CIVIL ENGINEERING

Soil Mechanics and Foundation Engineering

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Soil Mechanics and Foundation Engineering

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CHAPTER

1

Origin of Soil and its Formation

1.1 INTRODUCTION

The term 'soil', is generally used for upper layer of the earth surface which can support plants. However for engineering purposes, soil is defined as the uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles.

Soil is an unconsolidated material that has resulted from the disintegration of rocks by various weathering agencies like water, air etc. The soil may contain inorganic or organic matter and can be represented as a three phase system containing solids, water and air. Soil is used as a construction material in various civil engineering projects and it supports structural foundations.

1.1.1 Soil Mechanics Vs Soil Engineering Vs Geotechnical Engineering

Soil mechanics is the branch of science that deals with the study of physical properties of soil and the behaviour of soil masses subjected to various types of forces. The term 'Soil Mechanics' was given by Dr. Karl Terzaghi in 1925, who is also known as the Father of Soil Mechanics. According to Terzaghi, "Soil mechanics is the branch of civil engineering that is concerned with the application of the principles of mechanics, hydraulics and chemistry to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the weathering of rocks, that may or may not contain admixtures of organic constituents."

Soil Engineering is the application of principles of soil mechanics to practical purposes. It is a broader term including soil mechanics, geology, structural engineering and soil dynamics which are essential to obtain practical solution to problems related to the soil. It includes site investigation, lab testing, design, construction and maintenance of foundations and earth retaining structures.

Geotechnical Engineering is the sub-discipline of civil engineering that involves natural materials found closer to the surface of the earth. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures and earth structures. Geotechnical Engineering is a broader term which includes soil mechanics, rock mechanics, rock engineering, geology and soil engineering.

1.2 ORIGIN OF SOIL

Almost all the soils are formed by the disintegration of rocks either through physical disintegration or chemical decomposition. If weathered sediments remain over parent rock, then soil is called 'Residual soil' and if weathered sediments are transported and deposited at some other place, then soil is called 'Transported soil'. Residual soils have better engineering properties.

The process of soil formation is called '**Pedogenesis**'. The soil formation is cyclic which is called 'Geological cycle'.

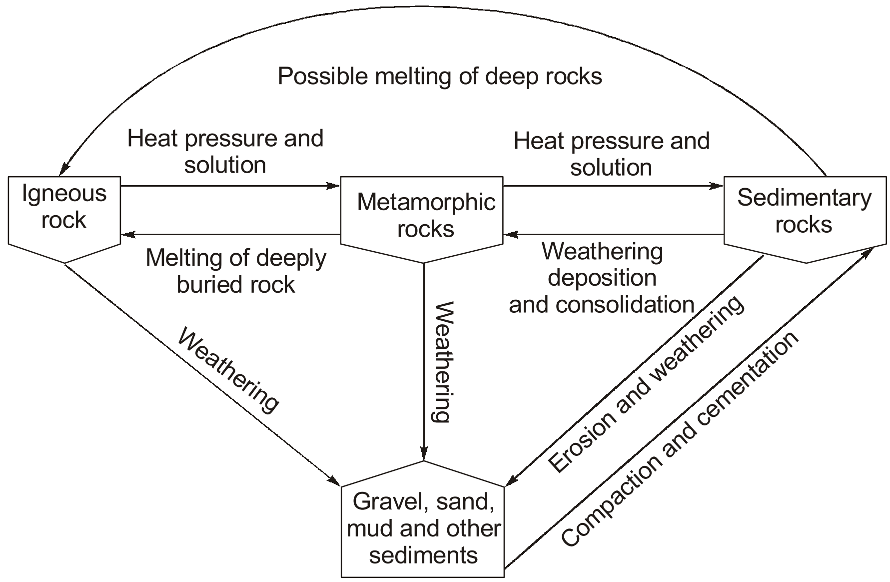


Fig. Geological cycle (suggested by Bowles, 1984)

The stages in the geological cycle of soil formation in transported soil are as follows:

(1) Weathering
(2) Transportation
(3) Deposition of weathered materials
(4) Upheaval

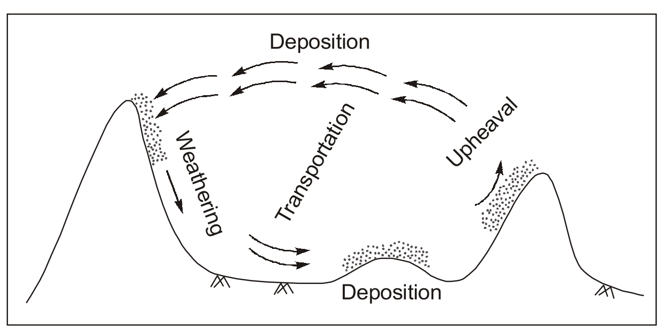


Fig. Stages of Geological Cycle in case of transported soil

1.2.1 Weathering Stage

Rock disintegration, also called weathering, is one of the important geological process. Weathering may be physical (mechanical) or chemical.

