Spintronic Technology & Advance Research(STAR)
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DIPLOMA

Lecture notes on

Geotechnical Engineering

By

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Chapter 1: Introduction

Soil and Soil Engineering

Definition of soil: The term 'soil' in soil engineering is defined as unconsolidated material, composed of soil particles, produced by the disintegration of rocks. The voids space between the particles may contain air, water or both. The soil particles may contain organic matter.

Definition of soil mechanics:

- The term 'soil mechanics' was coined by Dr. Karl Terzaghi in 1925, who is also known as the father of soil mechanics.
- According to Terzaghi, soil mechanics is the application of the laws of mechanics & hydraulics to engineering problems dealing with sediments & other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rook, regardless of whether or not they contain an admixture of organic constitute.
- **Soil mechanics is therefore, a branch of mechanics which deals with the action of forces on soil and with the flow of water in soil.**

Definition of soil engineering:

- Soil engineering is an applied science dealing with the applications of principals of soil mechanics to practical problems.
- It has a much wider scope than soil mechanics, as it deals with all engineering problems related with soils. It includes site investigations, design and construction of foundations, earth-retaining structures and earth structures.

Definition of geotechnical engineering:

- Geotechnical is a broader term which includes soil engineering, rock mechanics and geology.
- Sometimes geotechnical engineering is used synonymously with soil engineering.

Scope of Soil Mechanics:

Soil Mechanics is a basic subject and its scope will never end because all structures are built on soil and for buildings and structures to perform well and for a long time, soil tests should be done so that to know about the properties of soil and its characteristics.

Origin and formation of soil:

- In a broad sense, soil may be thought of an incidental material in vast geological cycle which has been going on continuously for millions of years of geological time.

- The geological cycle consists of 3 phases, Erosion, Transportation and deposition & Earth Movement.

a) Erosion Phase:

- The cycle starts with erosional phase in which there is degradation of exposed rock by weathering process.
- The weathering process may be
  i. Physical weathering
  ii. Chemical weathering

i. Physical weathering :

- ➢ The physical weathering process may be
  - ❖ Erosion of rock caused by the action of wind, water, glaciers.
  - ❖ Disintegration caused by alternate freezing and thawing in cracks in the rock.
- ➢ The resulting soil particles retain the same composition as that of parent rock.
- ➢ Their shape can be indicated by terms such as angular, rounded, flat and elongated.
- ➢ Gravel and sand fall into this group.

ii. Chemical weathering:

- ➢ The chemical process results in changes in the mineral form of parent rock due to the action of water.
- ➢ Chemical weathering results in the formation of group of crystalline particles of colloidal size ($< 2\mu$) known as clay mineral.
- ➢ If the products of rock weathering are still located at the place where they originated, they are called residual soil.

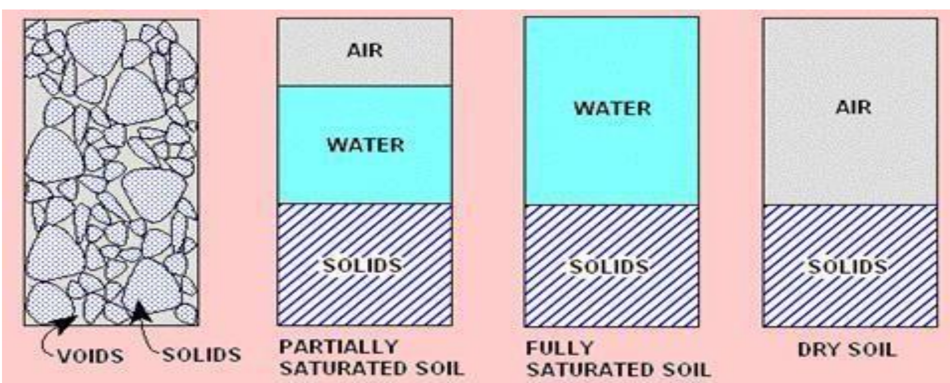
b) Transportation/Deposition:

