CIVIL ENGINEERING-CE

GATE / PSUs

STUDY MATERIAL

SOIL MECHANICS & FOUNDATION ENGINEERING

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CONTENT

SOIL MECHANICS

FOUNDATION ENGINEERING

PRACTICS SET

CHAPTER-1
SOIL FORMATION AND SOIL TYPES

- The term 'soil' has different definitions belonging to different disciplines.
- For a civil engineer, soil means all naturally occurring relatively unconsolidated earth material-organic or inorganic in character that lies above the bedrock.
- **Soil mechanics** is the branch of civil Engineering which deals with the application of principles of mechanics to engineering problems related to soil.
- **Soil Engineering** encompasses not only soil mechanics but also geology, structural engineering, soil dynamics and many other disciplines which are often required to obtain practical solutions to problems of soil.

Soil Formation and Soil Types:

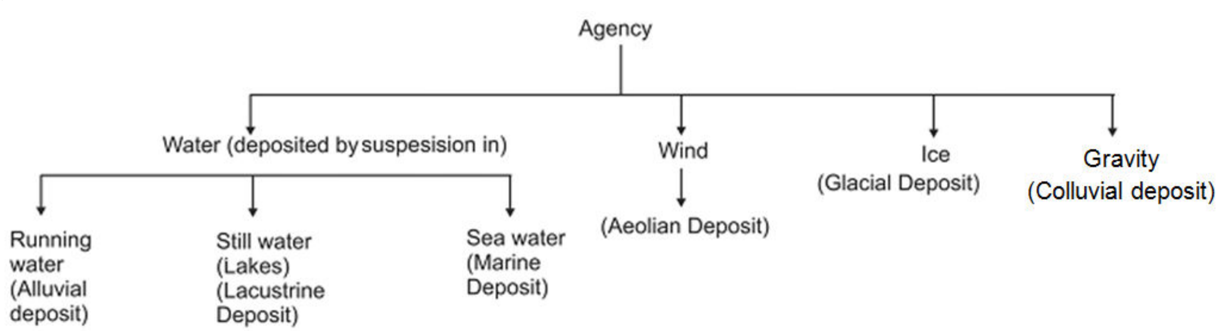
Soil is formed by four stages:

Soil formation: Disintegration → Transportation → Deposition → Upheaval

Soil can be divided into two main groups on the basis of their origin.

- (a) Formed by physical weathering by means of water, ice and wind. e.g. Gravel, sand
  (b) Formed by chemical weathering by oxidation & hydration. e.g.,Clays, silts
- Soils of organic origin are extremely compressible.
- Geological classification of soil
  i) Residual soils ii) Transported soils
- If a product of rock weathering remains available at the place of their origin it is called residual soil.
- If soil is transported from its place of origin by wind, water, ice etc. and gets deposited at other place it is called a transported soil.

According to the transporting agency and method of deposition transporting soil can be classified as:



Soil Formed by Method of Transportation and Deposition:

- **Alluvial/Fluvial Soils:** These soils are formed by running water. For example: river plains. These soils are uniformly graded.
- **Lacustrine Soils:** These soils are primarily silts or clays and found below the still water like lakes.
- **Aeolian Soil:** These soils are transported by winds and found in desert area. These are loose and poorly graded soils. Ex.: Sand dunes (coarse grained), Loess (fine grained) etc.

- **Loess:**Loose deposit of wind-blown silt which is weakly cemented with calcium carbonate and montmorillonite. It is formed in arid and semi-arid regions.

- **Tuff:**A small-grained volcanic ash transported by wind or water.
- **Bentonite:**A chemically weathered volcanic ash. These soils are highly plastic and compressible
- **Glacial till:**A mixture of boulders, gravel, sand, silt and clay, deposited by glacial and not transported or segregated by water. These soils are well graded.
- **Marl:**A very fine grained calcium carbonated soil of marine origin.
- **Colluvial soil:**Accumulation of rock debris or talus at the base of a steep cliff due to action of gravity.
- **Peat:** A highly organic soil, Brown to black in color, fibrous and highly compressible.
- **Muck:**A mixture of fine particle of inorganic soil and black decomposed organic matter. Generally found accumulated in conditions of imperfect drainages like swamps.