(a) Physical Weathering: In Physical weathering, rock disintegrates into smaller fragments due to various agencies like running water, heavy wind, temperature changes, rainfall and human activities. Physical weathering can also be caused by alternate freezing and thawing of water in cracks of the rocks. Generally, sand and gravel fall in this category.

The mineral constituents remains same as that of parent rock, if soil is formed as a result of physical weathering.

(b) Chemical Weathering: Fragmented rock materials obtained by physical weathering sometimes changes their mineral composition and new compounds are formed. This phenomenon is referred as 'Chemical Weathering'.

Chemical weathering is caused mainly by oxidation, hydration, carbonation, leaching water and organic acids. Generally, clays and to some extent silts fall in this category.

1.2.2 Transportation and Deposition

The fragmented rock material obtained by weathering may be transported by agents like running water (i.e. rivers), moving ice (i.e. glaciers), blowing wind and gravity to new locations. The weathered fragmented materials transported and deposited at some other place are called 'Transported soil'.

On the basis of transporting agency, soil may be classified as:

(a) Water transported soil: These sedimentary deposits are of three types:

(i) Alluvial deposit
(ii) Lacustrine deposit
(iii) Marine deposit

(i) Alluvial deposit (Alternate Layer of Sand + Silt + Clay): Swift running water carry a large quantity of soil either in suspension or by rolling and sliding along the bottom of stream. When decrease in water velocity occurs, these sediments get deposited from suspension in running water. This type of soil is called 'Alluvial soil'.

Some of the examples of alluvial soil deposit are Alluvial cones, Natural levees and Delta.

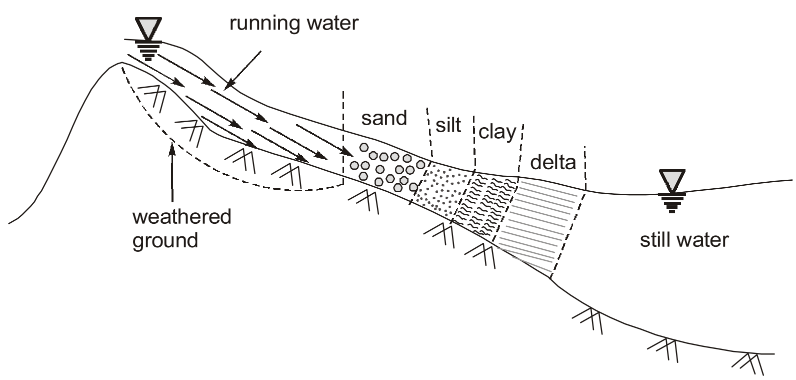


Fig. Alluvial deposit

(ii) Lacustrine deposit: Soil carried by river, while entering a lake, deposits all the coarse particles because of a sudden decrease in velocity but the fine grained particles moves to the centre of the lake and settles when the water becomes still. Alternate layers are formed with season, and such lake deposits are called 'Lacustrine deposit'.

(iii) Marine Soil: These are soils that have been formed by sedimentation of soil particles in the deep sea water. The marine deposits have very low shearing strength and are highly compressible. They contain a large amount of organic matter. The marine clays are soft and highly plastic.

(b) Wind Transported Soil: Like water, wind can erode, transport and deposit fine grain soils. The soils that have been transported and deposited by wind are called 'Aeolian deposits'. Dunes are formed due to accumulation of such wind deposited sand.

Loess: Loess is a silt deposit made by wind. These deposits have low density, slight cementation, high compressibility and poor bearing capacity in wet condition.

(c) **Glacial Deposits:** Glaciers are large masses of ice formed by the compaction of snow. A glacier moves extremely slow but deforms and scour the surface and the bedrock over which it passes. Melting of a glacier cause deposition of all the materials and such a deposit is referred to as till. Drift is a general term used for the deposits made by glaciers directly or indirectly.

The particles found in glacial deposits are generally angular, in contrast to the more rounded particles associated with typical waterborne deposits.

