SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Civil Engineering

Soil Mechanics

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY
PUBLICATIONS

Soil Mechanics

Contents

CHAPTER 01

Soil Types of Formation

1.1 Soil Mechanics

- It is the branch of science that deals with the study of physical properties of soil masses subjected to various types of forces.
- Terzaghi is known as the father of soil mechanics.
- According to Terzaghi (1948) soil mechanics is the application of civil engineering involving the study of soil, its behaviour and application as the engineering material.
- Apart from the testing and classification of various types of soil, in order to determine the physical properties, knowledge of soil mechanics is particularly helpful in following problems of civil engineering.
  1. Foundation design of construction
  2. Pavement design
  3. Design of underground structures and earth retaining structures.
  4. Design of embankment and excavation.
  5. Design of earth dams.

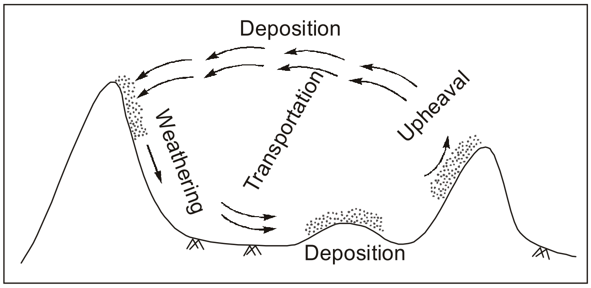
1.2 Soil

- It is defined as uncemented and unconsolidated aggregate of mineral grain and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles.
- Soil consists of gravel, sands, silts and clay.

1.3 Origin of Soil

- Soils are formed by the disintegration of rock either by physical weathering or by chemical weathering.
- Stages in geological cycle of soil formation on are:

  (i) Weathering (ii) Transportation
  (iii) Deposition (iv) Upheaval



Note: 1. Soil formation is a cycle called 'Geological cycle'.
2. Process of soil formation is called 'Pedogenesis.

Difference between Physical Weathering and Chemical Weathering

Physical weathering

1. Physical forces takes part in rock desintegration and the agencies due to which physical weathering takes place are-running water, heavy wind, rainfall, expansion due to freezing of water.
2. Soil formed have generally larges particles.
3. Mineral contituents remains same as parent rock.
4. Ex. Sand and gravel.

Chemical weathering

1. Chemical forces take part in the process of disintegration. These are oxidation, hydration, carbonation, leaching water and organic acids.
2. Soil formed have fine particles.
3. Mineral composition changes and new compounds are formed.
4. Ex. Silts and clay.

1.4 Residual and Transported Soil

Soils that remain at the locatio of its formation are called residual soils. While soil that are transported from its place of origin by wind, water or glacier are called transported soil.

Note: Residual soils haves better engineering properties as compared to the transported soil.

- According to transporting agencies, the soils are classified as follows:

  Alluvial soil: Deposited from suspension in running water/river.

  Lacustrine soil: Deposited by still water "or" lakes.

  Marine soil: Deposited by sea water.

  Aeolian soil: Deposited by wind e.g. loess

  Characteristics:

  (i) Low density (ii) High compressibility (iii) Low bearing capacity

  (iv) Permeability in vertical direction is large (v) Void ratio high

  Glacial soil: Transported by ice

  Colluvial soil: Transported by gravity.

1.5 Some special soils

1. **Bentonite:** Obtained from the decomposition of volcanic ash and is highly plastic in nature.
2. **Black cotton soil:** It is a residual soil formed from the Basalt trap having very low bearing capacity, and high swelling and shrinkage characteristic.
3. **LOAM:** It is mixture of sand, silt and clay.
4. **Tuff:** There are slightly cemented volcanic ash that has been transported by wind or water.
5. **Till:** It is unstratified soil for need by melting of glaciers.
6. **Indurated:** Hardened clay due to heat and pressure.
7. **Talus:** Soil transported by gravity.
8. **Marl:** A very fine grained calcium carbonate soil of marine origin.
9. **Organic soils:**
   - Formed by the growth and subsequent decomposition of plants.
   - They are highly compressible and are not suitable for engineering purposes.
   - Examples of organic soils are muck, peat, humus.

NOTE

- Underreamed piles should be used in foundation in black cotton soil.
- Loam soils are also called 'Garden soils'.
- Lithification: Process by which unconsolidated materials are connected into coherent solid rock as by compaction and cementation.
- Organic soils are also called cumulose soils.

