SAMPLE STUDY MATERIAL

Postal Correspondence Course

GATE, IES & PSUs

Civil Engineering

Soil Mechanics & Foundation Engineering

ENGINEERS INSTITUTE OF INDIA
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CHAPTER-1

SOIL FORMATION AND SOIL TYPES

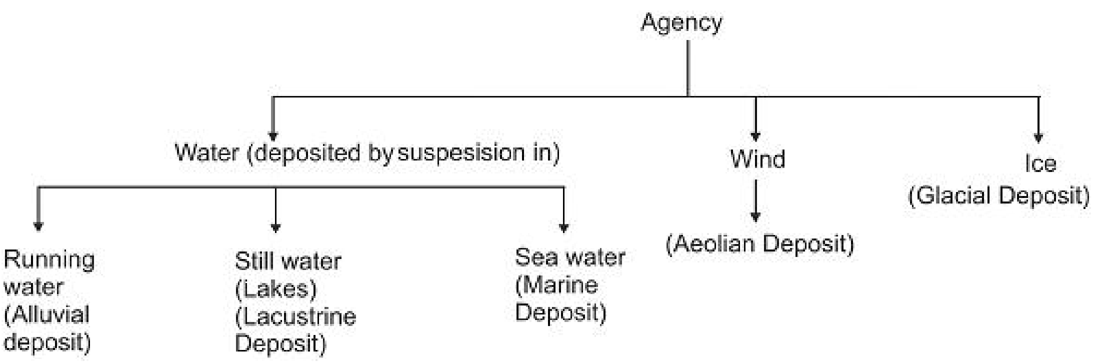
- The term 'soil' has different definitions belonging to different disciplines.
- For a civil engineer, soil means all naturally occurring relatively unconsolidated earth material-organic or inorganic in character that lies above the bedrock.
- **Soil mechanics** is the branch of civil Engineering which 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 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.
- 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:

- **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.

- **Glacial till:** A mixture of boulders, gravel, sand, silt and clay, deposited by glacial and not transported or segreGATEd by water.

- **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.

<u>Regional soil deposits of India:</u>

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 aluminium at the top of the soil profile.

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

→ 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 the Indian name given to the 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 montmorrillonite, 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.* $\frac{\Delta H}{\Delta \sigma'}$

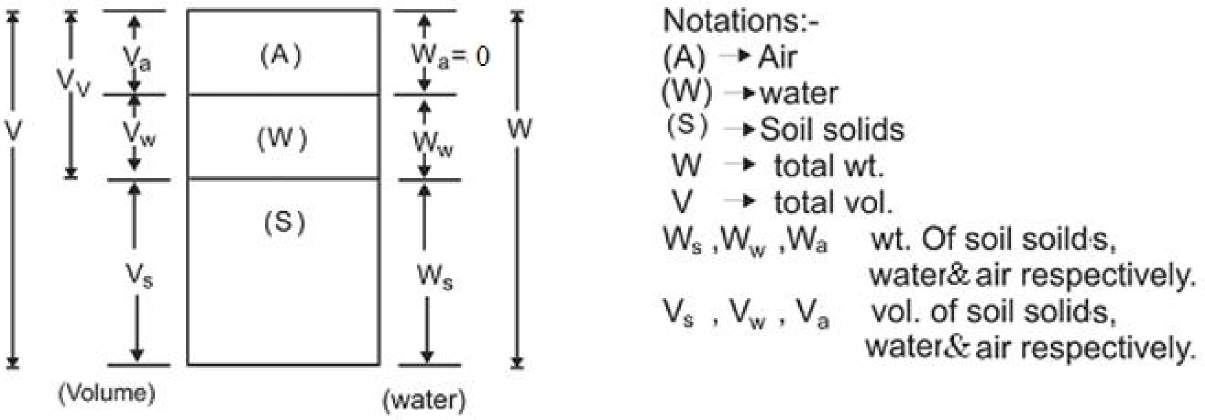
CHAPTER-2

PROPERTIES OF SOIL

Phase Diagram:

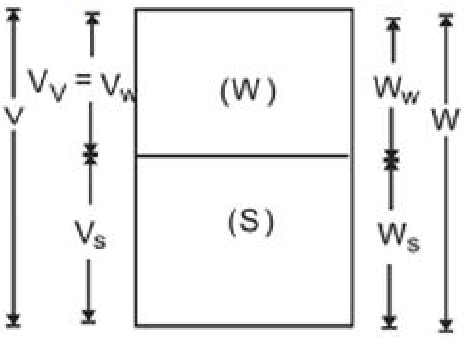
- In general, soil mass is a three-phase system composed of solid, liquid and gaseous matter.
- The diagrammatic representation of the different phases in soil mass is called the phase diagram.

Phase diagram (Partially saturated)

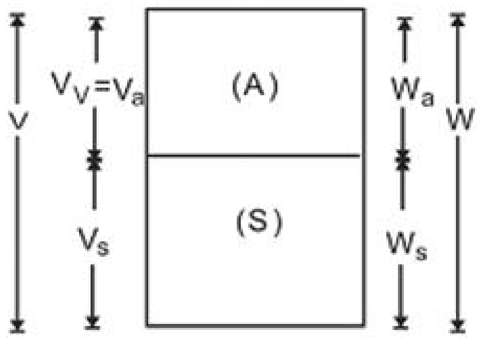


Phase diagram:

(a) Fully Saturated State:



(b) Dry State:



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.

$$w_{(\%)} = \frac{W_w}{W_s} \times 100$$

W_w = weight of water

W_s = weight of solids

There can be no upper limit to water content i.e. **w ≥ 0.**

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

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

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**

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

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

V_v = volume of void

V = total volume of soil.

The porosity of a soil cannot exceed 100% i.e.

$$0 < n < 100$$

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.

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

V_w = volume of water
V_v = volume of voids

The degree of saturation varies between 0 and 100 i.e.

$$0 \le s \le 100$$

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

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

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

$$n_{a(\%)} = \frac{V_a}{V} \times 100 \quad , \quad 0 \le n \le 100$$

$$n_a = n a_c$$

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)

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

W = weight of soil mass

V = total volume of soil mass

Its S.I unit is KN / m^3

(b) Dry unit weight (¥$_d$): Defined as the weight of solids (w_s) per unit of total volume (v). $\gamma_d = \frac{w_s}{v}$

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

$$\gamma_{sat} = \frac{W_{sat}}{V}$$

(d) Submerged unit weight (¥ '): $\gamma' = \gamma_{sat} - \gamma_w$ 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. $\gamma' = \frac{1}{2}\gamma_{sat}$

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).

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

At 4°C, γ_w = 1 g/cc. or 9.81 kN/m^3.

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).

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

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 between.
- Soils with high quantity of iron or mica exhibit higher values.

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:

$$\boxed{eS = w\,G}$$

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

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

¥$_t$ = bulk unit weight of soil. ¥$_w$ = unit weight of water.

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

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

¥$_{sat}$ = Saturated unit weight ¥$_w$ = unit weight of water. ($\because$ $S = 1$)

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

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

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

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

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

$$= g\frac{(\rho_s - \rho_e)D^2}{18\mu} \quad (¥_d - ¥_w)$$

8. Relation between γ_t, γ_d and w:

$$\boxed{\gamma_d = \frac{\gamma_t}{(1+w)}}$$

9. Relation between γ_d, G, w, and n_a:

$$G = \frac{\gamma s}{\gamma w}$$

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:

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

METHODS OF WATER CONTENT DETERMINATION:

1. Oven-drying method:

→ Commonly adopted and the simplest method used in laboratory.

→ Samples are dried for 24 hour in the oven at temperature 105-110°C.