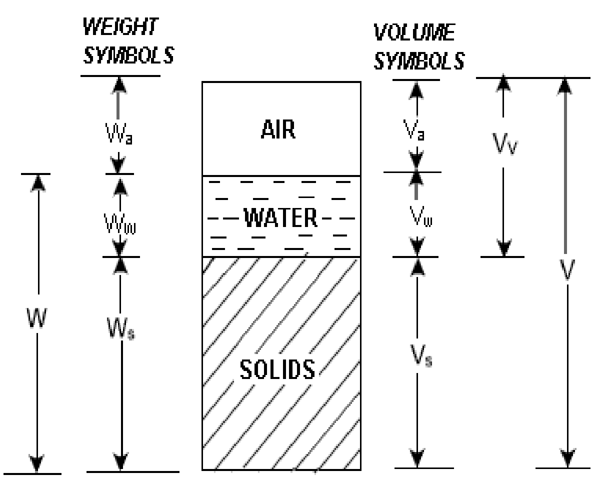
- ➢ In the second phase, the fragmented material is transported by agent such as wind, water or ice to new locations.
- ➢ Soil transported from their origin by wind, water, ice or any other agency and has been deposited is called transported soil. They have generally small grain size, large amount of pores.
- ➢ According to the transporting agency, soils are classified as:
  - Alluvial deposit – deposited by river water.
  - Lacustrine deposit – deposited by still water like lakes.
  - Marine deposit – deposited by sea water.
  - Aeolian deposit – transported by wind.
  - Glacial deposit – transported by ice.
  - Colluvial soil – deposited by gravity. (e.g. talus)

Chapter 2: Preliminary Definitions and Relationship

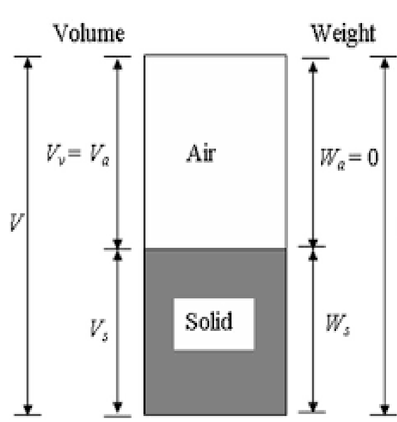
Soil as a three Phase system.

- A soil mass consists of solid particles which form a porous structure. The voids in the soil mass may be filled with air, with water or partly with air and partly with water. The three constituents are blended together to form a complex material.
- However, for convenience, all the solid particles are segregated and placed in the lower layer of the three phase diagram.
- Likewise water and air particles are placed separately, as shown in figure below.
- The 3-phase diagram is also known as **Block diagram**.
- It may be noted that the 3-constituents cannot be actually segregated, as shown.
- A 3-phase diagram is an artifice used for easy understanding and convenience in calculation.
- Soil can be either two-phase or three-phase composition.
- Fully saturated soil and fully dry soil are two phase system.
- Partially saturated soil are three phase system.

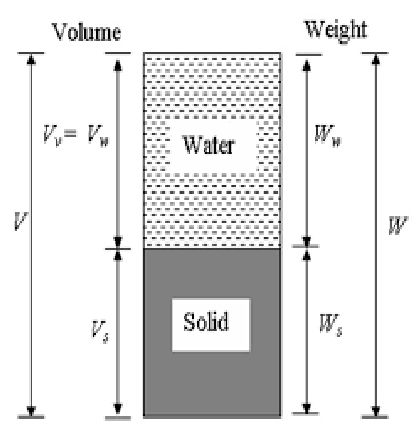




Three phase system



Two phase system



Two phase system

Where

V_a= Volume of air W_a = Weight of air = 0

V_w = Volume of water W_w = Weight of water

V = Total volume of Soil mass W_s = Weight of soil solid

V_v = Volume of voids W = Total weight of soil mass

V_s = Volume of Solid W_{sat} = Saturated weight of soil mass

Important definitions:

1. Water content (w):

- Water content or moisture content of a soil is defined as the ratio of weight of water to weight of solids (dry weight) of the soil mass.

$$w = \frac{Ww}{Ws} \times 100 \; ; \; w \geq 0$$

- It is denoted by the letter symbol w and is commonly expressed as percentage i.e. 20%, 50% etc.
- The minimum value of water content is 0.
- There is no upper limit for water content.
- Generally fine grained soil have higher water content as compared to course grained soil.

