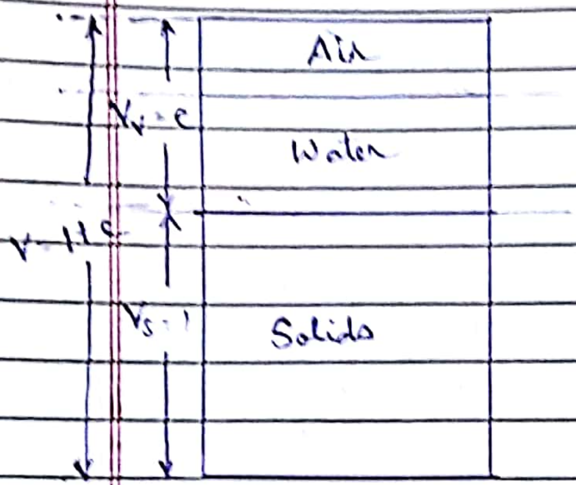
⊙ Relationships Between Index Properties of Soil :-

→ Three Phase Diagram in Terms of Voids Ratio



Let $V_s = 1$. $\quad \because e = \frac{V_v}{V_s} \quad \therefore V_v = e$

$\because V = V_s + V_v \quad \therefore V = 1 + e$

Let $V_a = e_a$ and $V_w = e_w$

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

Degree of Saturation $\quad S = \frac{V_w}{V_v} = \frac{e_w}{e} = \frac{V_w}{e}$

$\therefore V_w = S \times e$

$\therefore V_a = V_v - V_w = e - S \times e = e(1-S)$

Percentage Air Voids $\quad n_a = \frac{V_a}{V} = \frac{e(1-S)}{1+e}$

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

Bulk Density $\quad \rho = \frac{M}{V} = \frac{M_s + M_w}{1+e}$

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~~$G = \frac{\rho}{\rho_w} = \frac{V_s}{V_w} = \frac{V_s}{e_w} = \frac{1}{e_w}$~~

$$\therefore \rho = \frac{(G \times \rho_w) + (S \times e \times \rho_w)}{1+e}$$

$$= \frac{(G + Se)\rho_w}{1+e} \quad \ldots (i)$$

Dry Density $\quad \rho_d = \frac{M_s}{V} = \frac{G \times \rho_w}{1+e} \quad \ldots (ii)$

Saturated Density $\quad \rho_{sat} = \frac{M_{sat}}{V}$

When soil is saturated, $S = 1$

$\therefore$ putting $\rho = \rho_{sat}$ and $S = 1$ in eqn. (i)

$$\rho_{sat} = \frac{(G+e)\rho_w}{1+e} \quad (iii)$$

Submerged Density $\quad \rho' = \rho_{sat} - \rho_w$

or, $\rho' = \frac{(G+e)\rho_w}{1+e} - \rho_w$

or, $\rho' = \frac{(G+e)\rho_w - (1+e)\rho_w}{1+e}$

or, $\rho' = \frac{(G-1)\rho_w}{(1+e)} \quad \ldots (iv)$

In case the soil is not Fully saturated,

$$\rho' = \rho - \rho_w$$

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

$$= \frac{\{(G-1) - e(1-S)\}\rho_w}{1+e} \quad \ldots (v)$$

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Unit Weight $\gamma = \rho \times g$

$\gamma_w = \rho_w \times g$

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

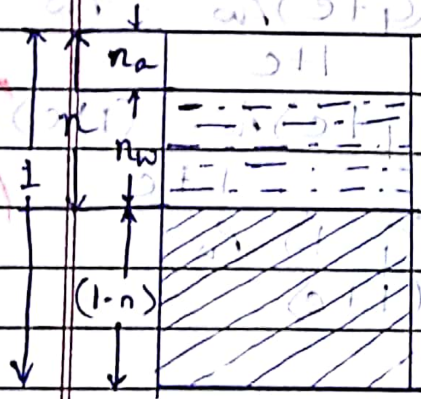
(i) $\therefore \gamma_d = \dfrac{G \times \gamma_w}{1+e} \Rightarrow e = \dfrac{G \times \gamma_w}{\gamma_d} - 1$

(ii) $\therefore \gamma_{sat} = \dfrac{(G+e)\gamma_w}{1+e}$

$\therefore \gamma' = \dfrac{(G-1)\gamma_w}{(1+e)}$

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

→ Three Phase Diagram in terms of Porosity:



Let $V = 1$ $\therefore n = \dfrac{V_v}{V}$ $\therefore V_v = n$

$\because V_s = V - V_v$ $\therefore V_s = 1 - n$

$\therefore S \times n = \dfrac{V_w}{V_v} \times \dfrac{V_v}{V} = \dfrac{V_w}{V} = V_w$ $\therefore V_w = (S \times n)$

