Introduction:

The term "soil" can have different meanings, depending upon the field in which it is considered.

To a geologist, it is the material in the relative thin zone of the Earth's surface within which roots occur, and which are formed as the products of past surface processes. The rest of the crust is grouped under the term "rock".

To a pedologist, it is the substance existing on the surface, which supports plant life.

To an engineer, it is a material that can be:

- built on: foundations of buildings, bridges
- built in: basements, culverts, tunnels
- built with: embankments, roads, dams
- supported: retaining walls

Soil Mechanics is a discipline of Civil Engineering involving the study of soil, its behaviour and application as an engineering material.

Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether or not they contain an admixture of organic constituents.

Soil consists of a multiphase aggregation of solid particles, water, and air. This fundamental composition gives rise to unique engineering properties, and the description of its mechanical behavior requires some of the most classic principles of engineering mechanics.

Engineers are concerned with soil's mechanical properties: permeability, stiffness, and strength. These depend primarily on the nature of the soil grains, the current stress, the water content and unit weight.

Formation of Soils:

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.



Fig. Geologic Cycle of Soil

Soils are formed from materials that have resulted from the disintegration of rocks by various processes of physical and chemical weathering. The nature and structure of a given soil depends on the processes and conditions that formed it:

- Breakdown of parent rock: weathering, decomposition, erosion.
- Transportation to site of final deposition: gravity, flowing water, ice, wind.
- Environment of final deposition: flood plain, river terrace, glacial moraine, lacustrine or marine.
- Subsequent conditions of loading and drainage: little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching, contamination.

All soils originate, directly or indirectly, from different rock types.

Weathering:

Physical weathering reduces the size of the parent rock material, without any change in the original composition of the parent rock. Physical or mechanical processes taking place on the earth's surface include the actions of water, frost, temperature changes, wind and ice. They cause disintegration and the products are mainly coarse soils.

The main processes involved are exfoliation, unloading, erosion, freezing, and thawing. The principal cause is climatic change. In exfoliation, the outer shell separates from the main rock. Heavy rain and wind cause erosion of the rock surface. Adverse temperature changes produce fragments due to different thermal coefficients of rock minerals. The effect is more for freeze-thaw cycles.

Chemical weathering not only breaks up the material into smaller particles but alters the nature of the original parent rock itself. The main processes responsible are hydration, oxidation, and carbonation. New compounds are formed due to the chemical alterations.

Rain water that comes in contact with the rock surface reacts to form hydrated oxides, carbonates and sulphates. If there is a volume increase, the disintegration continues. Due to leaching, water-soluble materials are washed away and rocks lose their cementing properties.

Chemical weathering occurs in wet and warm conditions and consists of degradation by decomposition and/or alteration. The results of chemical weathering are generally fine soils with altered mineral grains.

The effects of weathering and transportation mainly determine the basic nature of the soil (size, shape, composition

and distribution of the particles).

The environment into which deposition takes place, and the subsequent geological events that take place there, determine the *state* of the soil (density, moisture content) and the *structure* or fabric of the soil (bedding, stratification, occurrence of joints or fissures)

Transportation agencies can be combinations of gravity, flowing water or air, and moving ice. In water or air, the grains become sub-rounded or rounded, and the grain sizes get sorted so as to form poorly-graded deposits. In moving ice, grinding and crushing occur, size distribution becomes wider forming well-graded deposits.

In running water, soil can be transported in the form of suspended particles, or by rolling and sliding along the bottom. Coarser particles settle when a decrease in velocity occurs, whereas finer particles are deposited further downstream. In still water, horizontal layers of successive sediments are formed, which may change with time, even seasonally or daily.

Wind can erode, transport and deposit fine-grained soils. Wind-blown soil is generally uniformly-graded.

A glacier moves slowly but scours the bedrock surface over which it passes.

Gravity transports materials along slopes without causing much alteration.

Soil Types:

Soils as they are found in different regions can be classified into two broad categories:

(1)Residual soils(2) Transported soils

Residual Soils:

Residual soils are found at the same location where they have been formed. Generally, the depth of residual soils varies from 5 to 20 m.