STUDENT'S ASSIGNMENTS

Q.1 Bentonite clay is a material obtained due to the weathering of
(a) Lime stone (b) Quartzite
(c) Volcanic ash (d) Shales

Q.2 Which of the following is transported by gravitational forces.
(a) Loess (b) Talus
(c) Drift (d) Dune sand

Q.3 Which of the following is aeoline soil.
(a) Volcanic soil (b) Residual soil
(c) Organic soil (d) Transported soil

Q.4 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

	List-I		List-II
A.	Residual soil	1.	Soil transported by wind.
B.	Loess	2.	Organic soil
C.	Peat	3.	Deposition in lake during periods of high and low waters.
D.	Varved clays	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.5 Glaciers are formed by
(a) Compaction and recrystallization of snow.
(b) Continuous freezing of water.
(c) A sudden drop in temperature.
(d) None of the above.

Q.6 Identify the true statements:
(a) A soil transported by gravitational forces is called talus.
(b) Laterite soil is category of organic soil.
(c) Water held firmly to the clay particles has the same properties as ordinary water.
(d) A clay deposit which exhibit no evidence of fissuring is described as intact.

Q.7 Geological cycle for the formation of soil is
(a) upheaval → transportation → deposition → weathering
(b) weathering → upheaval → transportation → deposition
(c) weathering → transportation → deposition → upheaval
(d) Transportation → upheaval → weathering → deposition

ANSWER KEY // STUDENT'S ASSIGNMENTS

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

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENTS

6. (a)

Intact rock: The rock portion between two discontinuities is called intact rock. intact rock has more strength than rock mass.

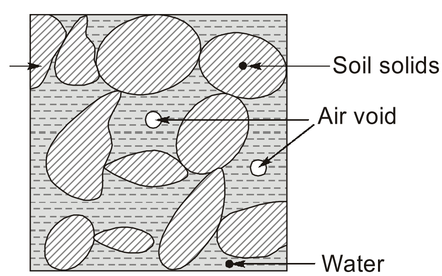
■■■■

CHAPTER 02

Properties of Soil

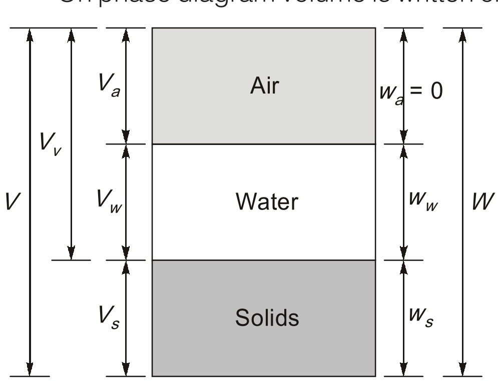
2.1 Introduction

Matter may exist in nature in three different states, viz., solid, liquid and gaseous. A soil mass in its natural state may consist of all three phases. The basic ingredient is the solid grains which form the soil skeleton, while the intermittent void spaces are filled up by either air, or water, or both. Thus, a soil mass in its natural state may be considered a three phase system.

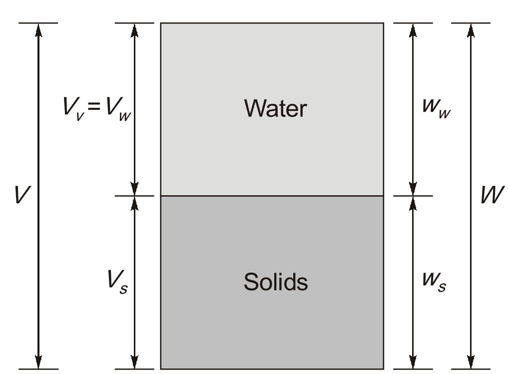


2.2 Phase Diagram

- Soil mass is in general a three phase system composed of solid, liquid and gaseous matter.
- The diagrammatic representation of the different phases in a soil mass is called the "phase diagram".
- A 3-phase system is applicable for partially saturated soil whereas, a 2-phase system is for saturated and dry states of soil.
- On phase diagram volume is written on the left hand side and weights are written on right hand side.



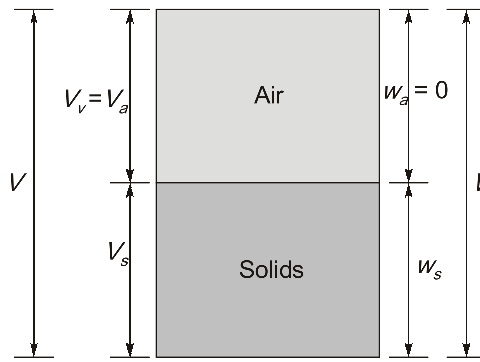
3-Phase (partially saturated condition)



2-Phase (saturated condition)

Where,

V_s = Volume of solids
V_w = Volume of water
V_a = Volume of air
V = Total volume
W_s = Weight of solids
W_w = Weight of water
$(W_a = 0)$ = Weight of air
W = Total soil weights



2-Phase (Dry condition)

Note: There can also be 4-phase diagram of soil when frozen water particles one also there is soil mass.