2. Void ratio (e):

- Void ratio (e) is the ratio of the volume of voids (Vv) to the volume of soil solids (Vs), and is expressed as a decimal.

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

- There is no upper limit of void ratio in soil suspension.
- Void ratio of fine grained soil are generally higher than those of course grained soil.
- Size of void in course grained soil are generally larger than that in fine grained soil.

3. Porosity (n):

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

$$n = \frac{V_v}{V} x\, 100$$

- $V = V_V + V_S$, $V_V = V_W + V_a$
- The porosity of soil cannot exceed 100% hence it has a upper limit of 100% or 1.
- Both porosity and void ratio are measured of denseness or looseness of soil.

Note:

Total volume V is a variable quantity. But, since solids are incompressible, V_s remain invariant in the total volume V of the soil.

4. Degree of saturation (S):

- Degree of saturation of soil mass is defined as the ratio of volume of water in the voids to volume of voids.
- $S = \frac{V_w}{V_v}$, $0 \leq S \leq 100$
- For a fully saturated soil mass $V_v = V_w$, hence for the saturated soil mass S = 100% .
- For fully dry soil $V_w = 0$, hence for a saturated soil mass s = 0%
- For partially saturated soil mass degree of saturation of soil mass varies between 0 – 100%, which is most common condition in nature.

5. Percentage Air voids (n_a):

- Percentage air voids (n_a) is the ratio of the volume of air to the total volume.
- $n_a = \frac{V_a}{V} \times 100$

6. Air content (a_c):

- Air content (a_c) is the ratio of the volume of air (Va) to the volume of voids V_v.

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

- $n_a = \frac{V_a}{V} = \frac{V_a \times Vv}{V \times Vv} = \frac{Vv}{V} \times \frac{V_a}{Vv} = n \times a_c$

  $n_a = n \times a_c$

7. Bulk unit weight (γ_t / γ):

- Bulk unit weight of a soil mass is defined as the weight per unit volume.
- $\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{Vw + Va + Vs}$
- It is generally expressed as KN/m^3, N/m^3, kgf/ KN/cm^3

8. Unit weight of Solid (γ_s):

- It is defined as the ratio of weight of solids to weight of volume of solids. It is also called **absolute unit weight** of soil mass.
- $\gamma_s = \frac{Ws}{V_s}$

9. Unit weight of water (γ_w):

- $\gamma_w = \frac{Ww}{V_w}$
- The value of γ_w changes with temperature but usually we take γ_w as 9.81 kN/m^3 which is at 4^oC.

10. Dry unit weight (γ_d):

- It is defined as weight of soil solid (or weight of dry soil) per total volume of soil.
- Unit is KN/m^3, N/m^3, kgf/ KN/cm^3
- $\gamma_d = \frac{Ws}{V}$
- Dry unit weight is used as a measure of denseness of soil. A high value of dry unit weight indicates that more solids are packed in unit volume of soil hence a more compact soil.

11. Saturated unit weight (γ_{sat}):

- It is defined as the bulk unit weight of soil mass in saturated condition.
- $\gamma_{sat} = \frac{\text{Wt. of Saturated soil}}{\text{Volume of soil}}$

12. Submerged unit weight (γ_{sub} or γ'):

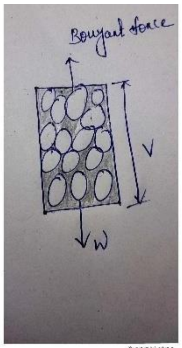
- It is defined as the weight of submerged soil per total volume of soil mass. When the soil exists below the ground water table, the soil mass is said to be in submerged condition.

