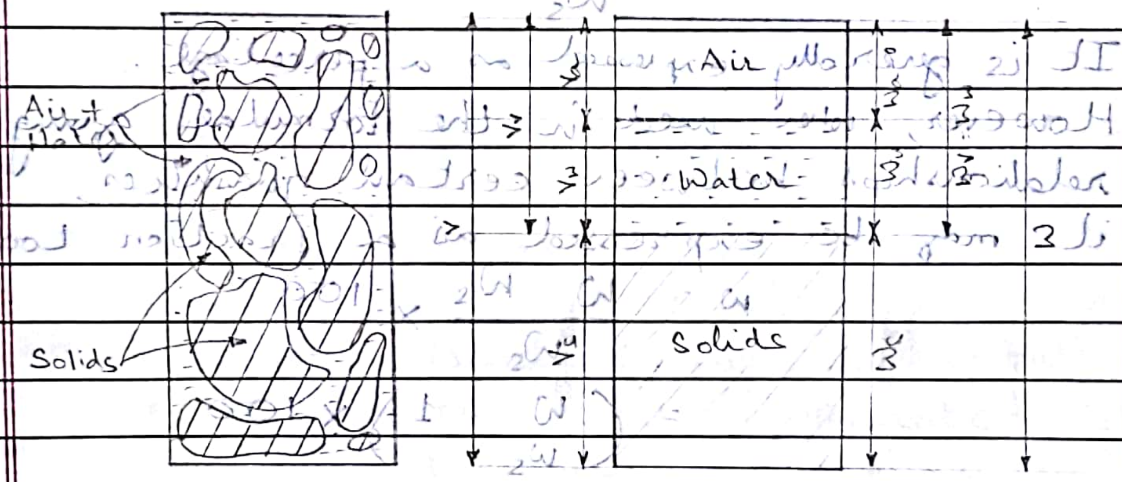
• SOIL AS A THREE PHASE SYSTEM :-

A soil mass is a three phase system consisting of solid particles, (called soil grains), water and air. The void space between the soil grains is filled partly with water and partly with air. However, if we take a dry soil mass, the voids are filled with air only. In case of a perfectly saturated soil, the voids are completely filled with water. In general, the soil mass has 3 components which donot occupy seperate spaces but are blended together forming a complex material as shown in fig; the properties of which depend



Element of Natural Soil (i) Volumes Element Separated into Three Phases (ii) Weights

upon the relative percentages of these constituents, their arrangement and a variety of other factors. For calculation purposes, it is always more convenient to show these constituents occupying separate spaces as shown in fig.

Total volume → $V = V_a + V_w + V_s$

Volume of voids → $V_v = V_a + V_w$

Total weight → $W = W_a + W_w + W_s$

But W_a is negligible

∴ $W = W_w + W_s$

Weight of voids → $W_v = W_w$

Note: W_s is the dry weight of soil sample.

(a) Water Content or Moisture Content (w):- is the ratio of W_w to W_s and in a given mass of soil,

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

It is generally expressed as a percentage. However, when used in the formulae giving relationships between certain quantities, it may be expressed as a fraction too.

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

$$= \left(\frac{W}{W_s} - 1\right) \times 100$$

~~IX~~ If M is the total ~~wei~~ mass of the soil, M_d the dry weight of the soil and M_w the mass of water in the soil, then,

$$w = \frac{M_w}{M_d} \times 100$$

$$\frac{M - M_d}{M_d} \times 100$$

$$w = \left(\frac{M}{M_d} - 1\right) \times 100$$

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(b) Density of Soil :- Mass of the soil per unit volume

(i) Bulk Density (ρ) or Moist Density is the total mass (M) of soil per unit of its total volume (V)

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

It is expressed in terms of gm/cm^3 or kg/m^3

(ii) Dry Density (ρ_d) is the mass of solids per unit of total volume (prior to drying) of the soil mass.

$$\rho_d = \frac{M_d}{V}$$

(iii) Density of solids (ρ_s) is the mass of solids per unit volume of solids.

$$\rho_s = \frac{M_d}{V_s}$$

(iv) Saturated Density (ρ_{sat}) is the bulk density of a soil mass which is saturated. It is the ratio of total mass of saturated soil sample to its total volume.

(v) Submerged Density (ρ') is the ratio of submerged mass of soil solids $(M_d)_{sub}$ to the total volume of the soil mass (V)

$$\rho' = \frac{(M_d)_{sub}}{V}$$

It is also expressed as

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

where ρ_w = density of water = 1 gm/

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(c) Unit Weight of Soil Mass :- is defined as its weight per unit volume.