(Peat and Muck are also called as cumulose soil)

- **Humus:**A dark brown, organic soil consisting of partly decomposed vegetative matter.

Regional soil deposits of India:

1. **Marine deposit:**

→ Marine clays are soft and may contain organic matter.

→ It possess low shear strength and high compressibility.

→ Not suitable as a foundation material.

2. **Laterites and Lateritic soil:**

→ Formed by the decomposition of rock, removal of the bases and silica and formation of oxides of iron and aluminum at the top of the soil profile.

→ There are two types of laterites: - Primary and Secondary.

→ Primary laterite is found in situ at high altitudes near hills. Secondary laterites are found in coastal belt.

→ Laterites are reddish in color and hard in dry state.

→ If the grain size increases upon alternate wetting and drying cycles, the soil is called laterite but lateritic soil does not show this characteristics.

→ Laterites are used as foundation material and retain their slopes well.

3. **Black cotton soil:**

→ This is type of expansive soil.

→ It is not necessary that Black cotton soils should be Black in colour always.

→ These are formed from basalt or trap and contain the clay mineral montmorillonite, which is responsible for excessive swelling and shrinkage characteristics of the soil.

→ Under-reamed piles are considered most suitable as foundation for these soils.

Note:Compressibility means compression (ΔH) per unit increase in effective stress ($\Delta\sigma'$) $i.e. \dfrac{\Delta H}{\Delta \sigma'}$

4. **Alluvial Soils:**

→Found in large parts of Northern India in the Indo-Gangetic and Brahmaputra.

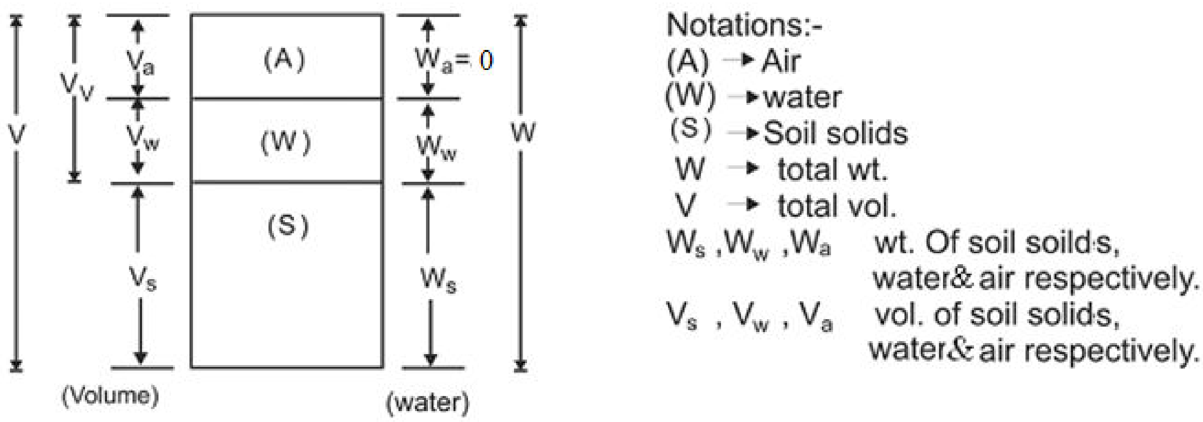
→Thickness of the alluvial soils layers sometimes extend 100 m having alternate layers of sand, silt and clay.