Water content, $w = \frac{W_2 - W_3}{W_3 - W_1} \times 100\ (\%)$

W_1 = weight of container

W_2 = weight of container with moist sample.

W_3 = weight of container with dried sample.

∴ Weight of water, $W_w = w_2 - w_3$

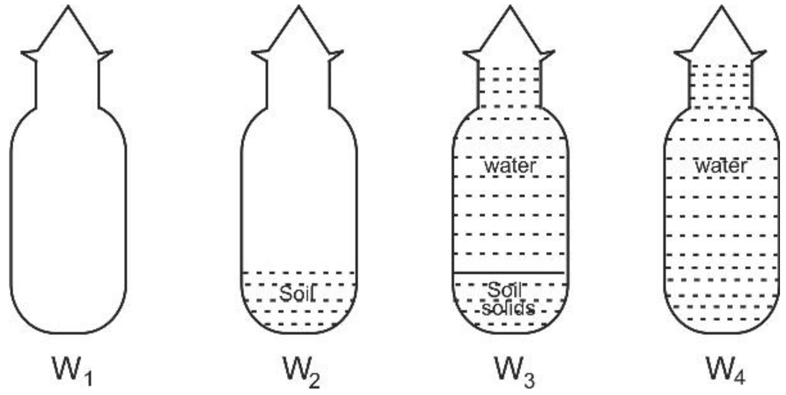
Weight of solids $W_s = w_3 - w_1$

2. Pycnometer method

→ Quick laboratory method.

→ Suitable for cohesionless soil.

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



W_1 = weight of empty pycnometer.

W_2 = weight of pycnometer + soil

W_3 = weight of pycnometer + soil + water

W_4 = weight of pycnometer + water

W_s = weight of soil solids.

∴ Water content, $\boxed{w = \frac{W_w}{W_s} \times 100}$ ....(i)

∴ Weight of water, $\boxed{W_w = (W_2 - W_1) - W_s}$ ....(ii)

Weight of solids (W_s) can be found by removing solids from 'W_3' and replacing it by weight of an equivalent volume of water, hence the weight 'W_4' will be:

$$W_3 - W_s + \left(\frac{W_s}{G\gamma_w}\right)\gamma_w = W_4 \qquad \left[\gamma_s = \frac{W_s}{V_s} \text{ and } G = \frac{\gamma_s}{\gamma_w}\right]$$

$$\Rightarrow \boxed{w_s = (w_3 - w_4)\frac{G}{G-1}} \qquad ....(iii)$$

Putting value of (ii) and (iii) in equation (i), water content will be

$$\therefore \qquad \boxed{W = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)} \cdot \frac{(G-1)}{G} - 1\right] \times 100\%}$$

Note: In this method G_s should be already known.

3. Sand Bath method:

→ Quick and field method.

→ Wet soil sample is placed in container and dried by placing it on a sand bath.

→ Water content is determined by using equation as used in *oven-drying method.*

→ Uniform heat is provided to soil mass in this method.

4. Rapid moisture Meter method:

→ Portable equipment.

→ Calcium carbide (CaC_2) is used as reagent.

→ It reacts with moisture of soil sample and produces acetylene gas (C_2H_2)

$$CaC_2 + 2H_2O \rightarrow C_2H_2 \uparrow + Ca(OH)_2$$

→ Instrument is calibrated to measure the pressure due to C_2H_2 as the percentage of moisture in the sample.

→ May not give actual value.