Chemical weathering rate is greater in warm, humid regions than in cold, dry regions causing a faster breakdown of rocks. Accumulation of residual soils takes place as the rate of rock decomposition exceeds the rate of erosion or transportation of the weathered material. In humid regions, the presence of surface vegetation reduces the possibility of soil transportation.

As leaching action due to percolating surface water decreases with depth, there is a corresponding decrease in the degree of chemical weathering from the ground surface downwards. This results in a gradual reduction of residual soil formation with depth, until unaltered rock is found.

Residual soils comprise of a wide range of particle sizes, shapes and composition.

Transported Soils:

Weathered rock materials can be moved from their original site to new locations by one or more of the transportation agencies to form transported soils. Transported soils are classified based on the mode of transportation and the final deposition environment.

(a) Soils that are carried and deposited by rivers are called *alluvial deposits*.

(b) Soils that are deposited by flowing water or surface runoff while entering a lake are called *lacustrine deposits*. atlernate layers are formed in different seasons depending on flow rate.

(c) If the deposits are made by rivers in sea water, they are called *marine deposits*. Marine deposits contain both particulate material brought from the shore as well as organic remnants of marine life forms.

(d) Melting of a glacier causes the deposition of all the materials scoured by it leading to formation of *glacial deposits*.

(e) Soil particles carried by wind and subsequently deposited are known as *aeolian deposits*.

Phase Relations of Soils:

Soil is not a coherent solid material like steel and concrete, but is a particulate material. Soils, as they exist in nature, consist of solid particles (mineral grains, rock fragments) with water and air in the voids between the particles. The water and air contents are readily changed by changes in ambient conditions and location.

As the relative proportions of the three phases vary in any soil deposit, it is useful to consider a soil model which will represent these phases distinctly and properly quantify the amount of each phase. A schematic diagram of the three-phase system is shown in terms of weight and volume symbols respectively for soil solids, water, and air. The weight of air can be neglected.



The soil model is given dimensional values for the solid, water and air components.

Total volume, $V = V_s + V_w + V_v$

Three-phase System:

Soils can be partially saturated (with both air and water present), or be fully saturated (no air content) or be perfectly dry (no water content).

In a saturated soil or a dry soil, the three-phase system thus reduces to two phases only, as shown.



The various relations can be grouped into:

- Volume relations
- Weight relations
- Inter-relations

Volume Relations:

As the amounts of both water and air are variable, the volume of solids is taken as the reference quantity. Thus, several relational volumetric quantities may be defined. The following are the basic volume relations:

1. Void ratio (e) is the ratio of the volume of voids (V_v) to the volume of soil solids (V_s) , and is expressed as a decimal.

$$e = \frac{V_V}{V_S}$$

2. Porosity (n) is the ratio of the volume of voids to the total volume of soil (V), and is expressed as a percentage.

$$n = \frac{V_{\rm V}}{V} x \, 100$$

Void ratio and porosity are inter-related to each other as follows:

$$e = \frac{n}{1-n}$$
 and $n = \frac{e}{(1+e)}$

3. The volume of water (V_w) in a soil can vary between zero (i.e. a dry soil) and the volume of voids. This can be expressed as the degree of saturation (S) in percentage.

$$S = \frac{V_W}{V_V} x \, 100$$

For a dry soil, S = 0%, and for a fully saturated soil, S = 100%.

4. Air content (a_c) is the ratio of the volume of air (V_a) to the volume of voids.

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

5. Percentage air voids (n_a) is the ratio of the volume of air to the total volume.

$$n_a = \frac{V_a}{V} x \, 100 = n \, x \, a_c$$

Weight Relations:

Density is a measure of the quantity of mass in a unit volume of material. Unit weight is a measure of the weight of a unit volume of material. Both can be used interchangeably. The units of density are ton/m³, kg/m³ or g/cm³. The following are the basic weight relations:

1. The ratio of the mass of water present to the mass of solid particles is called the water content (w), or sometimes the moisture content.

$$w = \frac{W_W}{W_S}$$

Its value is 0% for dry soil and its magnitude can exceed 100%.