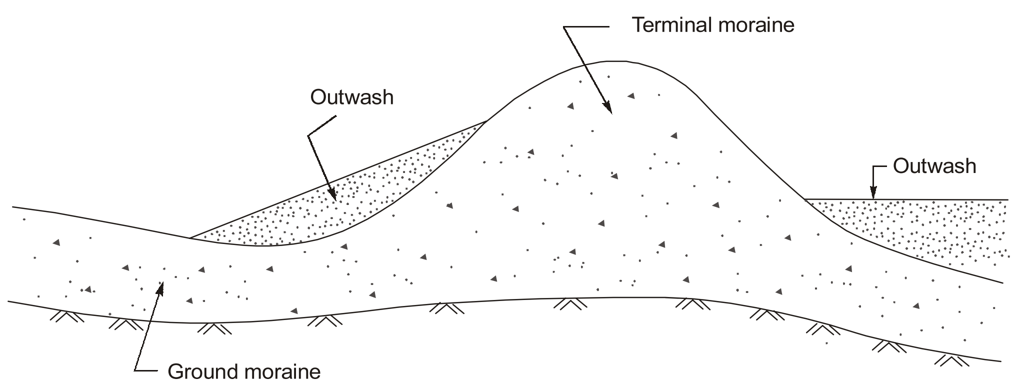


Fig. Glacier Deposited Soil

(d) **Gravity Deposits:** Gravity can transport materials for short distance. Gravity deposits are termed as Colluvial soil or Talus. These soils are found in mountain valley where these were transported from higher elevation by gravity forces. On sloppy mountain, due to moisture variation, sediments start creeping down. Also, due to swelling and shrinkage, land slide may occur which may result into deposits in the valley. These soil consists of irregular particles of varying size.

(e) **Swamp and Marsh Deposits:** In water stagnated areas where the water table is fluctuating and vegetation growth is possible, swamp and marsh deposits develop. These soils are soft, high in organic content and unpleasant in odour. Accumulation of partially or fully decomposed aquatic plants in swamps or marshes is termed 'muck or peat'. Muck soil is light in weight, highly compressible, so this is not suitable for construction purpose.

(f) **Soil transported by combined action:** Sometimes, more than one transportation agencies act jointly and transport the soil. For example, soil may fall under gravity which may be further carried by wind to a far off place. This soil might be picked up by flowing water and deposited at some other place.

1.3 SOIL DEPOSITS IN INDIA

In India, soil has been divided into five major groups

- Alluvial deposits
- Laterite soil
- Marine Deposits
- Black cotton soil
- Desert soil