- $\gamma_{sub} = \frac{\text{Wt. of Submerged soil}}{\text{Volume of soil}}$
- $\gamma' = \gamma_{sat} - \gamma_w$

Note:

Bulk unit weight = Saturated unit weight , (when soil is fully saturated)   Bulk unit weight = Dry unit weight, (when soil is completely in dry condition)

- When the soil exist below the ground water table, two forces are act on it.
- One is weight of soil, acting vertically downward and 2nd is buoyant force/weight acting vertically upward as shown in fig. below.



Buoyant weight/force = Submerged weight of soil

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

$\gamma' = \frac{\text{Wt. of Submerged soil}}{\text{Volume of soil}}$

Wt. of submerged soil = total weight of soil sample – weight of water displaced by the sample = Buoyant weight

$= W - \gamma_w \times V$

$\gamma' = \frac{W - \gamma_w \times V}{V} = \frac{W}{V} - \frac{\gamma_w \times V}{V} = \gamma_{sat} - \gamma_w$

13. Specific gravity of solids (G/G_s):

- It is defined as the ratio of the unit weight of solids (absolute unit weight of soil) to unit weight of water.
- $G_s = \frac{\gamma_s}{\gamma_w}$
- It is a unit less quantity.

- This is also known as Absolute specific gravity or Grain specific gravity.

14. Mass specific gravity (G_m):

- It is the ratio between the bulk unit weight of soil to unit weight of water
- $G_m = \frac{\gamma_t}{\gamma_w}$

5. Relative Density (D_r):

- $D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$
- e_{max} & e_{min} represents the soil in very dense and loose conditions respectively. e is the void ratio of natural soil.

Inter-Relations:

1. e.s = G.w

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

2. $W_s = \frac{W}{1+w}$
3. $V_s = \frac{V}{1+e}$
4. $e = \frac{n}{1-n}$
5. $n = \frac{e}{1+e}$
6. $\gamma_t = \frac{G+e.s}{1+e} \times \gamma_w$
7. $\gamma_{sat} = \frac{G+e}{1+e} \times \gamma_w$ (as S = 1)
8. $\gamma_d = \frac{G}{1+e} \times \gamma_w$ (as S = 0)
9. $\gamma_d = \frac{\gamma_t}{1+w}$

Chapter 3: Index Properties of Soil

- In this chapter, we shall describe the methods of determining those properties of soil which are used in their identification and classification.
- These include the determination of
  i. Water content (w)
  ii. Specific gravity (G)
  iii. Particle size distribution
  iv. Consistency limits
  v. In-situ density
  vi. Density index
- These properties are known as index properties.

i. Water content (w):

- Water content of soil is an important soil parameter which significantly influences the behavior of soil, particularly cohesive soils.
- Water content and unit weight changes during transportation and storage. Hence it is important to determine it before carrying out any other tests.
- Water content determination is also important because some physical state properties are calculated using water content following the practical measurements of others e.g. dry unit weight from bulk unit weight.
- The water content of a soil sample can be determined by any one of the following methods:
  a) Oven drying method
  b) Torsion balance method
  c) Pycnometer method
  d) Sand Bath method
  e) Alcohol method
  f) Calcium carbide method
  g) Radiation method

a) Oven drying method:

- The oven drying method is a standard laboratory method. This is very accurate method.
- The soil sample is taken in a small, non-corrodible, air tight container.

