_w}{V_v}.$$

$$= \frac{V_a + V_w}{V_v} = \frac{V_v}{V_v} = 1.$$

$$\therefore \boxed{a_c + S_r = 1}$$

$$n\,a_c = \frac{V_v}{V} \times \frac{V_a}{V_v} = \frac{V_a}{V} = n_a.$$

$$\boxed{n.a_c = n_a}$$

$W_s \longrightarrow$ weight of solids.

$W \longrightarrow$ weight of soil.

$W = W_s + W_w$ (W_a is negligible)

$W_d \longrightarrow$ total weight of soil in dry condition. $(= W_s)$.

* Water Content, w

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

For dry soil, $w = \frac{0}{W_s} \times 100 = 0$

For a saturated soil, $w > 0$.

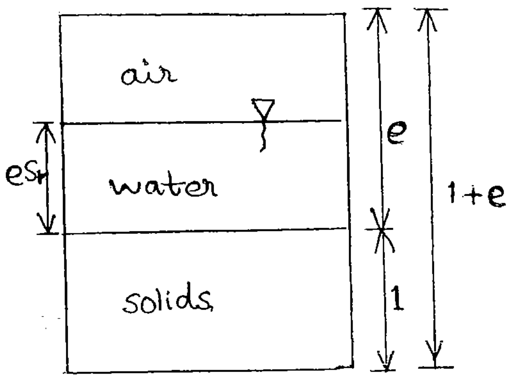
(i.e, water content can have any value greater than zero sometimes > 100 %, sometimes < 100%)

* Bulk unit weight of Soil, γ

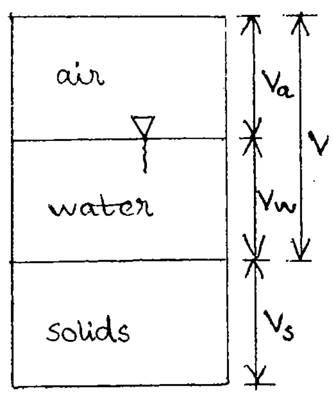
- it is the total weight of soil per unit volume of soil.

$$\gamma = \frac{W}{V}.$$

In a unit phase diagram, lets take $V_s = 1$



Unit Phase diagram.



Phase Diagram

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

If $V_s = 1$, then

$$e = V_v.$$

$$S_r = \frac{V_w}{V_v} \Rightarrow V_w = V_v \cdot S_r$$
$$= e.S_r$$

- To derive n & e relationship:

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

- To derive $e = \frac{\omega G}{S_r}$

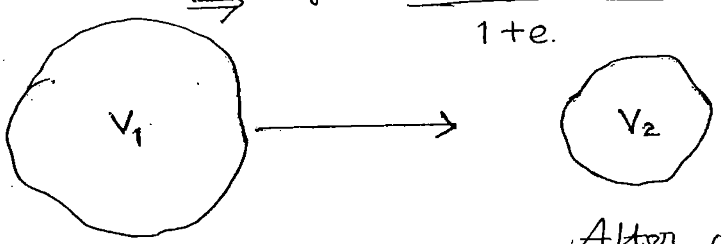
$$\omega = \frac{W_w}{W_s} = \frac{V_w \gamma_w}{V_s . \gamma_s} = \frac{eS_r}{1 . G}$$

$$\Rightarrow e = \frac{wG}{S_r}$$

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

$$\gamma = \frac{W_s + W_w}{V} = \frac{\gamma_s W_s + \gamma_w V_w}{V.}$$
$$= \frac{\gamma_s + \gamma_w e.S_r}{1+e.}$$

$$\Rightarrow \gamma = \frac{\gamma_w (G + eS_r)}{1+e.}$$



Before compaction

e_1, γ_{d1}, W_s

After compaction

e_2, γ_{d2}, W_s

$$\boxed{\frac{V_2}{V_1} = \frac{1+e_2}{1+e_1}} \qquad \because \; V \propto (1+e)$$

$$\gamma_d = \frac{W_s}{V} \Rightarrow \gamma_d \propto \frac{1}{V}$$

$$\boxed{\frac{V_2}{V_2} = \frac{\gamma_{d1}}{\gamma_{d2}}}$$

Q. Due to compaction, the void ratio of a soil reduced from 1 to 0.6. What is the % volume loss.

$$\frac{V_2}{V_1} = \frac{1+0.6}{1+1} = \frac{1.6}{2.}$$

$$V_2 = 0.8\, V_1$$

∴ vol. reduced <u>to</u> 80%.

vol. reduced <u>by</u> 20% ⇒ volume loss is 20%.