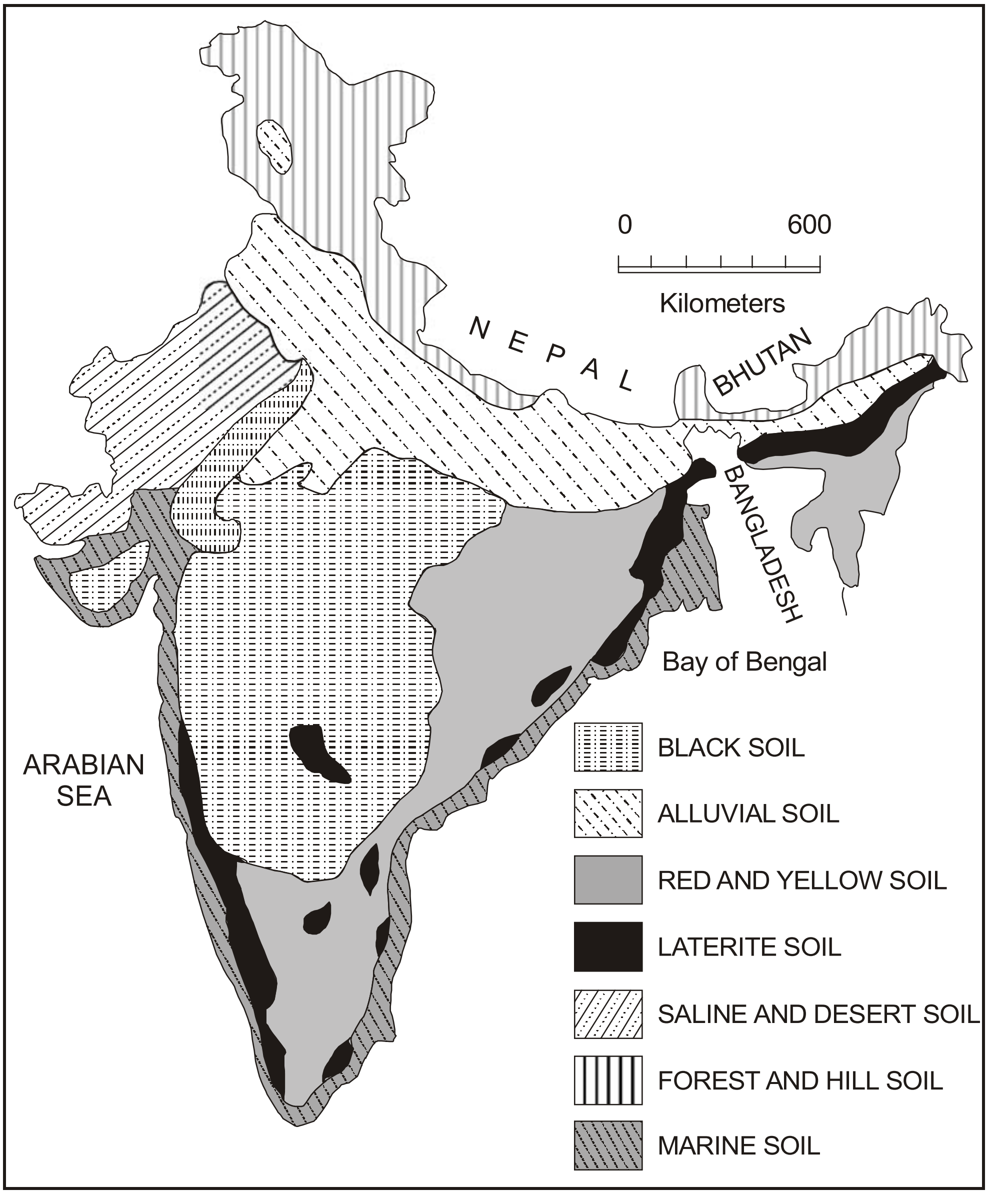


Fig. Soil map of India

1.4 ORGANIC AND INORGANIC SOILS

Soils can also be classified as organic or inorganic soil.

- Organic soils are formed by growth and subsequent decomposition of plant. For example, Peat and Mosses.
- In general, organic soil is that transported soil obtained from rock weathering which contains decomposed vegetable matter.
- Inorganic soil refer to ordinary soil obtained from rock disintegration due to weathering.

1.5 COMMON TYPES OF SOILS

- **Loess:** This is wind blown uniformly graded fine soil. Loess soil is having a particle size of 0.01 – 0.05 mm. These soils are slightly cementitious due to the presence of deposits of calcium carbonate, derived from decayed vegetative matter. When wet, it becomes soft and compressible because cementing action is lost. These are found in Rajasthan and North Gujarat.
- **Caliche:** It is cemented soil rich in calcium carbonate consisting of gravel, sand and clays. These are also wind blown in semi-arid climate and later on cemented by the calcium carbonate left out from the evaporation of capillary water.
- **Loam:** It is a mixture of sand, silt and clay in definite proportion which in some cases may consist of organic matter.
- **Cumulose:** Peaty (organic) soils are also called cumulose soil or muck. These are formed due to accumulation of organic content under waterlogged condition. It is generally found in the areas having deficient sewerage facilities or found after overflooding of the rivers.
- **Gumbo:** These are highly sticky, plastic and dark coloured soil.
- **Marl:** These are fine grained calcium carbonated soil of marine origin. These are formed due to decomposition of cell mass and bones of aquatic life.
- **Humus:** This soil is a mixture of mud and dead plants. The tiny pieces of rock and humus join to make various soils.
- **Peat:** It is a highly organic soil containing almost decomposed vegetable matter.
- **Gravel:** Gravel is a type of coarse grain soil having particle size in the range of 4.75 mm to 80 mm. It is a cohesionless material.
- **Sand:** They are cohesionless aggregates of rounded, sub angular or angular sediment in the range of 0.075 mm to 4.75 mm.
- **Silt:** It is a fine-grained soil, with particle size between 0.002 mm and 0.075 mm. Silt can be inorganic or organic. Inorganic silt consists of equidimensional grains of quartz, having no plasticity and is cohesionless. Whereas, organic silt is plastic and is cohesive.
- **Clay:** It is an aggregate of mineral particles of microscopic and submicroscopic range. Clay may be organic or inorganic. The particle size is less than 0.002 mm.
- **Cobbles:** Cobbles are large size particles in the range of 80 mm to 300 mm.
- **Boulders:** Boulders are rock fragment of large size (more than 300 mm).
- **Tuff:** These are small grained slightly cemented volcanic ash that has been transported by wind or water.
- **Bentonite:** It is a clay formed by chemical weathering of volcanic ash which have high content of montmorillonite. Hence it shows high swelling and shrinkage, high plasticity and low shear strength. Pulverized slurry of bentonite is highly plastic and is often used as a lubricant in drilling.
- **Kaolin (China Clay):** It is a very pure form of white clay, which is extensively used in ceramic industry.
- **Hardpans:** Hardpans are types of soils that offer great resistance to the penetration of drilling tools during soil exploration. These are generally dense, well graded, cohesive aggregates of mineral particles. They do not disintegrate when submerged in water.
- **Varved Clays:** These are sedimentary deposits consisting of alternate thin layers of silt and clay. These clays are the result of deposition in lakes during periods of alternate high and low waters.
- **Till:** It is formed by melting of glaciers and iceberg and may contain mixture of gravel, sand, silt and clay. These soils are well graded.
- **Black Cotton Soil**: It is chemically weathered residual soil formed from basalt. It contains high amount of Montmorillonite (clay mineral), hence it shows high swelling, shrinkage and low shear strength.
- **Laterite Soil**: It is formed due to leaching (washing out of silicious compound and accumulation of aluminium and Iron). It is found in humid areas like Western Ghats, Eastern Ghats and Great North East.

