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IES/GATE

CIVIL ENGINEERING

VOLUME – VII

Soil Mechanics

SIERRA INNOVATIONS

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Soil Mechanics

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Chapter 1 - Soil

TYPES OF SOILS

1. Alluvial Soil:

It is the soil which is being ~~to~~ deposited from the suspension in running water.

- Transported Soil (Running Water)
- Physical Weathering
- Found along the banks of rivers.

This soil is generally found along the banks of the rivers.

(NORTHERN INDIA)

2. ~~Lacu~~ Lacustrine Soil:

It is the soil that is deposited from the suspension in fresh still water for the lake.

- Physical Weathering
- Residual Soil (Water)

3. Marine Soil:

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

- Physical Weathering (Flowing Water)
- Transported Soil.

4. Aeoline Soil:

It is the soil which is formed due to transportatn by wind.

- Physical Weathering
- Transported Soil

5. Glacial Soil:

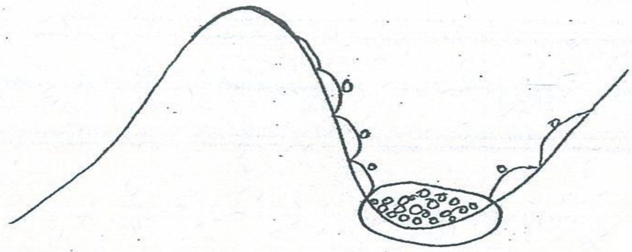
It is the soil that is being transported due to flowing ice.

- Physical Weathering (Ice)
- Transported Soil

6. Colluvial Soil:

This soil is known as TALLUS SOIL. It is formed due to weathering of the rocks by physical agencies and in which transportation is by the gravitational forces. This soil is generally found in the hilly areas at the bottom of the valleys.

- Physical Weathering
- Transported Soil (Gravity)



7. Loess Soil:

It is uniformly graded wind blown silt that is slightly cemented due to calcium compounds and Montmorilonite.

- Type of Aeoline Soil
- Physical Weathering
- Transported Soil

Cementous properties are induced by calcium compounds ($CaCO_3$) and Montmorilonite (highly plastic in ~~nate~~ nature).

8. Marl Soil:

It is fine graded calcium carbonated soil of marine origin which is formed due to decomposition of bones and cell mass of acquatic life (both plants and animals).

- Chemical weathering

9. Bentonite Soil:

It is chemically weathered volcanic ash that is generally used as a lubricant in drilling.
(Application is found in PILE FOUNDATION)

- Chemical Weathering

10. Tuff Soil:

It is finely graded slightly cemented volcanic ash which may be transported either by wind or by water.

• Physical Weathering

11. Loam Soil:

It is the mixture of clay, silt and sand in definite/different proportions in which organic matter may also be present. • Physical Weathering

12. Laterite Soil:

It is the soil which is formed due to Leaching Process (Leaching means washing out of silicious (chemical) compounds) in hilly areas ~~due~~ with humid atmosphere.

Eastern and Western Ghats.

• Chemical Weathering

13. Gumbo Soil:

It is sticky, highly plastic and dark in colour. Excessive presence of Montmorrilonite.

14. Peat Soil:

It is highly organic soil that almost entirely consists of vegetative matter in different stages of decomposition. Its colour varies from black to dark brown and it possesses organic odour. This soil is highly fibrous and possess high compressibility.

• Chemical weathering

15. Muck Soil :

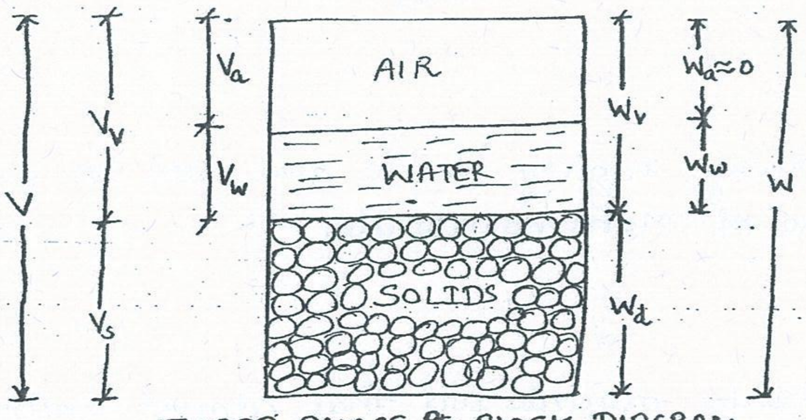
It is fine particled mixture of inorganic soil and black decomposed organic soil. It is generally found in the areas having indeficient sewarage facilities or may be observed after overflooding of the river.