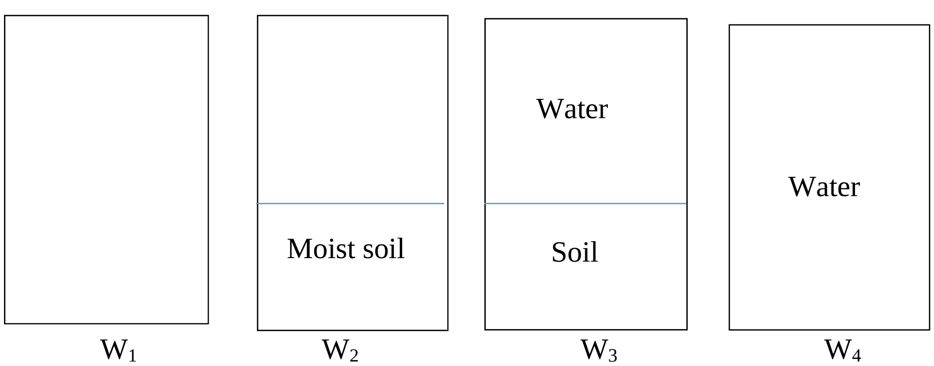
- The soil sample in container is then dried at temperature of 105-110^oC for 24 hour in laboratory. Above 110 ^oC, water of crystallization may lost.
- Water crystallization is the water in the molecular structure.
- For soil containing significant amount of organic matter, a temperature of 60^oC to 80^oC is recommended.
- If W_1 = weight of container, W_2 = wt. of container + wt. of moist soil and W_3 = wt. of container + wt. of dry soil, then water content is given by:

$$w = \frac{Ww}{Ws} = \frac{W2-W3}{W3-w1}$$

b) Pycnometer method:

- A pycnometer is a glass jar of about 1 liter capacity and fitted with a brass conical cap means of a screw-type cover. The cap has a small hole of 6mm dia. At its apex.

- The pycnometer meter method for determination of water content can be used only if the specific gravity of solid (G) particle is known.
- First the weight of empty pycnometer is determined (W_1) in the dry condition. Then the sample of moist soil, is placed in the pycnometer and its weight with the soil is determined (W_2).
- The remaining volume of the pycnometer is then gradually filled with distilled water or kerosene. The weight of pycnometer, soil and water is obtained (W_3).
- Lastly the bottle is emptied, thoroughly cleaned and filled with distilled water or kerosene, and its weight taken (W_4).



- $W_w = W_2 - W_1 - W_S$

$$w = \frac{W_W}{W_S} = \frac{W_2 - W_1 - W_S}{W_S}$$

$$W_4 - W_1 = W_3 - W_1 - W_S + \frac{W_s\, \gamma_w}{G_s\, \gamma_w}$$

$$W_S = [(W_3 - W_4) \times G_S] / G_S - 1$$

$$w = [(W_2 - W_1) / [\{(W_3 - W_4).G_S\} / (G_S - 1)]] - 1$$

$$w = [\frac{W_2 - W_1}{W_3 - W_4} \times \frac{(Gs-1)}{Gs} - 1]$$

- Tish method is more suitable for cohesion less soil as in case cohesive soil removal of entrapped air is difficult.

ii) <u>Specific gravity of soil particles:</u>

- We know $G = \frac{\gamma s}{\gamma_w} = \frac{\frac{W_s}{V_s}}{\frac{W_w}{V_w}}$
- If $V_s = V_w$, $G = \frac{W_s}{W_w} = \frac{M_s \times g}{M_w \times g} = \frac{M_s}{M_w}$
- Therefore Sp. Gravity of a soil particle is the ratio between mass of soil solid to mass of equivalent volume of water at same temperature.

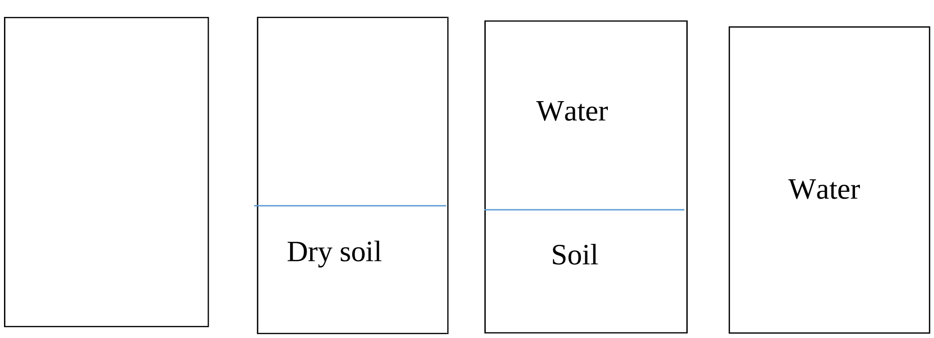
<u>Determination of sp. Gravity:</u>

Sp. gravity of soil is determined by 2- methods:

a) Density bottle method
b) Pycnometer method

Density bottle method is more accurate and suitable for all type of soil. But pycnometer method is suitable for course grained soil.