OBJECTIVE BRAIN TEASERS

Q.1 Glaciers are formed by
(a) Compaction and recrystallization of snow
(b) Continuous freezing of water
(c) A sudden drop in temperature below 0°C
(d) None of above process

Q.2 When the product of rock weathering are not transported as sediment but remain in place, then the soil is known as
(a) Alluvial soil (b) Glacial soil
(c) Residual soil (d) Aeolian soil

Q.3 Identify the true statements from the following
(a) A soil transported by gravitational force is called talus
(b) Lateritic soil is a category of organic soil
(c) Water held firmly to the clay particles has the same properties as ordinary water.
(d) A clay deposit which exibits no evidence of fissuring is described as intact.

Q.4 Bentonite is a material obtained due to the weathering of
(a) Lime stone (b) Quartzite
(c) Volcanic ash (d) Shales

Q.5 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	List-II
A. Wind	1. Lacustrine
B. Lake	2. Loess
C. Gravity	3. Till
D. Glacier	4. Talus

Codes:

	1	2	3	4
(a)	A	C	B	D
(b)	B	A	D	C
(c)	C	A	C	D
(d)	D	B	A	C

Q.6 Match **List-I** (Type of soil) with **List-II** (Mode of transportation and deposition) and select the correct answer using the codes given below the lists:

List-I
A. Residual soil
B. Loess
C. Peat
D. Varved clays

List-II
1. Soil transported by wind
2. Organic soil
3. Deposition in lake during periods of alternate high and low waters
4. Soil left in place after weathering of parent rock

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	3	4	1
(c)	4	1	2	3
(d)	3	2	1	4

Q.7 **Assertion (A):** Black cotton soils are clay and exhibit characteristic property of swelling.
Reason (R): These clays contain Montmorillonite which attracts external water into its lattice structure.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.8 **Assertion (A):** Collapsible soil suddenly decreases in volume when it becomes saturated.
Reason (R): Collapsible soils are mostly aeolin soils, which have high void ratio and a honey combed structure in natural state.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

ANSWER KEY

1. (a)	2. (c)	3. (a)	4. (c)	5. (b)
6. (c)	7. (a)	8. (a)		

■■■■

CHAPTER

2

Properties of Soils

2.1 INTRODUCTION

Soil is essentially made up of solid particles, with spaces or voids in between. The assemblage of particles in contact is usually referred to as the 'soil matrix' or the 'soil skeleton'. The intermittent void spaces are filled up by either air or water or both air and water. This means that an element of 'soil' may be considered as a three-phase material, comprising of some solid (soil grains), some liquid (pore water) and some gas (pore air). The proportion of these phases affects the properties of soil.

2.2 PHASE DIAGRAM

- Soil mass, in general is a three phase system composed of solid, liquid and gaseous phase.
- Different phases present in soil mass cannot be separated. For better understanding, all three constituents are assumed to occupy separate spaces as shown in figure below.