- Chemical weathering.

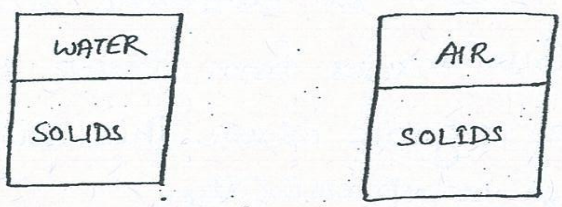
Mixture of Peat Soil and Muck Soil is termed as '<u>CUMULOSE SOIL</u>'.

PROPERTIES OF SOIL :

Soilmass is a three-phase system that comprises of solid, water and air that do not occupy separate spaces but are blended with each other resulting in the formation of complex material properties of which depends upon relative proportion of these constituents.



THREE PHASE BLOCK DIAGRAM



a) SOLIDS + WATER b) SOLIDS + AIR

TWO PHASE BLOCK DIAGRAM

$W_d \rightarrow$ Dry weight of Soil

($W_d \approx W_s$ as weight of air is taken to be zero)

1. Water Content (Moisture Content) (% Moisture):

Water content is defined as the ratio of weight of water to the ~~s~~ weight of ~~soils~~ solids present in the given soil mass.

$$w = \frac{\text{Weight of water}}{\text{Weight of solid}} \times 100$$

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

w can assume any value greater than zero. There is no upper limit for water content. ($w \geq 0$)

$w = 0$ (for dry soils)

Note :-

Water content of fine grained soils is more than that of the coarse grained soils.

For 1 void :- $(\text{Volume of voids})_{\text{FINE GRAINED}} \lesssim (\text{Volume of voids})_{\text{COARSE GRAINED}}$

$(\text{No. of voids})_{\text{FINE GRAINED}} > (\text{No. of voids})_{\text{COARSE GRAINED}}$

Total Volume of Voids = No. of Voids X Volume of 1 void

$(\text{Total vol. of voids})_{\text{FINE GRAINED}} > (\text{Total vol. of voids})_{\text{COARSE GRAINED}}$

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

$$w' = \frac{\text{weight of water}}{\text{Weight of soil}} \times 100$$

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

$$\omega' = \frac{W_v}{W} = \frac{W_v}{W_d + W_w}$$

$$\omega' = \frac{1}{\frac{W_d}{W_\omega} + 1} = \frac{1}{\frac{1}{\omega} + 1}$$

$$\boxed{\omega' = \frac{\omega}{1+\omega}}$$

or

$$\omega = \boxed{\omega = \frac{\omega'}{1-\omega'}}$$

<u>Note</u> :-

Both ω and ω' indicates the weight of water present in the soil in terms of weight of solids and weight of soil respectively. Since, wt. of solid do not change with change in water, it is a stable parameter in comparison to wt. of soil. Hence, engg. significance of ω is more than ω'.

2. <u>Void Ratio (e)</u> :

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

$$e = \frac{\text{Volume of voids}}{\text{Volume of solids}}$$

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

$\boxed{e > 0}$ (There is no upper limit for void ratio.)

$\boxed{e \neq 0}$ (because $V_v \neq 0$)

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3. Porosity (% voids) (η):

Porosity is defined as the ratio of volume of voids to the volume of soil of the given soilmass.

$$\eta = \frac{\text{Volume of voids}}{\text{Volume of soil}} \times 100$$

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

$$\boxed{0\% < \eta < 100\%}$$

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

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

$$\boxed{\eta = \frac{e}{1+e}}$$

(OR)

$$\boxed{1 - \eta = \frac{1}{1+e}}$$

Note :-

Porosity & Void ratio represents the vol. of voids in terms of vol. of soil and vol. of solids respectively. Volume of solid is comparatively stable than volume of soil. Hence, physical (engg.) significance of void ratio is more than porosity.