* To Find Water Content of Soil :

a) Oven drying Method. → most accurate method.

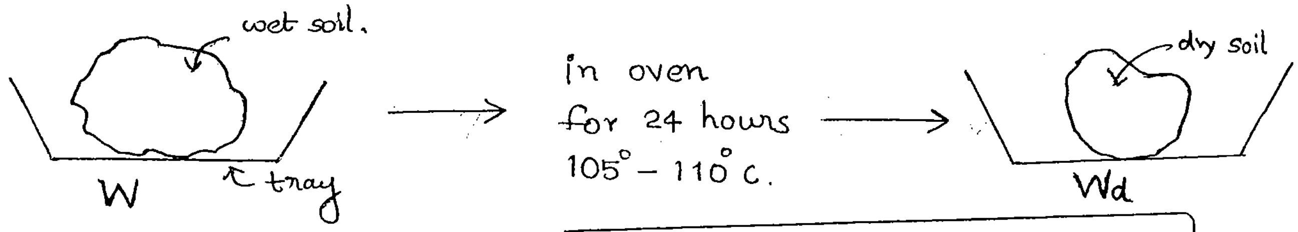
b) Pycnometer Method → can be used only if 'G' is known.

c) Sand bath method → quick field method. (approx. value).

d) Calcium Carbide method → quick method.

e) Torsion balance method → to find w.c at different depths below G.L

a) Oven Drying method :

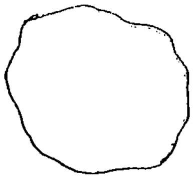


w → wt. of wet soil

Wd = wt. of dry soil = Ws

$$\boxed{w = \frac{W_w}{W_s} \times 100 = \frac{W - W_d}{W_d} \times 100}$$

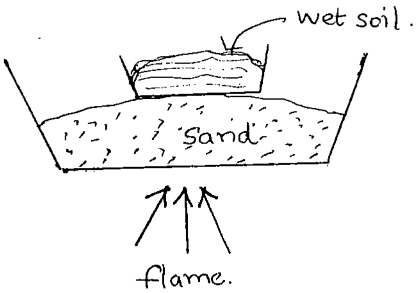
b) Calcium Carbide method.



\+ calcium carbide (CaC_2) ⟶ acetylene gas ↑

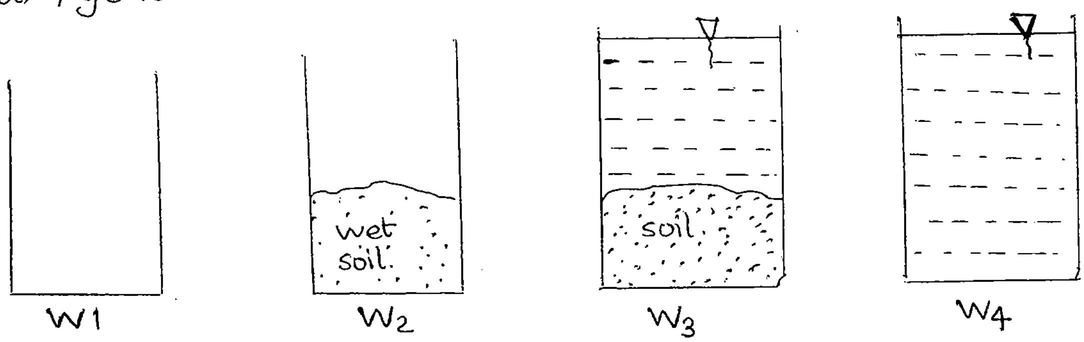
Amount of acetylene gas produced is directly proportional to water content of soil.

c) Sand Bath method.