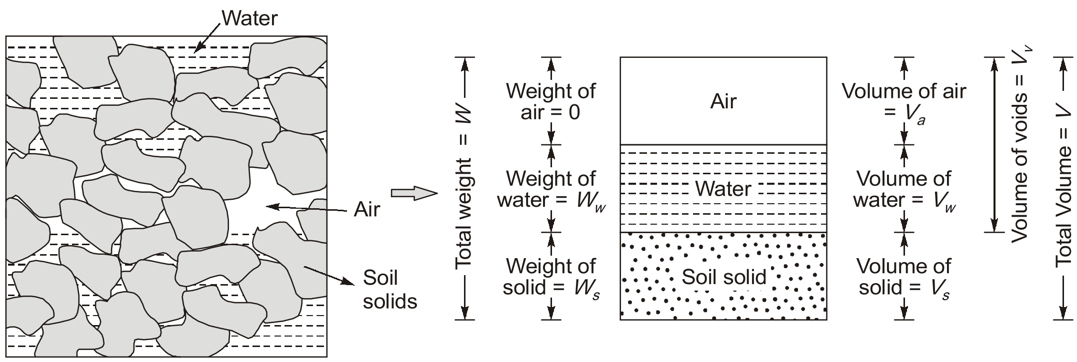
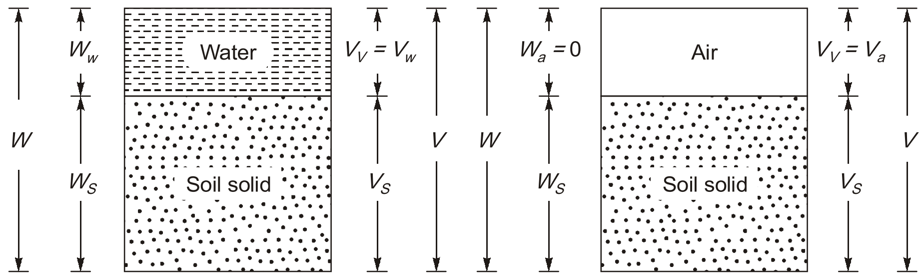


Fig. Three Phase diagram

- In phase diagrams, the weight of air is negligible as compared to soil solid and water and is thus assumed to be zero.
- The diagrammatic representation of the different phases in a soil mass is called the 'phase diagram', or 'block diagram'.
- A three-phase diagram is applicable for a partially saturated soil ($0 < S < 1$)
- When all the voids are filled with water, the sample becomes saturated and thus the gaseous phase is absent; whereas, in oven dry soil sample the liquid phase is absent. Thus, in saturated and oven dry soils, the three phase system reduces to two phase system.



(a) Water and soil solids (Fully saturated soil, S = 1)

(b) Air and soil solids (Oven dry soil, S = 0)

Fig. Two Phase diagram

2.3 BASIC DEFINITIONS

2.3.1 Water Content (*w*)

- Water content (w) is also called moisture content. It is the ratio of weight of water (W_w) to the weight of soil solids (W_s).

$$w = \frac{W_w}{W_s}; \qquad w \geq 0$$

- It is generally represented as a percentage.
- The water content of a oven dry soil is zero but natural water content for most soils is around 60%.
- There is no upper limit for water content. It can be greater than 100%.

NOTE

1. Fine-grained soils have higher values of natural moisture content as compared to coarse-grained soils.
2. There are four possible forms of water present in soil:
   (i) Gravity water (free water): Added due to rain or flooding
   (ii) Capillary water : Extracted through capillary action
   (iii) Hygroscopic water : Water absorbed by oven dried sample when it is placed in open atmosphere
   (iv) Structural water : Water bounded in crystalline structure of soil
   On oven drying, gravity water, capillary water and hygroscopic water are removed but structural water remains present in soil mass.
3. Water content in soil represents gravity water, capillary water and hygroscopic water, which can be removed on oven drying.
4. Water content can also be represented in terms of total weight of soil mass.

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

$$w' = \frac{W_w}{W} \times 100 = \frac{M_w}{M} \times 100$$

Range of w' is $0 \leq w' < 100\%$

If we consider w' =100%, i.e., $W_w = W$ which is not possible in soil mass, hence, $w' \neq 100\%$.

Relationship between *w* and *w′*:

$$w' = \frac{W_w}{W} = \frac{W_w}{W_w + W_S} = \frac{W_w}{W_w\left[1+\frac{W_S}{W_w}\right]} = \frac{1}{1+\frac{1}{w}}$$

$$\therefore \quad w' = \frac{w}{1+w} \text{ or } w = \frac{w'}{1-w'}$$

Total weight of soil mass changes with change in weight of water. Hence engineering significance of '*w*' is more than *w*' because solids are stable quantity.

2.3.2 Void Ratio (*e*)

- The void ratio (*e*) of soil is defined as the ratio of the total volume of voids(V_v) to the volume of soil (Vs).

$$e = \frac{V_v}{V_s}; \qquad e > 0$$

- It is generally expressed in decimal.
- In general $e > 0$, i.e. no upper limit for void ratio.
- Void ratio of fine grained soils is generally higher than that of coarse grained soils.

NOTE: The individual void spaces in coarse grained soil are larger than fine grained soils; but the total void space is generally more in fine grained soils.