- Various important relations can be defined on the basis of phase diagram.

2.3 Some Important Definitions

1. Water content (w):

$$w = \frac{W_w}{W_s} \times 100$$

- There is no upper limit of water content i.e. $w \geq 0$
- Generally, fine grained soils have higher water content than the coarse grained soil.

2. Void ratio (e):

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

- There is no upper limit of void ratio i.e. $e \geq 0$.
- Void ratio of fine grained soil is greater than coarse grained soil.

3. Porosity (n):

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

Porosity can't exceed 100% i.e. $0 < n < 100\%$.

Note: In comparison to porosity, void ratio is more of frequently used because volume of solids remain same whereas total volume changes or volume of solids is more stable parameter than volume of soil.

4. Degree of saturation (S):

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

- $0 \leq s \leq 100\%$.
- for perfectly dry soil, $s = 0$.
- for perfectly saturated soil, $s = 100\%$.
- for partially saturated soil $0 < s < 100\%$.
- $V_v = V_a + V_w$

5. Air content (a_c):

$$a_c = \frac{V_a}{V_v} \times 100$$

$$a_c + S = 1$$

6. **Percentage air voids (n_a):**

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

$$n_a = n.a_c$$

7. **Unit weights:**

(a) Bulk unit weight (γ)

$$\boxed{\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_a + V_w + V_s}}$$

Where, W = Total weight

V = Total volume

(b) Dry unit weight (γ_d)

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

- Dry unit weight is the measure of denseness of soil.
- More dry unit weight means more compacted soil.

(c) Saturated unit weight (γ_{sat})

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

(d) Submerged or Buoyant unit weight (γ')

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

- Roughly, $\gamma' = \frac{1}{2}\gamma_{sat}$

8. **Specific Gravity**

- 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.

$$\boxed{G = \frac{W_s}{V_s \cdot \gamma_w} = \frac{\gamma_s}{\gamma_w}}$$

- **Apparent or mass specific gravity (G_m)**
  Mass specific gravity is the specific gravity of the soil mass and is defined as the ratio of the total weight of a given mass of soil to the weight of an equivalent volume of water.

$$\boxed{G_m = \frac{W}{V\gamma_w} = \frac{\gamma}{\gamma_w}}$$

NOTE

Soil in submerged condition will be in saturated state whereas soil in saturated state need not to be in submerged state. For example: Soil mass below water table is submerged as well as saturated whereas soil mass in capillary saturated zone is in saturated condition only.

Example 2.1 A saturated sample of clay has a volume of 0.224×10^{-4} m^3 and weighs 0.0367 kg. After over drying, the volume is 0.140×10^{-4} m^3. The weight of dry soil is 0.0232 kg. Water content of saturated sample will be

(a) 58.18% (b) 80%
(c) 45% (d) 25%

Ans. (a)

As we know that,

$$w = \frac{W_w}{W_s} \times 100$$

$$W_w = 0.0367 - 0.0232 = 0.0135 \text{ kg}$$

$$W_s = 0.0332 \text{ kg}$$

$$w = \frac{0.035}{0.0232} \times 100 = 58.18\%$$

Example 2.2 Volume of water in 1 m^3 of soil is 0.30 m^3 and the volume of air is 0.50 m^3. The degree of saturation will be

(a) 40% (b) 37.5%
(c) 60% (d) 44.6%

Ans. (b)

As we know, Degree of saturation, $S = \frac{V_w}{V_v} \times 100$

$$V_w = 0.30 \text{ m}^3$$

$$V_v = V_a + V_w = 0.5 + 0.3 = 0.8 \text{ m}^3$$

Thus, $S = \frac{0.3}{0.8} \times 100 = 37.5\%$

Example 2.3 What is the dry unit weight of soil when, weight of water is 230 kg in total soil weight of 1950 kg having 1 m^3 of soil mass.

(a) 150 kg/m^3 (b) 1720 kg/m^3
(c) 1905 kg/m^3 (d) 1675 kg/m^3

Ans. (b)

As we know that,

$$\gamma_{dry} = \frac{W_{solids}}{V} \times 100$$

$$W_{solids} = 1950 - 230 = 1720 \text{ kg}$$

$$\gamma_{dry} = \frac{1720}{1} = 1720 \text{ kg/ m}^3$$

Do You Know?