5. Torsion Balance moisture meter method:

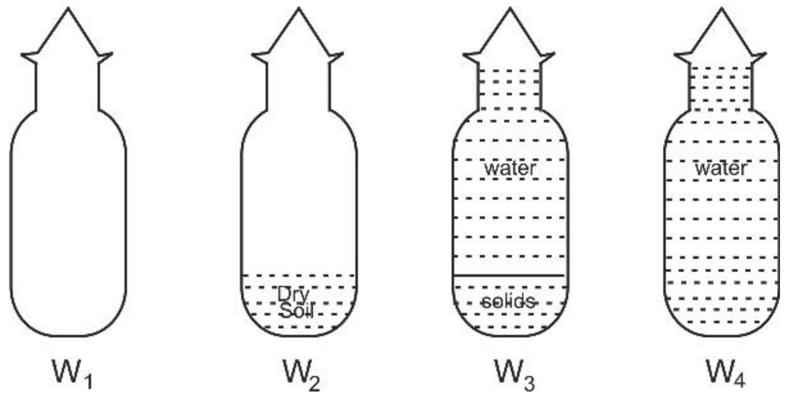
→ This method is good for soils which quickly reabsorb moisture from atmosphere. In this method weighing and drying is done simultaneously.

→ Laboratory method.

→ Infrared radiation is used for drying the sample.

<u>**DETERMINATION OF SPECIFIC GRAVITY OF SOIL SOLIDS:**</u>

→ Determined by using pycnometer.



W_1 = weight of empty pycnometer.

W_2 = weight of pycnometer + soil (oven dried)

W_3 = weight of pycnometer + soil solids + water

W_4 = weight of pycnometer + water

Weight of dry soil $W_s = (W_2 - W_1)$

Weight of water having the same volume as that of solids, W_w.

$$= (W_4 - W_1) - (W_3 - W_2) = (W_2 - W_1) - (W_3 - W_4)$$

$\therefore$ Specific gravity, $G = \dfrac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \dfrac{W_s}{W_s - W_3 + W_4}$

→ Specific gravity values are reported at 27°C (In India)

→ If T°c is the test temperature, then

Specific gravity at 27°C is given by:

$$G = \frac{\gamma s}{\gamma w}$$

As we know that γ_s does not very with change in temperature, so γ_s can be assumed const for all the temperatures.

There fore $G\gamma_{\omega} = \text{const.}$

or $G_{T°C}\gamma_{wT°C} = \text{const.}$

or $G_{27°C}\gamma_{w27°C} = \text{const.}$

Hence $$G_{T^\circ C} = \frac{G_{27^\circ C} \times \gamma_{w27^\circ C}}{\gamma_{wT^\circ C}}$$

DETERMINATION OF IN SITU WEIGHT:

1. Core cutter Method:

→ It cannot be used in case of hard and gravelly soil.

→ A core-cutter *(with 25 mm high dolly at top)* of known volume (1000 cc) is driven into soil using a hammer.

→ The cutter filled with soil is weighed and volume of cutter is calculated from the dimensions of cutter and thus In situ unit weight is determined by dividing soil weight by volume of cutter. $\gamma = \frac{W}{V}$

→ Dry unit weight, $\gamma_d = \frac{\gamma_t}{(1+W)}$

2. Sand replacement method:

→ Used in hard and gravelly soil.

→ A hole is made into the ground and the excavated soil is weighed. The volume of hole is determined by replacing with sand (*aeno sand*). Thus, In situ unit weight is calculated by dividing weight of excavated soil to the volume of the hole.

3. Water displacement method:

→ Suitable for cohesive soil only.

→ Suitable for soil from which lump can be taken out.

→ Sample is brought to a regular shape (weight W_1) and coated with a thin layer of paraffin wax and again weighed (*let* W_2). Now, the coated sample is placed into a metal container filled with water up to the brim. The displaced water (V_w) is measured. Hence the volume of uncoated soil specimen is given by

$$\boxed{V = V_w - \left(\frac{W_2 - W_1}{\gamma_{pa}}\right)}$$

γ_{pa} = unit weight of paraffin wax.

Hence, bulk unit weight of soil, $\gamma_t = \frac{W_1}{V}$

Dry unit weight of soil, $\gamma_d = \frac{\gamma_t}{(1+w)}\sigma_n$