CHAPTER-2
PROPERTIES OF SOIL

Phase Diagram:

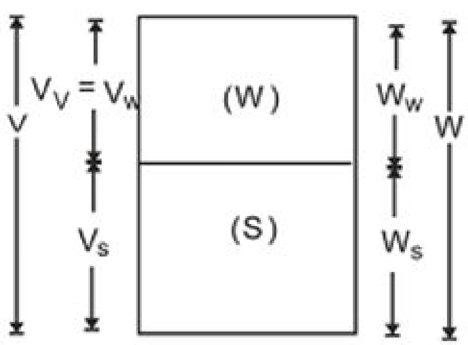
- In general, soil mass is a three-phase system composed of solid, liquid and gaseous matter.
- The solid phase is composed of mineral or organic matter or both. The solids enclose the open spaces termed as voids which are occupied by water (liquid phase) and air (gaseous phase).
- The diagrammatic representation of the different phases in soil mass is called the phase diagram.

Three Phase diagram (Partially saturated)

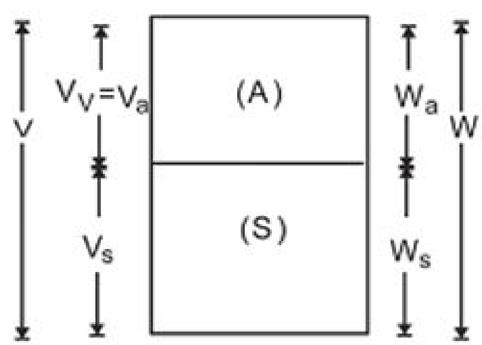


Two Phase diagram:

(a) Fully Saturated State:



(b) Dry State:



Types of Water in Soil

(i) Structural or molecular water

$\left.\begin{array}{l}(ii)\text{ Gravity water}\\(iii)\text{ Capillary water}\\(iv)\text{ Hygroscopic water}\end{array}\right\}$ These three types can be removed by oven drying.

→ If a soil sample is placed in open atmosphere, it absorbs water from the atmosphere which is called hygroscopic water. The capacity to absorb water depends upon the nature of soil which is least for Gravel and highest for clays (upto 70%).

→ Structural water cannot be removed by simple oven drying method. But if heated over a temperature of more than 500º C then it may be lost.

Some Definitions:

1. Water content (w): Defined as the ratio of weight of water (w_w) to the weight of solids (w_s) in a given mass of soil.

$$\boxed{\underset{(\%)}{w} = \frac{W_w}{W_s} \times 100}$$

W_w = weight of water

W_s = weight of solids

There can be no upper limit to water content i.e. $w \geq 0$. It can be even more than 100%

2. Void Ratio (e): Defined as the ratio of volume of voids (V_v) to the volume of solids (V_s).

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

V_v = volume of void

V_s = volume of solid.

Soil has to contain some voids but there cannot be an upper limit to the void volume i.e. **e > 0**and may be greater than 1.

Void sizes of coarse-grained soils are larger than fine-grained soils but void ratio of fine grained soils is much higher than coarse-grained.

3. Porosity (n): Defined as the ratio of the volume of voids to total volume of the soil (V).

$$\boxed{n_{(\%)} = \frac{V_v}{V} \times 100}$$

V_v = volume of void

V = total volume of soil.

The porosity of a soil cannot exceed 100% i.e. $\boxed{0 < n < 100}$

In soil engineering, void ratio is frequently used.

4. Degree of saturation (S): Defined as the ratio of volume of water to volume of voids.

$$\boxed{s_{(\%)} = \frac{V_w}{V_v} \times 100}$$

$$\boxed{\begin{aligned} V_w &= \text{volume of water} \\ V_v &= \text{volume of voids} \end{aligned}}$$

The degree of saturation varies between 0 and 100 i.e. $\boxed{0 \le s \le 100}$

9 = 0% → oven dried soil

9 = 100% → saturated soil

5. Air content (a_c): Defined as the ratio of volume of air (V_a) to volume of voids (V_v).

$$\therefore \qquad \boxed{a_c = \frac{V_a}{V_v} = 1 - S}\ , \ 0 \le a_c \le 100$$