$G_m < G$

Generally 'G' is used but not G_m because 'γ_s' is relatively stable as compared to γ.

Specific gravity is reported at 27°C, but if the temperature is different then standard temperature then it may be converted using the relation.

$$G_{T°C} = G_{27°C} \times \frac{\gamma_{w(T°C)}}{\gamma_{w(27°C)}}$$

2.4 Some Important Relationships

1. $W_s = \dfrac{W}{1+w}$ or $V_s = \dfrac{V}{1+e}$
2. $n = \dfrac{e}{1+e}$ or $e = \dfrac{n}{1-n}$
3. Se = w.G
4. $\gamma = \dfrac{G\gamma_w(1+w)}{(1+e)} = \left(\dfrac{G+Se}{1+e}\right)\gamma_w$
5. $\gamma_{sat} = \left[\dfrac{G+e}{1+e}\right].\gamma_w$
6. $\gamma_d = \dfrac{G\gamma_w}{1+e}$
7. $\gamma' = \left(\dfrac{G-1}{1+e}\right)\cdot\gamma_w$
8. $\gamma_d = \dfrac{\gamma}{1+w}$
9. $\gamma_d = \dfrac{(1-n_a)G\gamma_w}{1+wG}$
10. $S = \dfrac{w}{\dfrac{\gamma_w}{\gamma_t}(1+w) - \dfrac{1}{G_S}}$

Example 2.4 An over dry soil mass has mass specific gravity of 1.5 g/cc. If bulk density of soil in its natural state is 2 g/cc. Then water content in natural state will be

(a) 50% (b) 25%
(c) 100% (d) 33.33%

Ans. (d)

As we know that,

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

and
$$\gamma = 2 \text{ g/cc}$$
$$\gamma_d = 1.5 \text{ g/cc}$$

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

$\Rightarrow$ $$2 = (1+w)\times 1.5$$

$\Rightarrow$ $$w = \frac{2}{1.5} - 1 = \frac{1}{3}$$

$\Rightarrow$ $$w = \frac{1}{3}\times 100 = 33.33\%$$

Example 2.5 If the void ratio of soil is 0.67, water content is 0.188 and specific gravity is 2.68. The degree of saturation of soil is:

(a) 25% (b) 40%
(c) 75% (d) 60%

Ans. (c)

From equation

$$eS = wG_s$$

where,
$$e = 0.67,\ w = 0.188$$
$$G_S = 2.68$$

$\Rightarrow$ $$0.67\times S = 0.188\times 2.68$$

$$S = \frac{0.188\times 2.68}{0.67} = 0.752 \text{ or } 75.2\%$$

Example 2.6 A soil sample having void ratio of 0.5, its porosity shall be close to

(a) 0.33 (b) 0.47
(c) 0.78 (d) 1.28

Ans. (a)

As we have, $n = \frac{e}{1+e}$

and $e = 0.5$

$$n = \frac{0.5}{1+0.5} = \frac{1}{3}$$

$\Rightarrow$ $n \cong 0.33$

Example 2.7 Which of the following represents the void ratio of soil sample whose porosity is 0.452.

(a) 0.264 (b) 0.561
(c) 0.729 (d) 0.825

Ans. (d)

As we know, $e = \frac{n}{1-n}$ and $n = 0.452$

$$e = \frac{0.452}{1-0.452} = 0.8248$$

$$e \approx 0.825$$

Note: Void ratio of the sand lies between 0.6 to 0.7.

Example 2.8 A sample with a volume of 45 CC is filled with a soil sample. When the soil is poured into a graduated cylinder it displaces 25 CC of water. When is the void ratio of soil.

(a) 0.50 (b) 0.60
(c) 0.70 (d) 0.80

Ans. (d)

Total volume (V) = 45 CC

Volume of water displaced = Volume of soil solids (V_s) = 25 CC

Volume of voids in soil (V_v) = $V - V_s = 45 - 25 = 20$ CC

Thus, $e = \frac{V_v}{V_s} = \frac{20}{25} = 0.8$

Example 2.9 If the degree of saturation of soil is given by 67.87%, what is the air content?