a) <u>Density bottle method:</u>



M_1 M_2 M_3 M_4

$$G = \frac{M_s}{M_w} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

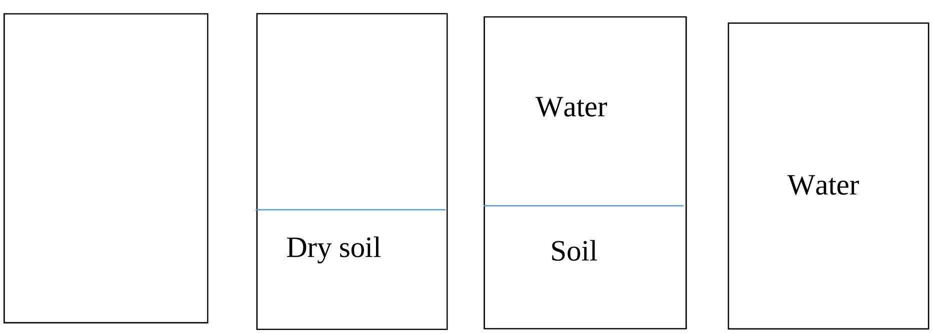
Procedure:

- A clean and empty density bottle is taken and weighted. Let the mass be M_1.
- Again the density bottle is poured with some dry soil whose sp. gravity is to determined and the whole assembly is weighted. Let the mass be M_2.
- Again the whole assembly is completely filled with water and weighted. Let the mass be M_3.
- Again the density bottle is cleaned and filled with water alone and weighted. Let the mass be M_4.
- Then, the sp. gravity $G = \frac{M_s}{M_w} = \frac{M2 - M1}{(M_4 - M_1) - (M_3 - M_2)}$
- When kerosene is used in case of water, then the sp. gravity of soil $G = \frac{M2 - M1}{(M_4 - M_1) - (M_3 - M_2)} \times G_k$.

  Where G_k = sp. gravity of kerosene.
- Generally sp. gravity test is carried out on 27℃.
- Then sp. gravity of soil at t℃ = $G_{t^\circ C} = \frac{G_{27^\circ C} \times \text{G of distilled water at } 27^\circ C}{\text{G of distilled water at } t^\circ C}$.

b) Pycnometer method:

- This method is same as pycnometer method of water content determination with the difference that here dry soil sample is taken instead of moist soil sample as was taken in water contents determination.



W_1 W_2 W_3 W_4

Sp. gravity $G = \frac{\text{wt. of solid}}{\text{wt. of equivalent volume of water}}$

Wt. of solid = $W_2 - W_1$

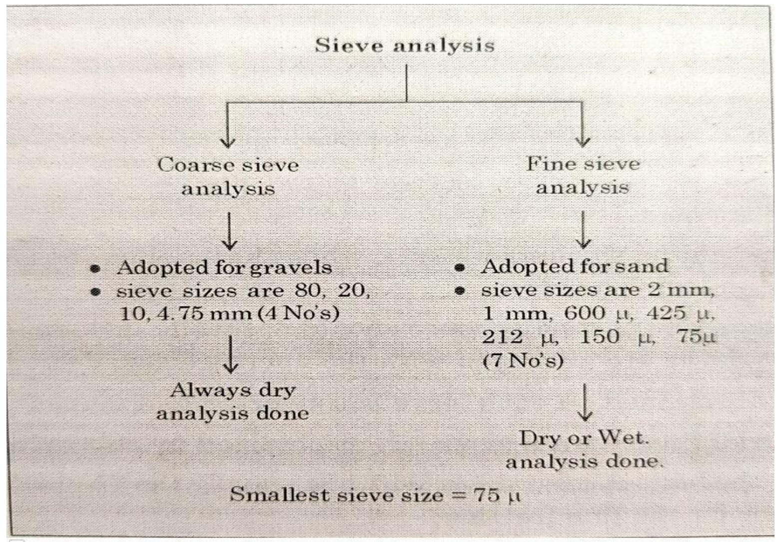
Wt. of equivalent volume of water = $(W_4 - W_1) - (W_3 - W_2)$

$$G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

➢ Sp. gravity values are generally reported at 27°C.