6. Percentage air voids (n_a): It is defined as volume of air voids (V_a) to the total volume (V) of soil mass.

$$\boxed{\underset{(\%)}{n_a} = \frac{V_a}{V} \times 100}\ , \ 0 \le n \le 100$$

$$n_a = na_c$$

7. Unit weight:

(a) Bulk unit weight (γ_t) or Total unit weight:

Defined as the total weight of a soil mass (w) per unit of total volume (v)

$$\boxed{\gamma_t = \frac{w}{v}} \qquad \text{or} \qquad \boxed{\gamma_t = \frac{w_s + w_w}{v_s + v_w + v_a}}$$

W = weight of soil mass

W_s = Weight of solids

W_w = weight of water

V_s = volume of solid

V_w = volume of water

V_a = volume of air

V = total volume of soil mass

Its S.I unit is KN / m^3

(b) Dry unit weight (γ_d): Defined as the weight of solids (w_s) per unit of total volume (v).

$$\boxed{\gamma_d = \frac{w_s}{v}}$$

(c) Saturated unit weight (γ_{sat}): Defined as the total weight of a fully saturated soil sample (w_{sat}) per unit of total volume (v)

$$\boxed{\gamma_{sat} = \frac{w_{sat}}{V}}$$

(d) Submerged unit weight (γ'): $\boxed{\gamma' = \gamma_{sat} - \gamma_w}$ where, γ_w = unit weight of water.

The reduction in unit weight occurs due to action of buoyant force on the soil solids.

→ The submerged unit weight is roughly one half of the saturated unit weight i.e. $\boxed{\gamma' = \frac{1}{2}\gamma_{sat}}$

Absolute/True:

8. Specific gravity (G_s or G): Specific gravity of solids may be defined as the ratio of unit weight of solids (γ_s) to that of water (γ_w).

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

At 4°C, γ_w = 1 g/cc. or 9.81 kN/m^3.

Specific gravity is dependent on the temperature (very little extent). In India, specific gravity is represented at 27° C and if test temperature is different than 27° C, it should be modified.

$$G_{27^\circ C} = G_{T^\circ C} \times \frac{\gamma_w \text{ at } T^\circ C}{\gamma_w \text{ at } 27^\circ C}$$

Since, γ_w is temperature dependent hence G also.

9. Apparent or Mass specific gravity (G_m):

It is defined as the ratio of the bulk unit weight of the soil (γ_t) to the unit weight of water (γ_w).

$$\boxed{G_m = \frac{\gamma_t}{\gamma_w}}$$

Value of G_s:

Soil Type	Specific Gravity
Clean sand and gravel	2.65 – 2.68
Silt and Silty sand	2.66 – 2.70
Inorganic clays	2.70 – 2.80
Soil having higher percentage of mica, iron	2.75 – 2.85

- The value of specific gravity for most of the soil lie between 2.65 – 2.80. Coarse-grained soil exhibit lower values.
- The presence of organic matter leads to very low values.
- The specific gravity of organic soils is quite variable may fall below 20.
- Soils with high quantity of iron or mica exhibit higher values.

10. Relative Density/Density Index: Relative density (I_D) of a soil can be defined as

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

It denotes the degree of packing between the loosest and densest possible states in coarse grained soil.

$$0\% \le I_D \le 100\%$$

In terms of porosity: $I_D = \frac{(n_{max} - n)(1 - n_{min})}{(n_{max} - n_{min})(1 - n)}$

Some important relationship:

All notations have their standard meaning (as already explained)

1. Relation between w_s, w and W:

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

$W_s \rightarrow$ Weight of solids

W $\rightarrow$ Total weight of soil

w $\rightarrow$ water content

Weight of solids is the ratio of total weight of soil to the (1+ water content).