(a) 10.5% (b) 20.25%
(c) 32.11% (d) 40.43%

Ans. (c)

As we have the relation

$$a_c + S = 1$$

$$S = 0.6787$$

$\Rightarrow$ $a_c = 1 - 0.6787$

$\Rightarrow$ $a_c = 0.3211$ or 32.11%

2.5 Determination of Various Soil Parameters

Method of determination of water content:

1. Oven Drying Method

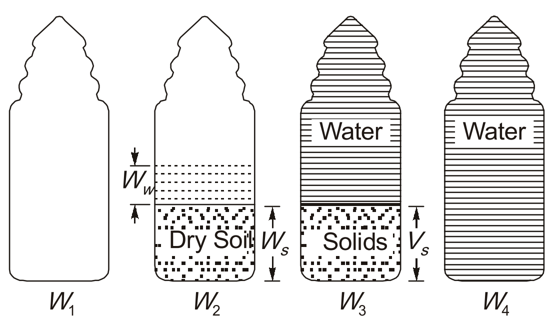
- Simplest and most accurate method
- Soil sample is dried in a controlled temperature (105-110°C)
- For organic soils, temperature is about 60°C.
- Sample is dried for 24 hrs.
- For sandy soils, complete drying can be achieved in 4 to 6 hrs.
- Water content is calculated as:

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100\%$$

where, W_1 = weight of container ; W_2 = weight of container + moist sample
W_3 = weight of container + dried sample ; Weight of water = $W_2 - W_3$
Weight of solids = $W_3 - W_1$

2. Pycnometer Method

- Quick method
- Capacity of pycnometer = 900 m*l*.
- A conical cap provided with a 6 mm diameter hole at the top can be screwed on to the glass bottle.
- Used when specific gravity of soil solids is known
- Let, W_1 = Wt. of empty dried pycnometer bottle
  W_2 = Wt. of pycnometer + Soil ; W_3 = Wt. of pycnometer + Soil + Water
  W_4 = Wt. of pycnometer + Water.



Now, water content $w = \frac{W_w}{W_s} \times 100$

Weight of water = $(W_2 - W_1) - W_s$ ...(1)

If from W_3, the weight of solids W_s could be removed and replaced by the weight of an equivalent volume of water, the weight W_4 will be:

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

$$\Rightarrow \quad W_s = (W_3 - W_4).\frac{G}{G-1} \qquad ...(2)$$

From (1) and (2)

$$w = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)}.\left(\frac{G-1}{G}\right) - 1\right] \times 100\%$$

NOTE

- In view of the difficulty in removing entrapped air from the soil sample, this method is more suited for cohessionless soils where this can be achieved easily.
- Pycnometer method is suitable for coarse grained soil but if it is used for fine grained soil then instead of water kerosine should be used because kerosine has good wetting properties.

3. Calcium carbide method/rapid moisture method.

- The water content of the soil is determined indirectly from the pressure of acetylene gas formed.

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

- The instrument used in this method is called moisture tester.
- The pressure of the acetylene gas produced acts on the diaphragm of the moisture tester. The quantity of gas is indicated on the pressure gauge. From the calibrated scale of pressure gauge, the water content is determined. The water content based on dry mass (w) is given by

$$w = \frac{w_t}{1 - w_t}$$

- This is very quick method but may not give accurate results.

4. Sand Bath Method

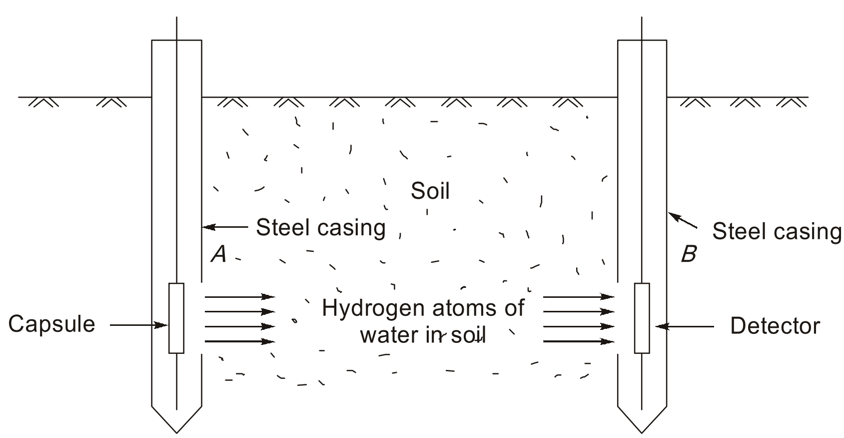
- quick, field method
- used when electric oven is not available.
- soil sample is put in a container & dried by placing it in a sand bath, which is heated on kerosene store.
- water content is determined by using same formula as in oven drying method.

5. Torsion Balance Moisture Meter Method

- quick method for use in laboratory.
- Infrared radiations are used for drying sample.