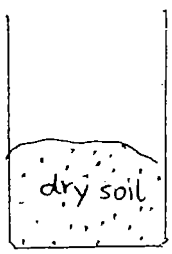
It's a crude method used in the field.

d) Pycnometer Method



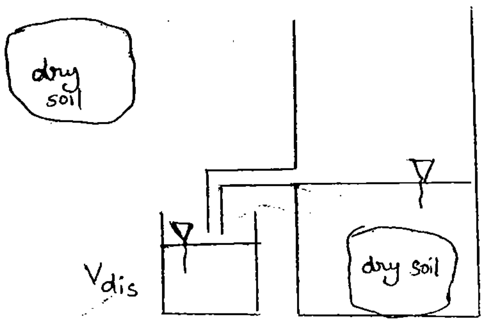
$$\text{Water content, } \omega = \left[\frac{W_2 - W_1}{W_3 - W_4}\left(\frac{G-1}{G}\right) - 1\right] \times 100$$

⊙ To find Specific Gravity, G, replace second container with dry soil



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

⊙ To find volume:



V_{dis} → volume of water displaced.

⊙ If dry soil is immersed, then
$V_{dis} = V_s$ (vol. of solids).

⊙ If partially saturated soil is immersed,
$V_{dis} = V_s + V_w$

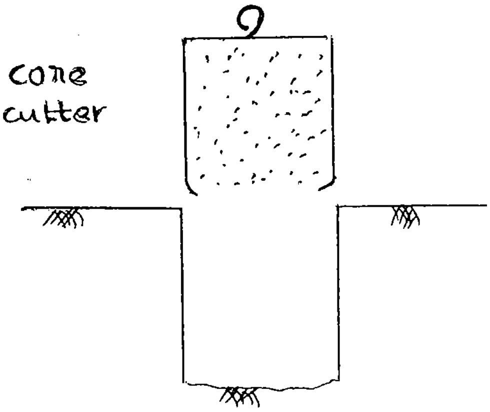
⊙ Partially saturated soil with wax coating, then

V_{dis} = total volume of soil = V + vol. of wa

* To determine in-situ γ_d and e

(i) Core Cutter Method → suitable for clays only (cohesive).

(ii) Sand Replacement method → suitable for any soil



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

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

12th Aug,
TUESDAY

P-8.

1. $V_a = \frac{V}{6}$, $V_w = \frac{V}{3}$

$V_a + V_w = V_v$

$\therefore V_v = \frac{V}{6} + \frac{V}{3} = \frac{V}{2}$

$V_s = V - V_v = \frac{V}{2}$

$\therefore e = \frac{V_v}{V_s} = \frac{0.5V}{0.5V} = \underline{\underline{1}}$

2. $\gamma_1 = 1.8$ g/cc. at $w_1 = 5\%$

$\gamma_2 = ?$ at $w_2 = 10\%$

'e' remains constant.

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

$\therefore \gamma \propto (1+w)$ (e is constant).

$$\frac{1.8}{\gamma_2} = \frac{1.05}{1.1}$$

$\underline{\underline{\gamma_2 = 1.886}}$ g/cc

4. Volume of soil = vol. of sampler.

$V = 45$ cc.

Given $V_s = 25$ cc.

$$e = \frac{V - V_s}{V_s} = \frac{20}{25} = \underline{\underline{0.8}}$$

5. Initial wt. of soil = 0.18 kg.

Water added = 0.02.

∴ Total weight, $w = 0.2$ kg.

Vol. of soil, $V = 10^{-4}\ m^3$. (initial volume assumed to be constant)

$$\gamma = \frac{w}{V} = \frac{0.2}{10^{-4}} = 2000\ kg/m^3$$

$\gamma_d = 1600\ kg/m^3$.

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

$$1600 = \frac{2000}{1+w}$$

$w = 0.25 = \underline{\underline{25\%}}$ (method is valid only if V remains const. after adding water)

(OR)

Initial weight, $w = 0.18$ kg, $V = 10^{-4}\ m^3$, $\gamma_d = 1600\ kg/m^3$

$$\gamma_d = \frac{W_s}{V}.$$

$W = W_s + W_w$

∴ $W_w = 0.02$ kg. (water present ini

$$1600 = \frac{W_s}{10^{-4}} \Rightarrow W_s = 0.16\ kg.$$

Water added additionally, = 0.02 kg.

$W_w = 0.02 + 0.02 = 0.04$ kg.