2. Relation between ‘e’ and ‘n’:

$$\boxed{n = \frac{e}{1+e}} \quad \& \quad \boxed{e = \frac{n}{1-n}}$$

n = porosity e = void ratio

3. Relation between e, W, G and S:

$$\boxed{eS = wG}$$

e = void ratio. w = Weight of water. S = Degree of saturation. G = Specific Gravity

4. Relation between γ_t, G, e, γ_w and S

$$\boxed{\gamma_t = \left(\frac{G + Se}{1 + e}\right)\gamma_w} \quad \ldots(1)$$

γ_t = bulk unit weight of soil. γ_w = unit weight of water.

5. Relation between γ_{sat}, G, e, and γ_w:

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

γ_{sat} = Saturated unit weight γ_w = unit weight of water. $(\because \quad S = 1)$

Obtained by putting value of S = 1 in above relationship (4).

6. Relation between γ_d, G, e and γ_w: (Dry soil)

$$\boxed{\gamma_d = \left(\frac{G\gamma_w}{1 + e}\right)} \text{ If } S = 0$$

Obtained by putting value of S = 0 in relationship (5).

7. Relation between γ', G, e and γ_w: (Submerged soil)

$$\text{Submerged unit weight} = \gamma_{sat} - \gamma_w = \left(\frac{G_s + e}{1 + e}\right)\gamma_w - \gamma_w$$

$$\text{Submerged unit wt., } \gamma' = \left(\frac{G_s - 1}{1 + e}\right)\gamma_w$$

8. Relation between γ_t, γ_d and w: $\boxed{\gamma_d = \dfrac{\gamma_t}{(1 + w)}}$

9. Relation between γ_d, G, w, and n_a: $\gamma_d = \dfrac{(1 - n_a)\, G_s\, \gamma_w}{1 + wG_s}$

This expresses the relationship between dry unit weight and the percentage air voids.

→ This is useful in the study of compaction behavior in soil.

→ When $n_a = 0$, i.e. when the soil becomes fully saturated at a given water content, 'γ_d'is given by:

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

Question-1: The water content of a saturated soil and the specific gravity of soils solids were found to be 30% and 2.70, respectively. Assuming the unit weight of water to be $10\ \text{kN/m}^3$, the saturated unit weight (kN/m^3), and the void ratio of the soil are **(GATE–2007)**

(*a*) 19.4, 0.81 (*b*) 18.5, 0.30 (*c*) 19.4, 0.45 (*d*) 18.5, 0.45

Solution: Water content, $w = 30\%$ Specific gravity, G = 2.70

$\gamma_w = 10\ \text{kN/m}^3$

$\because$ Soil is saturated $\therefore$ S = 1

As we know, $e = \dfrac{WG}{S} = \dfrac{0.3 \times 2.70}{1} = 0.81$

And saturated unit weight, $\gamma_{sat} = \left(\dfrac{G+e}{1+e}\right)\gamma_w$

$$= \left(\frac{2.7+0.81}{1+0.81}\right) \times 10\ \text{kN/m}^3 = 19.39\ \text{kN/m}^3$$

METHODS OF WATER CONTENT DETERMINATION:

1. Oven-drying method:

→It is most accurate method

→ Commonly adopted and the simplest method used in laboratory.

→Samples are dried for 24 hour in the oven at temperature 105-110°C. Temperature higher than 110ºC may break crystalline structure of clay particles

Water content, $\boxed{w = \dfrac{w_2 - w_3}{w_3 - w_1} \times 100\ (\%)}$

W_1 = weight of container

W_2 = weight of container with moist sample.

W_3 = weight of container with dried sample.

$\therefore$ Weight of water, $W_w = w_2 - w_3$

Weight of solids $W_s = w_3 - w_1$

2. Pycnometer method

→ Quick laboratory method.

→ Used for soil whose specific gravity is known.

→ Suitable for cohesion-less soil.

→ Pycnometer: Glass bottle with conical top-900ml. capacity;

Published Books