6. Radiation method

- Radioactive isotopes are used to determine the water content of the soil.
- Radioactive isotopes material such as cobalt 60 is used in this method.
- Neutrons are released by the radio active material which got scattered in the presence of hydrogen atom of water and loses energy. The loss of energy is directly proportional to the quantity of water presence in the soil.*



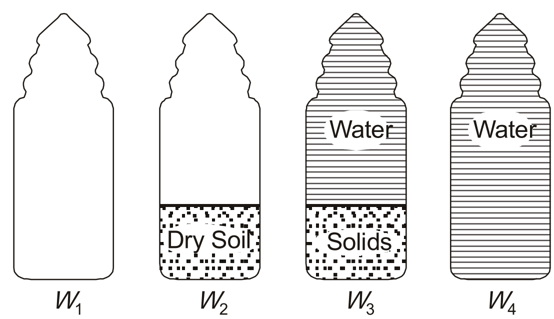
- **Principle:** The torsion wire is prestressed accurately to an extent equal to 100% of the scale reading. Then the sample is evenly distributed on the balance pan to counteract the prestressed torsion and the scale is brought back to zero. As the sample dries, the loss in weight is continuously balanced by the rotation of a drum calibrated directly to read moisture% on wet basis.

Determination of Specific gravity of soil solids

- Pycnometer method is used.
- Instead of pycnometer, Density bottle (50 ml) or Flask (500 ml) can also be used.

  Let, W_1 = Weight of empty pycnometer ; W_2 = Weight of pycnometer + soil sample (oven dried)

  W_3 = Weight of pycnometer + soil solids + water ; W_4 = Weight of pycnometer + water



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

NOTE

1. Specific gravity values are generally reported at 27°C (in India)
2. If T°C is the test temperature then Sp.Gr. at 27°C is given by,

$$G_{27°C} = G_{T°C} \times \frac{\text{Unit Wt. of water at T°C}}{\text{Unit Wt. of water at 27°C}}$$

3. If kerosene (better wetting agent) is used instead of water then,

$$G = \frac{W_s}{W_s - W_3 + W_4} \times K \quad [K = \text{Sp. gr. of Kerosene}]$$

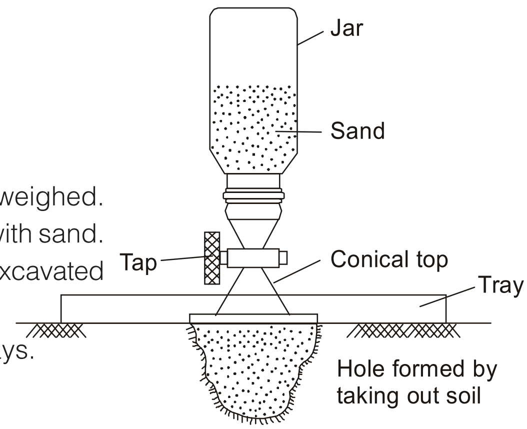
4. G can also be determined indirectly by using shrinkage limit

Methods for the determination of in-situ unit weight

1. Core-Cutter Method

- Used in case of non-cohesive soils.
- Cannot be used in case of hard and gravelly soils.
- Method consists of driving a core-cutter (Volume = 1000 cc) into the soil and removing it, the cutter filled with soil is weighed. Volume of cutter is known from its dimensions and in situ unit weight is obtained by dividing soil weight by volume of cutter. $\gamma = \frac{W}{V}$; $V = \frac{\pi}{4}D^2H$
- If water content is known in laboratory, the dry unit weight can also be computed.

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



2. Sand Replacement Method

- Used in case of hard and gravelly soils.
- A hole in ground is made. The excavated soil is weighed. The volume of hole is determined by replacing it with sand. Insitu unit weight is obtained by dividing weight of excavated soil with volume of hole.
- This method is adopted in construction of highways.

3. Water Displacement Method

- Suitable for cohesive soils only, where it is possible to have a lump sample.
- A regular shape, well trimmed sample is weighed. (W_1). It is coated with paraffin wax & again weighed (W_2). The sample is now placed in a metal container filled with water upto the brim. Let the volume of displaced water be V_w. Then volume of uncoated specimen is calculated as,

$$V = V_w - \left(\frac{W_2 - W_1}{\gamma_p}\right)$$

where γ_p = unit wt. of paraffine wax and bulk unit wt. of soil $\gamma = \frac{W_1}{V}$

2.6 Index properties of soil

- Index properties are those properties which are used for the identification and classification of soils and determining the engineering behaviour of soil.
- Index properties include indices which help in determining the engineering behaviour such as
  (a) Strength (b) Load bearing capacity (c) Swelling and shrinkage (d) Settlement etc

Index properties are divided into the types:

1. Soil grain properties

- Depends on individual grain size of soil mass.
- Most important grain properties are:
  (a) Grain size distribution: By sieve and sedimentation analysis.
  (b) Grain shape: Bulky, flaky shaped etc.

