MODULE 1-

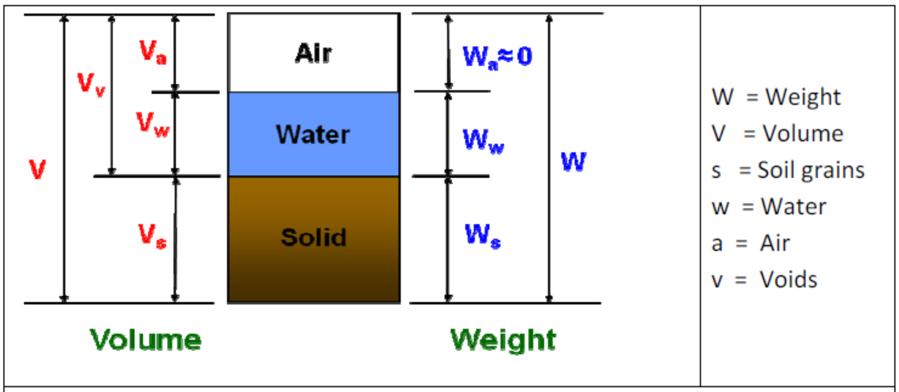
Introduction: Origin and formation of soil, Regional soil deposits in India, Phase Diagram, phase relationships, definitions and their interrelationships. Determination of Index properties: Specific gravity, water content, in-situ density, relative density, particle size analysis (sieve and Hydrometer analysis) Atterberg's Limits, consistency indices. Activity of clay, Field identification tests, Plasticity chart, BIS soil classification (IS: 1498-1970).

Soil formation: a geologic Cycle

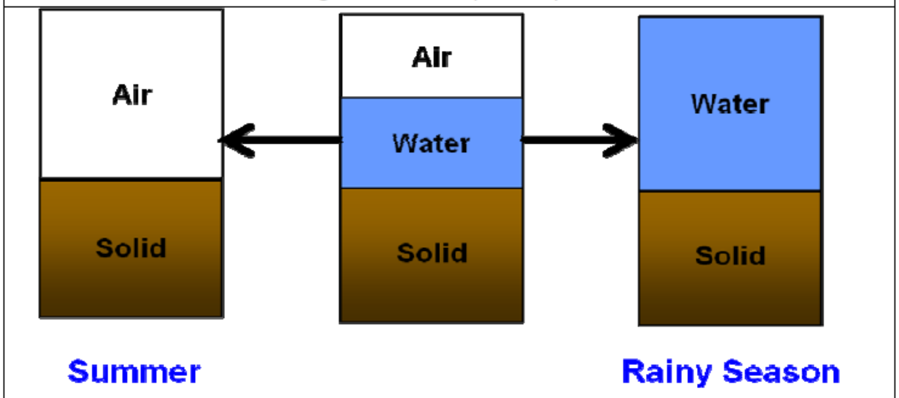
Soil is formed from rock due to erosion and weathering action. Igneous rock is the basic rock formed from the crystallization of molten magma. This rock is formed either inside the earth or on the surface. These rocks undergo metamorphism under high temperature and pressure to form Metamorphic rocks. Both Igneous and metamorphic rocks are converted in to sedimentary rocks due to transportation to different locations by the agencies such as wind, water etc. Finally, near the surface millions of years of erosion and weathering converts rocks in to soil.

Soil Mass, a three phase system

Soil mass comprises of solid particles and void space. The void space is filled with water and/or air. Hence, soil mass comprises of some volume of solid (soil particles), some volume of liquid (mostly soil water) and some volume of gas (air). Hence, the total volume of soil mass can be treated as a three phase system.



Basic terminologies in a three phase system of soil mass



Conversion from three to two phase system

Fig. 4 : Soil mass as three phase system

In general the soil sample will be consisting of soil solids, water & air which is designated as 3 phase system of soil. The sum of air content and water content of soil is called voids. If voids are completely filled with water such sample is called purely saturated sample. If voids are completely filled with air such sample is called purely dry sample.

On the other hand if part of the voids are filled with water and remaining with air it is called as partially saturated sample.

In the figure, W= Weight of soil sample
W_s or W_d = Weight of soil solids in the sample
W_w = Weight of water in the sample
$W_{a=}$= Weight of air in the sample can be consider as zero

V= Volume of soil sample
V_s = Volume of soil solids in the sample
V_w = Volume of water in the sample
V_a= Volume of air in the sample
V_v= Volume of voids in the sample($V_v = V_w + V_a$)
Further for 3 phase system , $V = V_s + V_w + V_a$
$W = W_s + W_w$
Further for 2 phase system (dry soil) , $V = V_s + V_a$
$W = W_s$

Further for 2 phase system(saturated soil) , $V = V_s + V_w$
$W = W_d + W_w$

Basic Definitions

The following are the basic definitions of soil.
1. Water Content (ω)
2. Void Ratio (e)
3. Porosity (n)
4. Degree of Saturation (S)
5. Air content (Ac)
6. Percentage air voids (na)
7. Bulk Density (γb)
8. Dry density (γd)
9. Density of soil solids (γs)
10. Saturated density (γsat)
11. Density of water (γω)
12. Submerged density (γsub)
13. Specific Gravity of Soil Solids (G)
14. Specific Gravity of Soil Mass (Gm)
15. Relative density (Dr)

Each of the above definition is defined with soil represented as three phase diagram.