Particle Size	Type of Soil
> 300 mm	Boulder
300 – 80 mm	Cobbles

80 mm — 4.75 mm	gravel	Coarse Grained soil
4.75 mm — 2 mm	coarse sand } Sand	
2 mm — 0.475 mm	medium sand } Sand	
0.475 mm — 75 μ	fine sand } Sand	
75 μ — 2 μ	silt	Fine Grained soil
less then 2 μ	clay	



iv) <u>Particle size distribution:</u>

➢ The classification of soils according to their size is known as particle size distribution.

➢ It is done by 2-methods.

a. Sieve analysis

b. Sedimentation analysis for particles of size less than 75μ

a) <u>Sieve analysis</u>:

➢ It is done for a soil which size lies more than 75μ.

➢ In this process sieves are places one over another in decreasing order of their aperture size.

➢ The sieve analysis is of 2 types

i. Coarse sieve analysis; which consist of sieving of soil through 40mm, 20mm, 10mm and 4.75mm IS sieve.

ii. Fine sieve analysis; which consist of sieving of soil though 2mm, 1mm, 600μ, 425μ, 212μ, 150μ, 75μ IS sieve.

<u>Procedure of sieve analysis:</u>

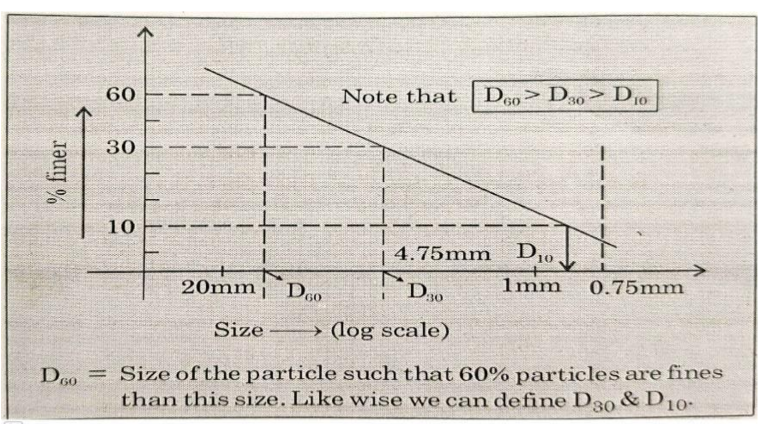
➢ The soil sample is tested is dried, lumps are broken if necessary, and the sample is pass through the series of sieves by shaking.

➢ The fraction retained on and passing 2mm IS sieve are tested separately.