2. The mass of solid particles is usually expressed in terms of their particle unit weight (γ_5) or specific gravity (G_s) of the soil grain solids.

$$\gamma_s = \frac{W_s}{V_s} = G_s, \gamma_W$$

where γ_{W} = Unit weight of water

For most inorganic soils, the value of G_s lies between 2.60 and 2.80. The presence of organic material reduces the value of G_s .

3. Dry unit weight (γ_d) is a measure of the amount of solid particles per unit volume.

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

4. Bulk unit weight $(\gamma_t \text{ or } \gamma)$ is a measure of the amount of solid particles plus water per unit volume. $\gamma_t = \gamma = \frac{(W_s + W_W)}{(\gamma_t + W_W)}$

$$\gamma_t = \gamma = \frac{(V_s - V_w)}{(V_s + V_v)}$$

5. Saturated unit weight (γ_{sat}) is equal to the bulk density when the total voids is filled up with water.

6. Buoyant unit weight (γ) or **submerged unit weight** is the effective mass per unit volume when the soil is submerged below standing water or below the ground water table.

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

Inter-Relations:

It is important to quantify the state of a soil immediately after receiving in the laboratory and prior to commencing other tests. The water content and unit weight are particularly important, since they may change during transportation and storage.

Some physical state properties are calculated following the practical measurement of others. For example, dry unit weight can be determined from bulk unit weight and water content. The following are some inter-relations:

$$w = \frac{W_W}{W_s} = \frac{\gamma_W \cdot V_W}{G_s \cdot \gamma_W \cdot V_s} = \frac{V_W}{G_s \cdot V_s} = \frac{S \cdot V_v}{G_s \cdot V_s} = \frac{S \cdot e}{G_s}$$

$$\gamma = \frac{(G_s + S \cdot e) \cdot \gamma_w}{1 + e}$$

$$\gamma_d = \frac{(1 + w) \cdot G_s \cdot \gamma_w}{1 + e}$$

$$\gamma_d = \frac{G_s \cdot \gamma_w}{1 + e}$$

$$\gamma_d = \frac{\gamma}{1 + w}$$

$$\gamma' = \frac{[(G_s - 1) + (S - 1)e] \times \gamma_w}{1 + e}$$

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

Example 1: A soil has void ratio = 0.72, moisture content = 12% and $G_s = 2.72$. Determine its (a) Dry unit weight

(b) Moist unit weight, and the

(c) Amount of water to be added per m^3 to make it saturated.

Use $\gamma_w = 9.81 \, kN \, m^3$

Solution:

(a)
$$\gamma_d = \frac{G_s \cdot \gamma_w}{1+e} = \frac{2.72 \times 9.81}{1+0.72} = 15.51 \text{ kN/m}^3$$

(b)
$$\gamma = \gamma_d (1 + w)$$

 $= \frac{1 + 0.12}{1 + 0.72} \times 2.12 \times 9.81$
 $= 17.38 \text{ kN/m}^3$
(c) $\gamma_{sat} = \frac{G_s + e}{1 + e} \cdot \gamma_w$
 $= \frac{2.72 + 0.72}{1 + 0.72} \times 9.81$
 $= 19.62 \text{ kN/m}^3$

Water to be added per m³ to make the soil saturated

 $= \gamma_{sat} - \gamma = 19.62 - 17.38 = 2.24$ kN

Example 2: The dry density of a sand with porosity of 0.387 is 1600 kg/m³. Find the void ratio of the soil and the specific gravity of the soil solids. [Take $\gamma_{w} = 1000 \text{ kg}/m^{3}$]

n = 0.387 $\gamma_d = 1600 \text{ kg/m}^3$

Solution:

(a)
$$e = \frac{n}{1-n} = \frac{0.387}{1-0.387} = 0.631$$

(b) $\gamma_d = \frac{G_s \cdot \gamma_w}{1+e}$

$$\therefore \mathbf{G}_{s} = \frac{(1+e)}{\gamma_{w}}, \gamma_{d} = \frac{1+0.631}{1000} \times 1600 = 2.61$$