(i) Bulk Unit Weight (γ) or moist unit weight is the total weight W of a soil mass per unit of its total volume V.

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

(ii) Dry Unit Weight (γ_d) is the weight of solids per unit of its total volume (prior to drying) of the soil mass.

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

(iii) Unit Weight of Solids (γ_s) is the weight of soil solids (W_d) per unit volume of solids (V_s).

$$\gamma_s = \frac{(W_d)}{V_s}$$

Note: γ_s is constant as W_d and V_s never alter, but γ_d is not constant as V alters.

(iv) Saturated Unit Weight (γ_{sat}) is the bulk unit weight of the soil when it is saturated. It is the ratio of total weight W of saturated soil sample to its total volume.

(v) Submerged Unit Weight (γ') is the submerged weight of soil solids $(W_d)_{sub}$ per unit vol. of total volume V of the soil mass.

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

When the soil mass is submerged, the weight of soil solids is reduced due to buoyancy. The submerged weight (W_d) sub is therefore, the weight of soil solids in air minus weight of water displaced by solids :-

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

where γ_w = unit wt of water = 9.81 kN/m³

$$\frac{1\ gm}{cm^3} = \frac{9.81 \times 10^{-6}\ kN}{1 \times 10^{-6}\ m^3} = 9.81\ kN/m^3$$

$\therefore \gamma = 9.81 \rho$

- Specific Gravity (G) is defined as the ratio of the weight of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at that temperature, both weights being taken in air. In other words, it is the unit weight of soil solids to that of water :-

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

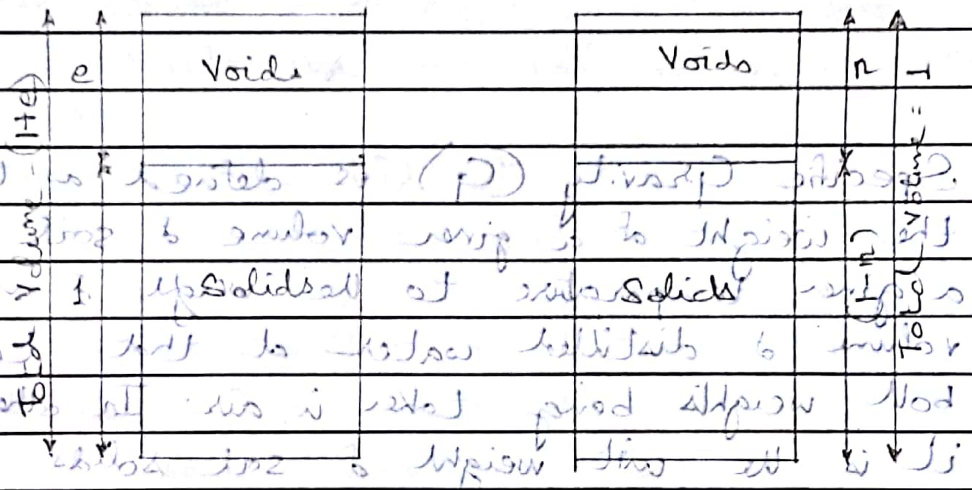
- Voids Ratio (e) of a given soil sample is the ratio of the volume of the volume of voids to the volume of soil solids in the given soil mass. It is generally expressed as a fraction.

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

or percentage voids

- Porosity (n) of a given soil sample is the ratio of volume of voids to the total volume of the given sample

$$n = \frac{V_v}{V}$$ ... It is generally expressed as %



Soil Elements
in terms of
(a) Voids Ratio (b) Porosity

If volume of voids (V_v) is taken equal to voids ratio (e), then volume of solids (V_s) will be equal to 1 and total volume (V) will be equal to (1+e)

Similarly,
if V_v is taken equal to n, the V = 1 and V_s = (1-n)