2.3.3 Porosity (*n*)

- The porosity (*n*) of a soil is defined as the ratio of volume of voids(V_v) to the volume of soil (V).

$$n = \frac{V_v}{V} \times 100\%$$

- It is generally expressed in percentage.
- In porosity, total volume of soil is used which includes volume of voids. Hence porosity (*n*) of soil cannot exceed 100%.
- The range of porosity is $0 < n < 100\%$.

NOTE: Void ratio (*e*) and porosity (*n*) both have same significance but void ratio (*e*) is more widely adopted than porosity because volume of solid which is used in void ratio is more stable than total volume used in porosity.

2.3.4 Degree of Saturation(S)

- Degree of saturation (*S*) of a soil is defined as the ratio of the volume of water (V_w) to the volume of voids (V_v) in the soil mass.

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

- It is generally expressed in percentage.
- For dry soil, $S = 0\%$ and for fully saturated soil, $S = 100\%$, whereas partially saturated soil has $0 < S < 100\%$.

NOTE: If soil is partially saturated, then total volume of soil and volume of void remain constant during variation of moisture content. If soil is super saturated due to addition of water beyond saturation, then volume of void and total volume increases. Hence void ratio will change but degree of saturation remains constant equal to 100%.

2.3.5 Air Content (a_c)

- It is defined as the ratio of the volume of air (V_a) to the total volume of voids (V_v) present in soil.

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

where, V_a = volume of air in voids
V_v = volume of voids

- It is expressed in percentage.

NOTE:
(i) For dry condition : $S = 0\%$ and $a_c = 100\%$
(ii) For saturated condition : $S = 100\%$ and $a_c = 0\%$
(iii) For partially saturated condition : $0 < S < 100\%$ and $0 < a_c < 100\%$.

Relationship between S and a_c

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

$$\therefore \quad a_c + S = 1$$

2.3.6 Percentage Air Voids (n_a)

- Percentage air voids (n_a) is defined as the ratio of volume of air (V_a) to the total volume of soil mass (V).

$$n_a = \frac{V_a}{V} \times 100$$

- It is generally expressed in percentage.

Relation between n_a and a_c

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

$$n_a = n \times a_c$$

2.3.7 Unit Weights

(a) Bulk Unit Weight (γ_t or γ_b or γ)

- It is the ratio of total weight of soil to the total volume of soil mass.

$$\frac{\gamma_t}{\gamma_b} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}$$

- It is generaly expressed as $\frac{\text{kN}}{\text{m}^3}$ or $\frac{kgf}{\text{cm}^3}$

NOTE

- Bulk density is defined as the ratio of total soil mass to the total volume.

$$\rho_t = \frac{M}{V} = \frac{M_s + M_w}{V_s + V_w + V_a}$$

- It is generally expressed as $\frac{kg}{m^3}$ or g_{cc}.

(b) Dry Unit Weight (γ_d)

- It is the ratio of total dry weight of soil to the total volume of soil mass.

$$\gamma_d = \frac{\text{Dry weight of soil}}{\text{Total volume}} = \frac{W_{dry}}{V}$$

- Dry unit weight is used as a measure of denseness of soil. If dry unit weight value is more, it means the soil is more dense or compacted for same type of soil solids.

NOTE

Dry density is defined as the ratio of total dry mass to the total volume.

$$\rho_d = \frac{M}{V} = \frac{M_{dry}}{V}$$

(c) Saturated Unit Weight (γ_{sat})

- It is defined as the ratio of total saturated weight of soil to the total volume of soil mass

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

NOTE

- Saturated density is defined as the ratio of total saturated soil mass to the total volume of soil mass.

$$\rho_{sat} = \frac{M_{sat}}{V}$$

- If the exiting condition is dry, then its bulk unit weight will be same as of its dry unit weight.
  $\therefore$ If $S = 0$, $\gamma_t = \gamma_d$
- If the existing condition is fully saturated then its bulk unit weight will be same as of its saturated unit weight.
  $\therefore$ If $S = 100\%$, $\gamma_t = \gamma_{sat}$

(d) Submerged Unit Weight or Buoyant Unit Weight (γ_{sub} or γ')

- It is the ratio of buoyant weight of soil to the total volume of soil mass.

$$\gamma' = \frac{W_{sub}}{V}$$

- When soil is below water i.e. in submerged condition, a buoyant force acts on the soil solids which is equal in magnitude to the weight of water displaced by the soil solids. Hence the net weight of soil is reduced and reduced weight is known as buoyant weight or submerged weight.

$$\therefore \quad \gamma' = \frac{W_{sub}}{V} = \frac{W_{sat} - V\gamma_w}{V} = \frac{W_{sat}}{V} - \frac{V\gamma_w}{V} = \gamma_{sat} - \gamma_w$$

- γ' is roughly half of saturated unit weight (γ_{sat})

NOTE
- Submerged density or buoyant density is defined as the total mass of soil submerged to the total volume of soil mass, $\rho' = \rho_{sat} - \rho_w$
- Soil in submerged condition will be in saturated condition also, but soil in saturated condition need not to be in submerged condition.
- Soil mass below the water table is saturated as well as submerged but soil mass in capillary zone is in saturated condition only.