4. Degree of Saturation (% Saturation) (S) :-

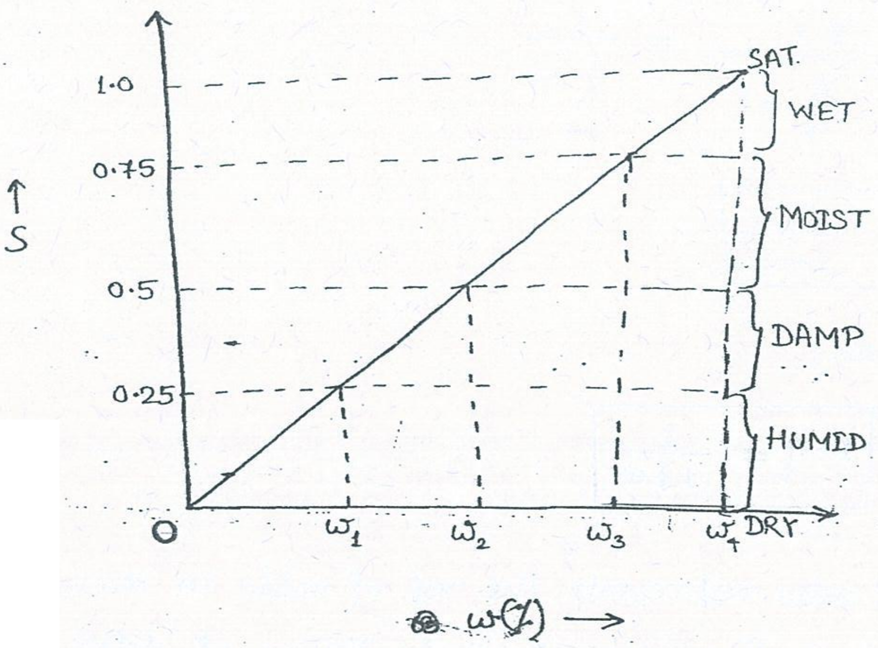
It is defined as the ratio of volume of water to the volume of voids present in given soil mass.

$$S = \frac{\text{Volume of water}}{\text{Volume of voids}} \times 100$$

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

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

Depending upon the degree of saturation, the soil may be stated as dry, humid, damp, moist, wet and saturated.



5. Air Content (a_c) :

Air content is defined as the ratio of volume of air to the volume of voids present in given soil sample.

$$a_c = \frac{\text{Volume of air}}{\text{Volume of voids}}$$

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

$$\boxed{0 \leq a_c \leq 1}$$

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

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

$$a_c = 1 - S$$

$$\boxed{a_c + S = 1}$$

6. Percentage Air Voids (η_a) :

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

$$\eta_a = \frac{\text{Volume of air}}{\text{Volume of soil}} \times 100$$

$$\boxed{\eta_a = \frac{V_a}{V} \times 100}$$

$$\boxed{0\% \leq \eta_a < 100\%}$$

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

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

$$\boxed{\eta_a = a_c \eta}$$

7. <u>Unit Weight (or) Density of Soil:</u>

a) <u>Bulk Unit Wt. (or) Bulk Density</u> :-

It is defined as the ratio of weight of the soil in existing condition to the volume of soil.

$$\boxed{\gamma = \frac{W}{V}} \quad \text{or} \quad \boxed{\rho = \frac{M}{V}}$$

$$W = W_d + W_w$$

$$\boxed{\gamma = \frac{W_d + W_w}{V}} \quad \text{or} \quad \boxed{\rho = \frac{M_d + M_w}{V}}$$

b) <u>Dry Unit Wt. (or) Dry Density</u> :-

It is defined as the ratio of wt. of the soil in dry state to the volume of the soil.

$$\boxed{\gamma_d = \frac{W_d}{V}} \quad \text{or} \quad \boxed{\rho_d = \frac{M_d}{V}}$$

Dry unit weight or dry density represents the denseness of the soil. Higher is the value of γ_d, more compactly solids are packed in the given volume of soil resulting in its higher degree of denseness.

Void ratio is related to degree of denseness.

$e \uparrow \Rightarrow$ Degree of denseness $\downarrow$

$e \downarrow \Rightarrow$ Degree of denseness $\uparrow$

c) Saturated Unit Wt. (or) Saturated Density :-

It is defined as the ratio of saturated weight of soil to the volume of the soil.

$$\gamma_{SAT} = \frac{W_{SAT.}}{V} \quad (or) \quad \rho_{SAT} = \frac{M_{SAT.}}{V}$$

Note :- When the soil is dry, its bulk unit wt. is equal to the dry unit wt. and when soil is saturated, it ~~saturated~~ bulk unit wt. is equal to saturated unit wt.

d) Submerged Unit Wt. (or) Submerged Density :-

When the soil is submerged below the water table; it is being acted upon by force of buoyancy in vertically upward direction that is equal in magnitude of the wt. of the water displaced by the soil.

$$\gamma_{SUB} = \gamma' = \gamma_{SAT} - \gamma_w \quad (or) \quad \rho_{SUB.} = \rho' = \rho_{SAT} - \rho_w$$

Hence, it results in decrease in weight of the soil. This effective wt. of the soil in ~~subse~~ submerged ~~unit~~ condition is termed as submerged unit wt. or buoyant wt.