2. Soil aggregate properties

- Soil aggregate properties depends on the soil mass.
- The various soil aggregate properties are:
  (a) Unconfined compressive strength (q_u).
  (b) Consistency and atterberg's limits.
  (c) Sensitivity
  (d) Thixotropy and soil activity
  (e) Relative density

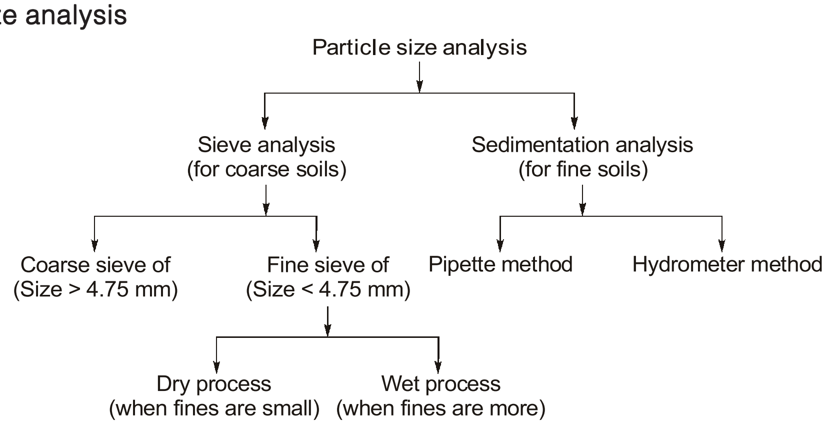
S.No.	Type of soil	Index property
1.	Coarse soil	Particle size, grain, shape, relative density
2.	Fine soil	Atterberg's limit, consistency, UCS, Thixtropy, activity

2.7 Particle Size Analysis

IS classification

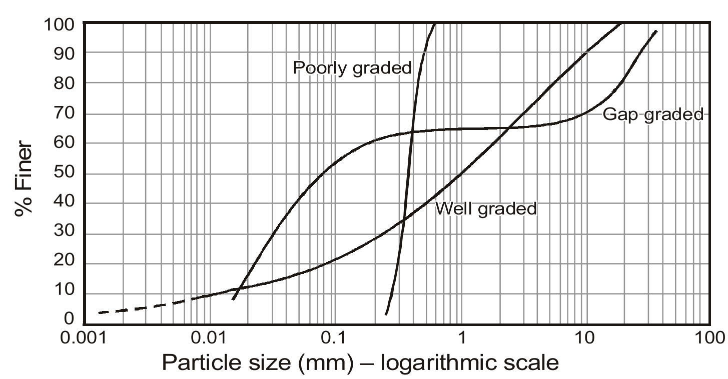
S.No.	Type of soil	Particle size	Remarks
1.	Boulder	> 300 mm	Not considered as soil
2.	Cobbles	80 mm - 300 mm	
3.	Gravel	4.75 mm - 80 mm	Coarse soils
4.	Sand	0.075 mm - 4.75 mm	
	(a) Coarse sand (b) Medium sand (c) Fine sand	2 mm - 4.75 mm 0.425 mm - 2 mm 0.075 mm - 0.425 mm	
5.	Silt	0.002 mm - 0.075 mm	Fine soils
	(a) Coarse silt (b) Medium silt (c) Fine silt	0.02 mm - 0.075 mm 0.01 mm - 0.02 mm 0.002 mm - 0.01 mm	
6.	Clays	< 0.002 mm	

Particle size analysis



1. **Sieve analysis**

- Grain size distribution curves



Typical Particle size distribution curve

Curve (1): Well graded soil-almost all size of particle are available

Curve (2): Poorly or uniformly graded (coarse) soil very less range of particle is present which is coarse in nature.

Curve (3): Gap graded soil: In this case, some of the particle sizes are missing.

Curve (4): Poorly graded or uniformly graded (fine) soils very less range of particles are present which are fine in nature.

Note: 1. If the shape of the curve is steep, soil is poorly graded.
2. If the slope is inclined it is well graded soil.