(e) Unit Weight of Water (γ_w)

- It is the ratio of weight of water to the volume occupied by the water

$$\gamma_w = \frac{W_w}{V_w}$$

- Unit weight of water depends on its temperature. However, the unit weight of water is taken to be constant as 9.81 kN/m^3 or 1g/cc for soil conditions.
- It is expressed in $\frac{kN}{m^3}$ or $\frac{kgf}{cm^3}$

(f) Unit Weight of Solids (γ_s)

- It is the ratio of weight of soil solids to the volume occupied by the soil solids.

$$\gamma_s = \frac{W_s}{V_s}$$

- It is expressed in $\frac{\text{kN}}{\text{m}^3}$ or $\frac{\text{kgf}}{\text{cm}^3}$

NOTE
Order of unit weight of soil.
$\therefore \quad \gamma_S > \gamma_{sat} > \gamma_t > \gamma_d > \gamma'$

2.3.8 True/absolute Specific Gravity (G or G_s)

- Specific gravity of soil solids (G) is the ratio of the weight of a given volume of solids to the weight of an equivalent volume of water at 4°C.

$$G \text{ or } G_s = \frac{W_s}{V_s\gamma_w} = \frac{\gamma_s}{\gamma_w} \qquad \left[\because \gamma_s = \frac{W_s}{V_s}\right]$$

- The specific gravity of most of the inorganic soils lies in the range of 2.65 to 2.80.
- For organic soils, it lies in the range of 1.2 to 1.40.

NOTE
$[G]_{\text{fine grained}} > [G]_{\text{coarse grained}}$
$\because$ Fine grained soil contains Al^{3+}, Fe, mg in clay minerals.

2.3.9 Apparent or Mass Specific Gravity (G_m)

- Mass specific gravity is defined as the ratio of the total weight of a given volume of soil to an equivalent volume of water.

- Mass specific gravity can be defined as the ratio of bulk unit weight of soil to unit weight of water.

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

If soil is in saturated state,

$$G_m = \frac{\gamma_{sat}}{\gamma_w}$$

If soil is in dry state,

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

> **REMEMBER**
>
> - Generally, specific gravity is represented either at 27°C or at 20°C. If test temperature is different than the standard temperature, then correction has to be done as follows–
>
> $$G = \frac{\gamma_s}{\gamma_w}$$
>
> $$\therefore \quad G \times \gamma_w = \text{constant}$$
>
> $$\Rightarrow \quad G_{27°C} \times \gamma_{w\,27°C} = G_{T°C} \times \gamma_{w,\,T°C}$$
>
> $$\therefore \quad G_{27°C} = G_{T°C} \times \frac{\gamma_{w,T°C}}{\gamma_{w,27°C}}$$

2.4 SOME IMPORTANT RELATIONSHIPS

2.4.1 Relation between W_s, W_w and w

From block diagram,

$$W = W_s + W_w + W_a$$

$$W = W_s + W_w + 0 \quad (\because\ W_a = 0)$$

$$W = W_s\left(1 + \frac{W_w}{W_s}\right)$$

$$W = W_s(1 + w) \quad \left(\because \text{ Water content, } w = \frac{W_w}{W_s}\right)$$

$$\therefore \quad W_s = \frac{W}{1 + w}$$

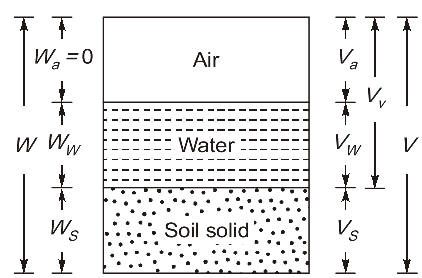


Fig. Three phase diagram

2.4.2 Relation between e and n

We know, Porosity, $n = \frac{V_v}{V} = \frac{V_v}{V_s + V_v} = \frac{\left(\frac{V_v}{V_s}\right)}{1 + \left(\frac{V_v}{V_s}\right)}$

$$\Rightarrow \quad n = \frac{e}{1 + e} \qquad \left(\because\ e = \frac{V_v}{V_s}\right)$$

$$\text{or} \quad e = \frac{n}{1 - n}$$