Water Content (ω)

$$\omega = \frac{W_w}{W_d}$$

1. It is defined as ratio of weight of water to weight of solids.
2. It is also called Moisture Content.
3. It has no unit. It is expressed in percentage or decimals (for calculation purpose).
4. It indicates the amount of water present in the voids in comparison with weight of solids.
5. In dry soil, water content ω = 0.

6. Clayey soil may possess very large water content leading to unfavourable situation.
7. Water content of soil mass changes with season, being close to zero in summer and maximum during rainy season.
8. It represents the amount of water present in soil mass. In dry soil, water content $\omega = 0$
9. Higher the water content, greater will be the vulnerability, especially in clayey soil.

Void Ratio (e)

$$e = \frac{Vv}{Vs}$$

1. It is defined as the ratio of volume of voids to volume of solids
2. It has no unit. It is normally expressed in decimals.
3. It indicates the amount of voids present in a soil mass in comparison with the amount of solids.
4. Normally, void ratio of clayey soil will be large.
5. The more the void ratio, more loose will be the soil mass and hence, less strong and less stiff.
6. It is not possible to determine void ratio in the laboratory. Hence, it is computed from other properties.

Porosity (n)

$$n = \frac{Vv}{V}$$

1. It is defined as the ratio of volume of voids to total volume of soil mass.
2. It has no unit. It is expressed in decimals or percentage.
3. Its value ranges from 0 to 100 % ($0 < n < 1$).
4. Similar to void ratio, it indicates the amount of voids in comparison with the total volume of soil mass.
5. In some countries, it is more familiar than void ratio. But either can be used interchangeably in calculation.
6. Like void ratio, porosity is computed and can not be directly determined in the laboratory.

Degree of Saturation (S)

$$S = \frac{Vw}{Vv}$$

1. It is defined as the ratio of volume of water to volume of voids.
2. It has no unit. It is usually expressed in percentage.
3. Its value ranges from 0 to 100 % ($0 < S < 100$ %)
4. It represents the amount of water present in the void space of soil mass.
5. In dry soil, S = 0 and in fully saturated soil S = 100 %. Hence, during summer S is close to zero, while during rainy season, S is close to 100 %. In partially saturated soil, S lies between zero to 100 %.
6. It is computed and cannot be directly determined in the laboratory.

Air content (a_c)

$$a_c = \frac{Va}{Vv}$$

1. It is defined as the ratio of volume of air to volume of voids.

2. It has no unit. It is usually expressed in percentage.
3. Its value ranges from 0 to 100 % ($0 < Ac < 100$ %).
4. It represents the amount of air present in the void space of soil mass.
5. In dry soil, Ac is 100 % and in fully saturated soil Ac is 0 %. In partially saturated soil Ac lies between 0 and 100 %.
6. S + Ac = 1
7. It is computed and can not be directly determined in the laboratory.

<u>Percentage air voids (na)</u>

$$n_a = \frac{Va}{V}$$

1. It is defined as the ratio of volume of air to total volume of soil mass.
2. It has no unit. It is expressed in percentage.
3. Its value ranges from zero to 100 % ($0 < na < 100$ %).
4. It represents the amount of air present in the total volume of soil mass.
5. Always na < Ac.
6. It is computed and can not be directly determined in the laboratory.

<u>Bulk unit weight (γb) or (γ)</u>

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

1. It is defined as the ratio of total weight to total volume of soil mass.
2. In SI units, it is expressed as kN/m3.
3. Its value normally ranges from 12 to 24 kN/m3.
4. It includes the weights of air, water and solids as a function of total volume of soil mass. It changes with season, being maximum during rainy season and minimum in summer.
5. Bulk unit weight of soil mass can be determined experimentally. It is therefore used to compute other properties such as dry unit weight and void ratio.

<u>Dry unit weight (γd)</u>

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

1. It is defined as the ratio of weight of soil solids to total volume of soil mass.
2. In SI units, it is expressed as kN/m3.
3. Dry unit weight will always be less than or equal to bulk unit weight of soil mass.
4. Dry unit weight is independent of season. Hence, it is used in many design calculations such as safe bearing capacity of soil.
5. Knowing water content and bulk unit weight, dry unit weight can be computed.