Note :-
Saturated unit wt. is approximately twice the unit wt. of soil. Hence, submerged unit wt. ~~of~~ is approximately half of saturated unit wt. ~~of water~~

$$\gamma_{SAT} \simeq 2\gamma_w$$

$$\gamma' = \frac{1}{2}\gamma_{SAT}$$

$$\gamma_{SAT.} > \gamma > \gamma_d > \gamma_{SUB.}$$

→ Change is due to the change in wt. of water only.

8. Specific Gravity:

a) True Specific Gravity (Absolute Specific Gravity):-

It is defined as the ratio of unit wt. of solids of given volume to the unit wt. of standard fluid (water) of same volume.

$$G_s = \frac{\text{Unit wt. of solids of given volume}}{\text{Unit wt. of water of same volume}}$$

$(V_s = V_\omega)$

$$G_s = \frac{W_d}{W_\omega} = \frac{W_d}{V_s} \times \frac{V_s}{W_\omega}$$

$$G_s = \left(\frac{W_d}{V_s}\right)\left(\frac{V_\omega}{W_\omega}\right)$$

$$\boxed{G_s = \frac{\gamma_s}{\gamma_\omega}}$$

It is indicating the denseness of solids w.r.t the denseness of water.

Note :- $\gamma_s \rightarrow$ Unit wt. (or) Density of Solid

γ_s is defined as the ratio of wt. of solids to the volume of the solids.

$$\boxed{\gamma_s = \frac{W_d}{V_s}}$$

$\gamma_s >> \gamma_d$ as $V_s << V$

γ_s is even more greater than γ_{SAT}.

$$\boxed{\gamma_s > \gamma_{SAT} > \gamma > \gamma_d > \gamma_{SUB.}}$$

For inorganic Soil : $G_s = 2.6 - 2.9$ (normally taken as 2.65)

For organic soil : $G_s = 1 - 2.2$ (normally taken as 1.2)

Higher value of G_s is ~~more tt~~ for fine grained soil and lower value of G_s is for coarse grained soil.

With increase in mineral content like iron and mica, specific gravity of the soil increases.

b) Apparent / Bulk / Mass Specific Gravity :-

It is defined as the ratio of unit wt. of soil of given volume in existing condition to the unit wt. of standard fluid of same volume.

$$G_M = \frac{\text{Unit wt. of soil of given vol.}}{\text{Unit wt. of water of same vol.}}$$

$(V = V_w)$

$$G_M = \frac{W}{W_w} = \frac{W}{V} \cdot \frac{V}{W_w}$$

$$G_M = \left(\frac{W}{V}\right)\left(\frac{V_w}{W_w}\right)$$

$$\boxed{G_M = \frac{\gamma}{\gamma_w}}$$

$\boxed{G_s > G_s}$ (because $\gamma_s > \gamma$ and γ_w is same)

Note :-

In India, specific gravity of the soil is reported at 27°c and if it is required to compute the specific gravity at any other temperature, corresponding change in unit wt. of water should also be considered.

$$G_{T^\circ c}\, \gamma_{w_{T^\circ c}} = G_{27^\circ c}\, \gamma_{w\,27^\circ c}$$

$$\boxed{G_{T^\circ c} = G_{27^\circ c} \left(\frac{\gamma_{w\,27^\circ c}}{\gamma_{w\,T^\circ c}}\right)}$$

9. Density Index / Relative Density / Degree of Density (I_D):

Density Index represents the relative compactness of natural cohesionless soil.

It is defined as the ratio of difference of void ratio of the soil in its loose state and void ratio of the soil in its natural state to the difference of void ratio of soil in loose state and void ratio of the soil in its densest state.