Final water content $= \frac{0.04}{0.16} \times 100 = \underline{\underline{25\%}}$

6. $W = 34.62$ g, $V = 24.66\ cm^3$, $W_d = W_s = 20.36$ g

$G = 2.68$, $e = ?$ $S_r = ?$

$$w = \frac{W - W_d}{W_d} \times 100 = 70\%$$

$$e = \frac{wG}{S_r} = \frac{0.7 \times 2.68}{S_r} \longrightarrow (1)$$

$$\gamma = \frac{W}{V} = \frac{34.62}{24.66} = 1.40 \text{ g/cc.}$$

$$\gamma = \gamma_w \left(\frac{G + eS_r}{1+e} \right) \Rightarrow 1.4 = \frac{1\,(2.68 + 0.7 \times 2.68)}{1+e}.$$

$$\therefore \; e = 2.25$$

$$S_r = \frac{0.7 \times 2.68}{2.25} = \underline{\underline{83.4\%}}$$

OR

$$\gamma_d = \frac{W_d}{V} = \frac{20.36}{24.66} = 0.825 \text{ g/cc}$$

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

$$e = \underline{\underline{2.25}}$$

819. $w = 18\%$, $\gamma = 2.05$ g/cc., $G = 2.67$.

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

$$\frac{2.67 \times 1}{1+e} = \frac{2.05}{1.18}$$

$$\underline{\underline{e = 0.54}}$$

$$e = \frac{wG}{S_r} \Rightarrow S_r = \frac{0.18 \times 2.67}{0.54} = \underline{\underline{89.52\%}}$$

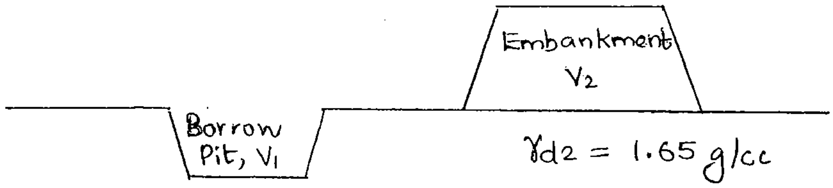
8. $w = 39.3\%$, $G_m = \frac{\gamma_{sat}}{\gamma_w} = 1.84$ (Soil is saturated).

$$e = \frac{wG}{S_r} = 0.393\,G$$

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

$$1.84 = \frac{G + 0.393\,G}{1 + 0.393\,G} \Rightarrow G = 2.70 \;,\; e = 0.393\,G = \underline{\underline{1.08}}$$

10.



$\gamma_1 = 1.75$ g/cc
$w_1 = 12\%$
$V_1 = ?$

$\gamma_{d2} = 1.65$ g/cc
$w_2 = 18\%$
$V_2 = 1000\ m^3$.

$\gamma_{d1} = \frac{\gamma_1}{1+w_1} = \frac{1.75}{1+0.12}$

$= 1.57$

$\frac{V_1}{V_2} = \frac{\gamma_{d2}}{\gamma_{d1}}$

→ 1 g/cc = 1 ton/m

$V_1 = \frac{1.65}{1.57} \times 1000 = 1056\ m^3$

To raise w.c from $w_1 \rightarrow w_2$:

Weight of water to be added $= \gamma_d V (w_2 - w_1)$

$= 1.65 \times 1000 \times 1000 (0.18 - 0.12)$.
g/cc

$= 99000$ kg $= 99$ tons

$\gamma_{borrow} = 1.66$
$w_b = 8$
$V_b = ?$
$\gamma_{d1} = 1.54$

$\gamma_{truck} = 1.15$
$w_t = 6$.
$V_t = ?$
$\gamma_{d2} = 1.08$

$\gamma_{fill} = 1.82$
$w_f = 14$.
$V_f = 100\ m^3$
$\gamma_{d3} = 1.25$.

$\frac{V_2}{V_3} = \frac{\gamma_{d3}}{\gamma_{d2}}$.

$V_2 = \frac{1.25}{1.08} \times 100 = 147\ m^3$.