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

Bulk Density $\rho = \frac{M}{V} = \frac{M_s + M_w}{V} = \frac{\rho_s V_s + \rho_w V_w}{V}$

$= \frac{(G \times \rho_w) \times V_s + \rho_w V_w}{V}$

$\because S = \frac{V_w}{V_v} = \frac{V_w}{n} \Rightarrow V_w = S \times n$

$\therefore \rho = \frac{(G \times \rho_w) \times V_s + (\rho_w) \times V_w}{V}$

$= G \times \rho_w \times (1-n) + \rho_w \times (S \times n)$

$= \{G(1-n) + (S \times n)\} \rho_w \quad \ldots (vi)$

Dry Density $\rho_d = \frac{M_s}{V} = \frac{\rho_s \times V_s}{V} = \frac{(G \times \rho_w)(1-n)}{1}$

or, $\rho_d = G \times \rho_w \times (1-n) \quad \ldots (vii)$

Saturated Density $\rho_{sat} = \frac{M_{sat}}{V} = \{G(1-n) + n\} \rho_w \quad \ldots (viii)$

Submerged Density $\rho' = \rho_{sat} - \rho_w$

$= \{G(1-n) + n\} \rho_w - \rho_w$

$= \{G(1-n) - (1-n)\} \rho_w$

$= (G-1)(1-n) \rho_w \quad \ldots (ix)$

Unit Weights $\gamma = \{G(1-n) + (S \times n)\} \gamma_w$

$\gamma_d = G(1-n) \gamma_w$

$\gamma_{sat} = \{G(1-n) + n\} \gamma_w$

$\gamma' = (G-1)(1-n) \gamma_w$

→ Relationship between Void Ratio and Water Content:

$$w = \frac{M_w}{M_s} = \frac{V_w \times \rho_w}{V_s \times \rho_s}$$

$$S = \frac{V_w}{V_v} \Rightarrow V_w = S \times V_v$$

$$G = \frac{\rho_s}{\rho_w} \Rightarrow \rho_s = G \times \rho_w$$

$$\therefore w = \frac{(S \times V_v) \times \rho_w}{V_s \times (G \times \rho_w)} = \frac{S \times V_v}{G \times V_s}$$

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

$$\therefore w = \frac{S \times e}{G} \quad \text{or} \quad e = \frac{wG}{S} \quad \ldots (x)$$

→ Expressions for Mass Density in terms of Water Content:

$$\rho = \frac{(G + Se)\rho_w}{1+e} = \frac{(G + wG)\rho_w}{1 + wG/S}$$

$$= \frac{(1+w) G \rho_w}{1 + wG/S} \quad \ldots (xi)$$

$$\rho_{sat} = \frac{(1+w) G \rho_w}{1 + wG} \quad (xii)$$

$$\rho' = \rho_{sat} - \rho_w = \frac{(G-1)\rho_w}{1+w} \quad (xiii)$$

From eq. (ii), $\rho_d = \frac{G \times \rho_w}{1+e}$

$$= \frac{G \times \rho_w}{1+\left(\frac{wG}{S}\right)} \quad \ldots (xiv)$$

From (xi) and (xiv)

$$\rho_d = \frac{\rho}{1+w}$$

From (xiv) when $S = 1$,

$$(\rho_d)_{sat} = \frac{G \times \rho_w}{1+wG} \quad \ldots (xv)$$

Unit Weights:

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

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

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

$$\gamma_d = \frac{G \gamma_w}{1+\left(\frac{wG}{s}\right)}$$

$$(\gamma_d)_{sat} = \frac{G \times \gamma_w}{1+wG}$$

→ Relationship between Dry Mass Density and Percentage Air Voids

$$V = V_s + V_w + V_a$$

or $1 = \frac{V_s}{V} + \frac{V_w}{V} + \frac{V_a}{V}$

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

$1 = \frac{V_s}{V} + \frac{V_w}{V} + n_a$

or, $1 - n_a = \frac{\left(\frac{M_s}{\rho_s}\right)}{V} + \frac{\left(\frac{M_w}{\rho_w}\right)}{V}$

$= \frac{\left(\frac{M_s}{G \times \rho_w}\right)}{V} + \frac{\left(\frac{M_w}{\rho_w}\right)}{V}$ $\quad w = \frac{M_w}{M_s}$

$= \frac{\rho_d}{G \times \rho_w} + \frac{(w M_s)/\rho_w}{V}$

$= \frac{\rho_d}{G \times \rho_w} + \frac{w\,\rho_d}{\rho_w}$

$= \frac{\rho_d}{\rho_w}\left(\frac{1}{G} + w\right)$

or, $\rho_d = \frac{(1 - n_a)\,G\,\rho_w}{1 + wG}$ ... (xvi)