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

$e_{max} \rightarrow$ Void ratio in loosest state

$e \rightarrow$ Void ratio in natural state

$e_{min} \rightarrow$ Void ratio in densest state

If $e = e_{max}$ (Soil is in loosest state) $\Rightarrow I_D = 0$

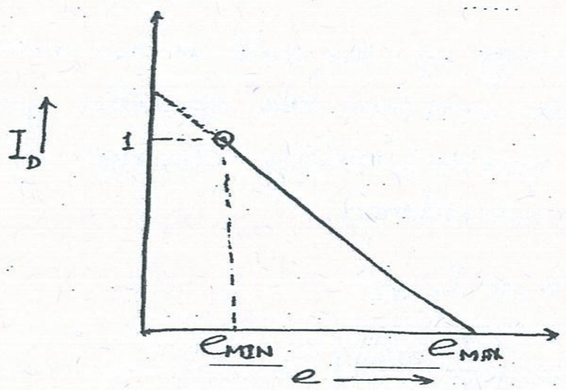
If $e = e_{min}$ (Soil is in densest state) $\Rightarrow I_D = 100\%$

$$0 \leq I_D \leq 100\%$$

$$I_D = f(e)$$

Note :-

Density Index is not used to analyse cohesive soils as large uncertanities are involved in computation of void ratio of cohesive soils in its loosest state.



$$I_D = \frac{\frac{1}{\gamma_{D_{MIN}}} - \frac{1}{\gamma}}{\frac{1}{\gamma_{D_{MIN}}} - \frac{1}{\gamma_{D_{MAX}}}}$$

$$\boxed{I_D = \frac{\gamma_{D_{MAX}}}{\gamma}\left(\frac{\gamma - \gamma_{D_{MIN}}}{\gamma_{D_{MAX}} - \gamma_{D_{MIN}}}\right)}$$

$$\boxed{I_D = \frac{(\eta_{MAX} - \eta)(1 - \eta_{MAX})}{(\eta_{MAX} - \eta_{MIN})(1 - \eta)}}$$

Note :-
Density Index is best indicator of denseness of soil as compared to void ratio and dry density as it indicates the absolute value of compactness of the soil.

I_D (%)	DESCRIPTION OF SOIL
0 – 15	VERY LOOSE SOIL
15 – 35	LOOSE SOIL
35 – 65	MEDIUM DENSE SOIL
65 – 85	DENSE SOIL
85 – 100	VERY DENSE SOIL

Note :-
Soil showing similar shape and size characteristics of the grain possesses different engineering properties if their relative density in different.

Soil having higher relative density (I_D) is more dense, possess high shear strength and low compressibility.

10. Relative Compaction (R_c):

Relative compaction represents the relative compactness of both cohesive and cohesionless soil.

It is defined as the dry density of soil in its ~~loosest~~ natural state to the dry density of soil in its densest state.

$$R_c = \frac{\gamma_d}{\gamma_{d_{MAX}}} = \frac{1 + e_{MIN}}{1 + e}$$

Relative compaction can be empirically related to density index by the following relation:-

$$R_c = 80 + 0.2 I_D$$

If $I_D = 0\%$ (Soil is in loosest state) $\Rightarrow R_c = 80\%$

If $I_D = 100\%$ (Soil is in densest state) $\Rightarrow R_c = 100\%$

$$80\% \leq R_c \leq 100\%$$

Note:-

For partially saturated soil ($0 < S < 1$); change in water content does not lead to change in volume of voids or volume of soil but if the soil is in super-saturated state ($S \simeq 1$) change in water content leads to corresponding change in volume of voids and volume of soil.

Though the size of individual void is more in coarse grained soil than in fine grained soil but volume of voids of fine grained soil is more than volume of voids in coarse grained soil.

INTER-RELATIONSHIP B/W PROPERTIES OF SOIL

i) <u>e, w, G, S</u>

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

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

$$\left[\begin{array}{l} \gamma_w = \frac{W_w}{V_s} \\ G = \frac{\gamma_s}{\gamma_w} = \frac{W_d}{V_s \gamma_w} \end{array} \right]$$

$$e = \frac{1}{S} \left(\frac{W_w}{\gamma_w} \right) \left(\frac{G \gamma_w}{W_d} \right)$$

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

$$\boxed{e = \frac{G w}{S}}$$

ii) <u>$\gamma, G, e, S, \gamma_w$</u>

$$\gamma = \frac{W}{V} = \frac{W_d + W_w}{V}$$

$$V = V_s + V_v$$

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

$$V = V_s (1+e)$$

$$\gamma = \frac{W_d + W_w}{V_s (1+e)}$$

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

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

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

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

$$\therefore \boxed{\gamma = \frac{(G+es)\gamma_w}{1+e}}$$

If soil is dry :- $\gamma = \gamma_d$; $S = 0$

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

If ~~sat~~ soil is saturated :-

$\gamma = \gamma_{SAT}$; $S = 1$

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

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

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

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