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

$$\therefore\ e = \frac{V_v}{V_s} = \frac{n}{1-n}$$

$$\therefore\ n = e \times (1-n)$$

$$\text{or, } (1-n) = \frac{n}{e} = \frac{1}{1+e}$$

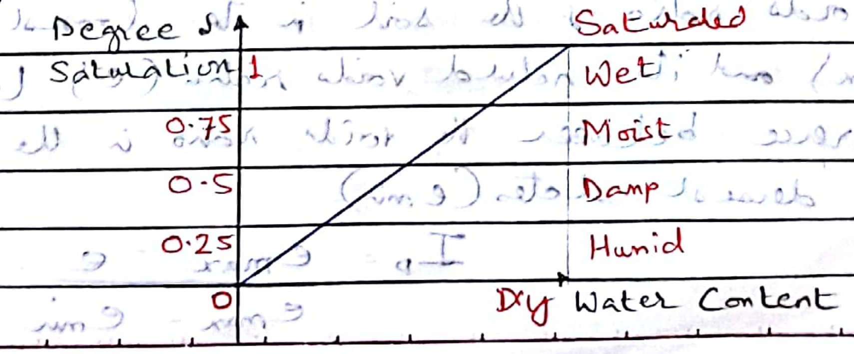
- Degree of Saturation (S) is defined as the volume of water (V_w) present in a given soil mass to the total volume of voids (V_v) in it.

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

Note: For a fully saturated sample, $V_w = V_s$.
$\therefore\ S = 1$

For a perfectly dry sample, $V_w = 0$
$S = 0$

Depending upon degree of saturation, a soil sample is generally described as follows:



- Percentage Air Voids (n_a) is defined as the ratio of volume of air voids (V_a) to the total volume of soil mass (V) and is expressed as a percentage.

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

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

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

$V_a = V_v - V_w$

Dividing both sides by V_v

$$\frac{V_a}{V_v} = 1 - \frac{V_w}{V_v}$$

$$a_c = 1 - S$$

Imp. - Density Index or Relative Density or Degree of Density (I_D) is used to express the relative compactness (or degree of compaction) of a natural cohesionless soil deposit.
It is defined as the ratio of the difference between the voids ratio of the soil in its loosest state (e_{max}) and its natural voids ratio (e) to the difference between the voids ratio in the loosest and densest states (e_{min}).

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

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~~these~~ This term is used for cohesionless soil only. This term is not applicable to cohesive soil because of uncertainities in the laboratory determination of voids ratio in the loosest state of the soil (e_{max}).

When the natural state of the cohesionless soil is in its loosest form, $e = e_{max}$ and hence $I_D = 0$.

When the natural state of the cohesionless soil is in its densest state, $e = e_{min}$ and hence $I_D = 1$.

Based on the value of relative density, we can get a fair idea about how dense the soil is

Relative Density	Density Description
0 - 0.15	Very loose
0.15 - 0.35	Loose
0.35 - 0.615	Medium
0.65 - 0.85	Dense
0.85 - 1	Very Dense

We have $e = \frac{G \times \gamma_w}{\gamma_d} - 1$; $e_{max} = \frac{G \times \gamma_w}{\gamma_{d\,min}} - 1$; $e_{min} = \frac{G \times \gamma_w}{\gamma_{d\,max}} - 1$

$$\therefore I_D = \frac{\left(\frac{G \times \gamma_w}{\gamma_{d\,min}} - 1\right) - \left(\frac{G \times \gamma_w}{\gamma_d} - 1\right)}{\left(\frac{G \times \gamma_w}{\gamma_{d\,min}} - 1\right) - \left(\frac{G \times \gamma_w}{\gamma_{d\,max}} - 1\right)}$$

$$= \frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}} \times \frac{\gamma_{d\,max}}{\gamma_d}$$

The above equation gives relative density in terms of densities.

It may also be expressed in terms of porosity as

$$I_D = \frac{(n_{max} - n)(1 - n_{min})}{(n_{max} - n_{min})(1 - n)}$$

- Relative Compaction: (R_c) or degree of compaction is defined as the ratio of dry unit weight (γ_d) to the maximum dry unit weight ($\gamma_{d\,max}$) from compaction test

$$R_c = \frac{\gamma_d}{\gamma_{d\,max}}$$

In the recent years, it has become an accepted practice for judging the measure of compaction of both coarse grained as well as cohesive soil.

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

$$\therefore \quad R_c = \frac{1+e_{min}}{1+e}$$

Relative compaction may also be expressed in terms of relative density (I_D) as follows

$$R_c = \frac{R_o}{1 - I_D(1-R_o)}$$

where

$$R_o = \frac{\gamma_{d,min}}{\gamma_{d,max}}$$

Lee and Singh (1971) gave the following approximate relation between R_c and I_D

$$R_c = 80 + 0.2 I_D$$

(where both R_c and I_D are in %)

Soil → loosest form → $I_D = 0$, $R_c = 80\%$

Soil → densest form → $I_D = 100$, $R_c = 100\%$

$$R_c \simeq 80\% \text{ to } 100\%$$