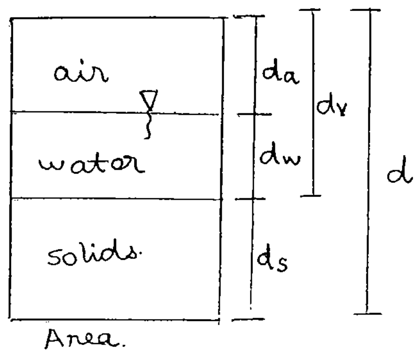
No: of truck loads $= \frac{147}{6} = 24.6$ no.s $= 25$ no.s

13. If $d_w = 1$ m, $d = ?$

Given: $e = 0.5$, $S_r = 80\%$

$S_r = \frac{d_w}{d_v}$

$d_v = \frac{1}{0.8} = 1.25$m



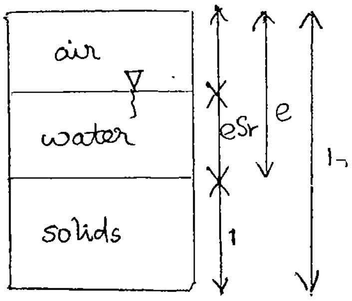
depth of voids, $d_v = 1.25$ m.

$$e = \frac{d_v}{d_s} \Rightarrow d_s = \frac{1.25}{0.5} = \underline{\underline{2.5 \text{ m}}}$$

Total depth of soil, $d = d_s + d_v = \underline{\underline{3.75 \text{ m}}}$

(OR) based on Unit Phase Diagram.

Given, depth of water = 1 m



$$e.S_r = 0.5 \times 0.8 = 0.4 \text{ m.}$$

$$1 + e = 1 + 0.5 = 1.5 \text{ m.}$$

0.4 m depth of water makes 1.5 m depth of soil 80% saturated.

$$\text{Depth of soil} = \frac{1.5}{0.4} \times 1 = \underline{\underline{3.75 \text{ m}}}$$

14. $n = 40\%$, $G = 2.5$, $\omega = 12\%$

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

$$e = \frac{n}{1-n} = \frac{0.4}{1-0.4} = 0.666.$$

$$e = \frac{\omega G}{S_r} = \omega G \text{ (at full saturation).}$$

$$\omega = \frac{2}{3 \times 2.5} = 26.6\%$$

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

Take $\gamma_w = 1$ ton/m³. $\Rightarrow \gamma_d = 1.5$ t/m³.

Weight of water to be added to achieve full saturation

$$= 1.5 \times 100 \left(\frac{26.6 - 12}{100}\right)$$

$$= \underline{\underline{21.9}} \text{ tons.}$$

16. Let e_2 be void ratio at increased volume of soil

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

$$\frac{1.05 V_1}{V_1} = \frac{1+e_2}{1+0.667} \Rightarrow e_2 = \underline{\underline{0.75}}$$

Let w_3 be water content at increased volume,

$$e_2 = \frac{w_3 G}{S_r}$$

$$0.75 = \frac{w_3 \times 2.5}{S_r = 1}$$

$$\Rightarrow w_3 = \underline{\underline{30\%}}$$

17. $W_d = W_s = 135$ g.

Wet weight, $W = 195$ g.

Total vol. of soil ~~solid~~, $V = 5^3 = 125$ cm³.

$$w = \frac{W - W_d}{W_d} \times 100 = \frac{60}{135} \times 100 = \underline{\underline{44.44\%}}$$

$$e = \frac{wG}{S_r} \Rightarrow e = 0.44G$$

$$\gamma_{sat} = \frac{W}{V} = \frac{195}{125} = 1.56 \text{ g/cc.}$$

$$\gamma_{sat} = \gamma_w \left(\frac{G+e}{1+e}\right) \Rightarrow 1.56 = 1\left(\frac{G + 0.44G}{1 + 0.44G}\right)$$

$$= 2.07.$$

$$e = 0.44G = \underline{\underline{0.92}}$$

(OR)

$V = 125$ cm³.