- D_{10} is that size below which 10% particles are finer than this size by weight. D_{10} is also called effective size.
- D_{50} is called average size.
- D_{30} and D_{60} are the grain dia.(mm) corresponding to 30% fine and 60% fine.
- Using D_{10}, D_{30} and D_{60}, following shape parameters are defined:
  (a) Coefficient of uniformity (Cu)
  $$Cu = \frac{D_{60}}{D_{10}}$$
  For well graded sand, Cu > 6 ; For well graded gravel, Cu > 4 ; For poorly graded soil, Cu ≈ 1
  (b) Coefficient of curvature (Cc): $C_C = \frac{D_{30}^2}{D_{60} \times D_{10}}$
  For well graded soil, $1 \le C_C \le 3$
  (c) Concept to of 'Percentage finer'
  $$\% \text{ retained on a particular sieve} = \frac{\text{Weight of soil retained in that sieve}}{\text{Total weight of soil taken}} \times 100$$
  Cumulative retained = Sum of % retained on all the sieves of larger size and % retained on that sieve
  % finer = 100 – Cumulative % retained

2. Sedimentation analysis

- Most convenient for determining the grain size distribution of the soil fraction finer than 75 μm.
- The analysis is based on stokes's law:
- If a single sphere is allowed to fall freely through a liquid of infinite extent, its vertical velocity is first increased rapidly under the action of gravity, but a constant velocity called the terminal velocity is reached with in a short time.
  According to stokes law, the terminal velocity is given by,
  $$V = \frac{g}{18} \cdot \frac{\rho_s - \rho_w}{\mu} \cdot D^2 = \frac{(G-1)\gamma_w D^2}{18\mu}$$
  ρ_s = Density of grains (g/cm^3) ; ρ_s = Density of water (g/cm^3)
  μ = Viscosity of water ; g = Acceleration due to gravity (cm/s^2)
  D = Diameter of grain (cm)
  By putting the values at 20°C, we get,
  $V \approx 91\, D^2$ .... at 20°C
  where v is in cm/s
  and D is in mm. 2. $V \approx 107\, D^2$ .... at 27°C

NOTE

- Stokes law is applicable for spheres of diameter between 0.2 mm and 0.0002 mm.
- Spheres of diameter larger than 0.2 mm falling through water cause turbulence, whereas, for spheres with diameter less than 0.0002 mm, Brownian motion takes place and the velocity of settlement is too small for accurate measurement.

Limitations of Stokes Law

1. The analysis is based on the assumption that the falling grain is spherical. But in soils, the finer particles are never truly spherical.
2. Stokes's law considers the velocity of free fall of a single sphere in a suspension of infinite extent, whereas, the grain size analysis is usually carried out in a glass jar in which the extent of liquid is limited.
3. The finer grains of the soil carry charge on their surface and have a tendency for floc formation. If the tendency to floc formation is not prevented, the diameter measured will be the diameter of the floc and not of the individual grain.

There are two methods of sedimentation analysis:

(a) Pipette method

- 10 ml of sample of suspension is drawn off with a pipette from a specified depths from the surface of different time intervals.
- This 10 ml volume of sample as put in a container and dried in oven to get dry unit weight and dry density.
- % finer than '*d*' = $\frac{\text{Container at time } 't'}{\text{Initial container}}$
- Diameter '*d*' of following particle is given by stokes law

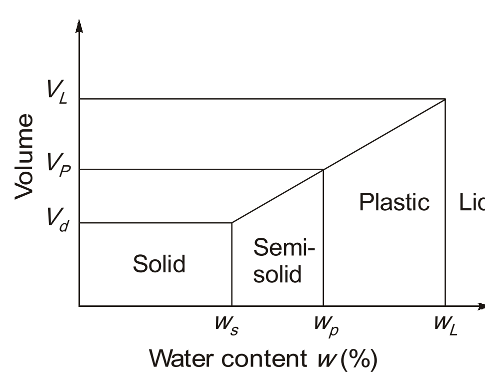
$$\frac{H_e}{t} = V = \frac{(G-1)\gamma_w d^2}{18\mu}$$

where, *He* = Effective depth through which particle settles.

(b) Hydrometer method

- The hydrometer method differs from the pipette analysis in that way, the weights of solids per me in suspension in the chosen depth at chosen instants of time are obtained indirectly by reading the sp. gravity of soil suspension with the aid of hydrometer.
- Corrections to hydrometer readings:
  1. Meniscus correction (C_m) → It is always (+)ve
  2. Temperature correction (C_t) → If the temperature is more than the standard temperature correction is (+)ve and vice-versa.
  3. Defflocculating agent correction (C_d) : This correction is always negative.

2.8 Consistency of clays: Atterberg Limits



- Consistency represents relative ease with which a soil can be deformed.
- In practice, consistency is a property associated only with fine grained soils, especially clays.
- Depending on percentage water content, four stages of consistency are used to describe the state of a clayey soil :
  1. Solid State
  2 Semi Solid State
  3. Plastic State
  4. Liquid State
- The boundary between any two states is called consistency limit. They are also known as Atterberg's limits after Swedish scientist Atterberg, who first demonstrated the significance of these limits.