<u>Unit weight of soil solids (γs)</u>

$$\gamma s = \frac{W\,d}{Vs}$$

1. It is defined as the ratio of weight of soil solids to volume of soil solids.
2. In SI units, it is expressed as kN/m3.
3. It is always greater than dry unit weight of soil.
4. It can not be determined experimentally. Hence, it is computed from other parameters. It is used to calculate other properties such as specific gravity of soil solids.

<u>Saturated unit weight (γsat)</u>

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

1. It is defined as the ratio of total weight to total volume of soil mass when

the soil is fully saturated. Hence, it is the bulk unit weight of soil mass when S =1.
2. In SI units, it is expressed as kN/m3.

Unit weight of water (γω)

1. It is defined as the ratio of weight of water to volume of water.
2. In SI units, it is expressed in kN/m3 and can be taken as 9.8 kN/m3.
3. It is used in computation of other quantities.

Submerged unit weight (γsub) or γ'

1. It is defined as the net weight of weight per volume of soil mass in water.
2. In SI units, it is expressed as kN/m3.
3. It is equal to saturated unit weight minus unit weight of water.
4. $\gamma' = \gamma_{sat} - \gamma_\omega$
5. It is also called buoyant unit weight
6. In saturated soil, water exerts upward pressure on soil. Net weight of soil particles acting downward will be actual weight of soil minus weight of water.

Bulk Density (ρ)

1. It is defined as the ratio of total mass to total volume of soil mass.
2. It is expressed as g/cm3.
3. It includes the mass of air, water and solids as a function of total volume of soil mass. It changes with season, being maximum during rainy season and minimum in summer.
5. Bulk density of soil mass can be determined experimentally. It is therefore used to compute other properties such as dry density and void ratio.

Dry density (ρ_d)

1. It is defined as the ratio of mass of soil solids to total volume of soil mass.
2. It is expressed as g/cm3.
3. Dry density will always be less than or equal to bulk density of soil mass.
4. Dry density is independent of season. Hence, it is used in many design calculations such as safe bearing capacity of soil.
5. Knowing water content and bulk density, dry density can be computed.

Density of soil solids (ρ_S)

1. It is defined as the ratio of mass of soil solids to volume of soil solids.
2 It is expressed as g/cm3.
3. It is always greater than dry density of soil.
4. It can not be determined experimentally. Hence, it is computed from other parameters. It is used to calculate other properties such as specific gravity of soil solids.

Saturated density (ρsat)

1. It is defined as the ratio of total mass to total volume of soil mass when the soil is fully saturated. Hence, it is the bulk density of soil mass when S =1.
2. It is expressed as g/cm3

Density of water (ρω)

1. It is defined as the ratio of mass of water to volume of water.
2 It is expressed as g/cm3 and can be taken as 1 g/cm3
3. It is used in computation of other quantities.

Submerged density (ρsub) or ρ'

1. It is defined as the net weight of mass per volume of soil mass in water.
2. It is equal to saturated density minus density of water.

3. **ρ' = ρsat − ρω**
4. It is also called buoyant density.
5. In saturated soil, water exerts upward pressure on soil. Net weight of soil particles acting downward will be actual weight of soil minus weight of water.

Specific Gravity of Soil Solids (G)

1. It is defined as the weight of soil solids to weight of equal volume of water.
2. Hence, it is the ratio of density of soil solids to density of water.
3. It has no units and is expressed in decimals.
4. Normally, G of most soils varies from 2.6 to 2.75. Organic soils may have G up to 2.
5. G is determined in the laboratory and is used to compute other parameters such as void ratio.
6. Many a times, specific gravity means G

Specific Gravity of Soil Mass (Gm)

1. It is defined as the weight of soil mass to weight of equal volume of water.
2. It is also called Apparent Specific Gravity.
3. It has no units and is expressed in decimals.
4. Its magnitude is always smaller than that of G.
5. It is less commonly used in calculations.

Relative density (Dr) or (I_D)

1. It is also called Density Index.
2. It has no unit. It is expressed in percentage.
3. Dr ranges from 0 to 100 %.
4. It is applicable for coarse grained soil such as sand and gravel.
5. It indicates whether the insitu density of soil is close to loosest or densest state.

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

7. In terms of dry density, relative density is given as follows.

$$D_r = \left(\frac{\gamma_{d\,max}}{\gamma_d}\right)\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}$$

8. When Dr = 1, soil in its densest state and when Dr = 0, soil is in its loosest state.

Table : Influence of Relative density on Soil State

Relative Density (%)	State of Soil
0 to 20	Very Loose
20 to 40	Loose
40 to 60	Medium dense
60 to 80	Dense
80 to 100	Very Dense