Wt. of water added $= 195 - 135 = 60$ g

$\therefore$ Vol. of water $= \frac{W_w}{\gamma_w} = \frac{60}{1} = \underline{\underline{60 \text{ cc}}}$

Vol. of voids = vol. of water added

$\Rightarrow V_v = 60$ cc. $\quad \therefore V_s = 125 - 60 = 65$ cm³.

$$e = \frac{V_v}{V_s} = 0.92.$$

$$\gamma_s = \frac{W_s}{V_s} = \frac{135}{65} = 2.07 \text{ g/cc} \Rightarrow G = \frac{\gamma_s}{\gamma_w} = \frac{2.07}{1} = \underline{\underline{2.07}}$$

Q. 100 g of dry soil having G = 2.7 is mixed with water and 1 L of soil slurry is prepared. What is the unit weight of soil slurry in g/cc.

$$G = \frac{\gamma_s}{\gamma_w} \Rightarrow \gamma_s = 2.7 \text{ g/cc}$$

$$\gamma_s = \frac{W_s}{V_s} \quad \therefore V_s = \frac{W_s}{\gamma_s} = \frac{100}{2.7} = 37.037 \text{ cc}$$

$V = 1 \text{ L} = 1000 \text{ cm}^3$ $\Rightarrow V_w = V - V_s = 1000 - 37.037 = 962.963$

$$\gamma_{sat} = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{100 + V_w \times \gamma_w}{V}$$

$$= \frac{100 + 962.963 \times 1}{1000} = \underline{\underline{1.063}} \text{ g/cc}$$

16th Aug, SATURDAY

Q A marine soil has sp. gr. of solids as 2.7 and void ratio as 0.8. If sp. gr. of sea water is 1.063, calculate γ_{sat} of the soil. Take γ_w of fresh water as 9.81 kN/m³.

$G = 2.7$

$\Rightarrow$ ~~γ_{sat}~~ $\gamma_s = 2.7$ g/cc.

$e = 0.8$.

$$\gamma_{sat} = \frac{\gamma_w (G+e)}{1+e} \times = 19.64 \text{ kN/m}^3$$ (valid only if pure ~~sea~~ water is used!)

$$G = \frac{\gamma_s}{\gamma_w} \rightarrow \text{pure water}$$

$\gamma_{sea} = 1.03 \times 9.81 = 10.1043$ g/cc

$$\gamma_{sat} = \frac{W_w + W_s}{V} = \frac{V_s \gamma_s + V_w \gamma_{sea\ water}}{V}$$

$$= \frac{1 \times G\gamma_w + e.S_r \times 10.1043}{1+e}$$

$V_s = 1$, $V_w = eS_r$, $V = 1+e$ } unit phase

$$= \frac{9.81 \times 2.7 \times 1 + 0.8 \times 1 \times 10.1043}{1+0.8}$$

$= \underline{\underline{19.206}}$ kN/m³

Q The mass of an empty pycnometer is 0.498 kg. When completely filled with water, its mass is found to be 1.528 kg. An oven dried soil of mass 0.198 kg is placed in the pycnometer and water is added to fill the pycnometer and t total mass is found to be 1.653 kg. Determine sp. gravity of soil particles

$W_1 = 0.498$, $W_2 = 0.198$ $(-W_1)$, $W_3 = 1.653$, $W_4 = 1.528$.

$$G = \frac{W_2 - W_1}{(W_2-W_1)-(W_3-W_4)} = \frac{0.198}{0.198-0.125} = \underline{\underline{2.712}}$$

Wt. of dry soil $= W_2 - W_1 = 0.198$

Q A sample of clay was coated with paraffin wax and the total mass of soil and wax was found to be 700 g. The sample was immersed in water and the vol. of water displaced was found to be 355 mL. The mass of the sample without wax was 690 g. and water content of the soil was 18 %. Determine bulk density, dry density, void ratio and degree of saturation. Take sp. gr. of soil solids as 2.7 and that of wax as 0.89.

355×1 ~~$= \frac{690}{2.7} \times + \frac{10}{0.89}$~~

Weight of wax $= 700 - 690 = 10$ g.

Density of wax $=$ ~~0.89~~ $\times 1 = .89$ g/cc.

Volume of wax $= \frac{10}{0.89} = 11.236$ cc.

Volume of soil $=$ vol. of water displaced $-$ vol of wax

$= 355 - 11.23 = \underline{\underline{343.77 \text{ cm}^3}}$

$$\gamma = \frac{W}{V} = \frac{690}{343.77} = 2.007 \text{ g/cc}.$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{2.007}{1.18} = 1.7 \text{ g/cc}$$

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow \underline{\underline{e = 0.588}}$$

$$e = \frac{wG}{S_r} \Rightarrow S_r = \underline{\underline{82.65\%}}$$