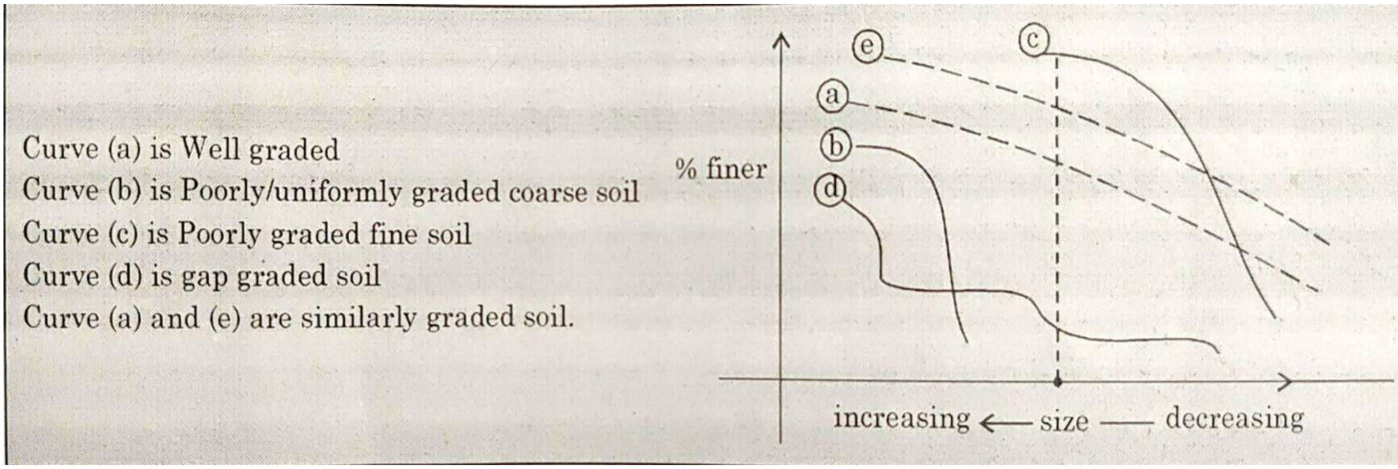
- An automatic sieve shaker, run by an electric motor, may be used; about 10 to 15 minutes of shaking is considered as adequate.
- Larger particles are caught on the upper sieves, while the smaller ones is filter through to be caught on one of the smaller underling sieves.
- The material retained on any particular sieve should naturally include that retained on the sieves on the top of it, since the sieves are arranged with the aperture size decreasing from top to bottom.
- The weight of the material retained on each sieve is converted to a percentage of the total sample.
- The percentage material finer than a sieve size is obtained by subtracting tis from 100.
- The materials passing the bottom most sieve, which is usually 75µ sieve, is used to conduct the sedimentation analysis for the fine fraction.
- If the soil is clayey in nature the fine fraction cannot be easily passed through the 75µ sieve in dry condition.
- In such case, the material is to be washed through it with water, until the wash water is fairly clean.
- The material which passes through the sieve is obtained by evaporation. This is called wet sieve analysis, may be required in case of cohesive granular soil.
- The resulting data are conventionally presented as a grain size distribution curve plotted on semi log co-ordinates, where the sieve size is on a horizontal logarithmic scale, and the percentage by weight of size smaller than a particular sieve size is on the vertical arithmetic scale.
- Logarithmic scales for the particle diameter gives a very convenient representation of the sizes because a wide range of particle diameter can be shown in a single plot.

Sieve size	Total wt. of soil taken	Wt. retained on a particular sieve (gram)	Cumulative wt. retained	Cumulative %retained	% finer = 100 – cumulative %retained

- The resulting grain size distribution curve is as shown :



- Actually sieve size is assumed to correspond to size of particle.
- The various types of curves obtained in sieve analysis are classified as follows:



- Well graded means soils of all sizes are present.
- Poorly graded/uniformly graded means soil of predominantly one size is only present.
- Gap graded means some of the soil particle size are missing.
- Position of the curve indicates **type of soil** whereas shape of the curve indicates **gradation**.
- As the slope of the curve decrease – gradation increase.
- D_{10} = effective size of article i.e. particle size which if present alone will cause the same effect as is caused by the soil.
- Grain size distribution curve is used to find out the following shape parameters.
    1. Co-efficient of uniformity (C_u) = $\frac{D_{60}}{D_{10}}$
    2. Co-efficient of curvature (C_c) = $\frac{D_{30}^2}{D_{60} \times D_{10}}$

If, $C_u = 1$ – Soil is perfectly uniformly graded. (Curve will be vertical)

$C_u > 4$ – well graded gravel

$C_u > 6$ – well graded sand

$1 \leq C_c \leq 3$ – well graded soil

- For well graded sand, $C_u > 6$, $1 \leq C_c \leq 3$
- For well graded gravel, $C_u > 4$, $1 \leq C_c \leq 3$

Larger the value of C_u, larger is the range of particles in soil.