MPSC 2019

Maharashtra Public Service Commission

Assistant Engineer Examination

Civil Engineering

Geotechnical Engineering

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

MADE EASY Publications

Geotechnical Engineering

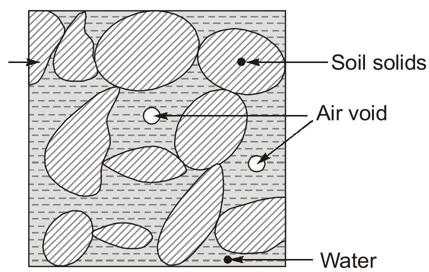
Contents

Chapter 02

Properties of Soil

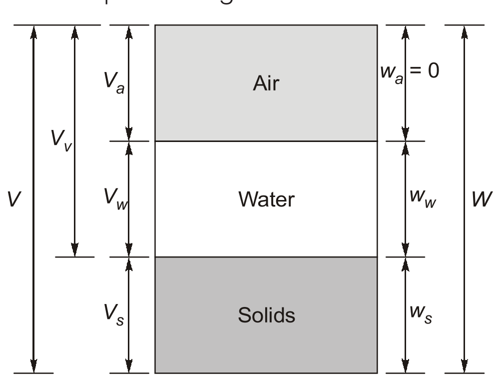
2.1 Introduction

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.

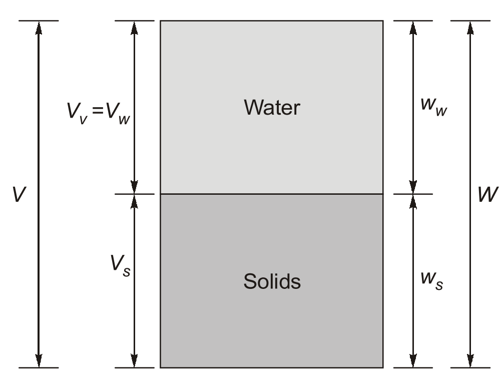


2.2 Phase Diagram

- 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.

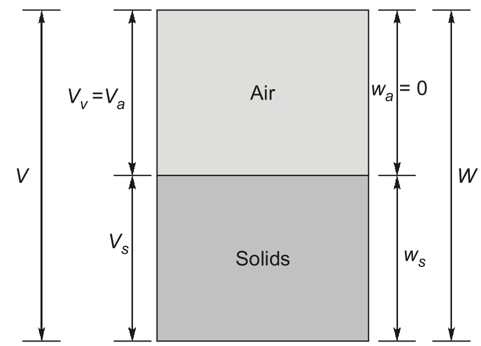


3-Phase (partially saturated condition)



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)

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

Where, W = Total weight

V = Total volume

(b) Dry unit weight (γ_d)

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

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

(c) Saturated unit weight (γ_{sat})

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

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

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

- 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.

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

- 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.

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

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} m³ and weighs 0.0367 kg. After over drying, the volume is 0.140×10^{-4} m³. 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 m³ of soil is 0.30 m³ and the volume of air is 0.50 m³. 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 m³ of soil mass.

(a) 150 kg/m³ (b) 1720 kg/m³
(c) 1905 kg/m³ (d) 1675 kg/m³

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 $\gamma = 2$ g/cc

$\gamma_d = 1.5$ g/cc

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

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

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

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

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, $e = 0.67$, $w = 0.188$

$G_S = 2.68$

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

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

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

2.5.1 Method of determination of water content:

1. Oven Drying Method

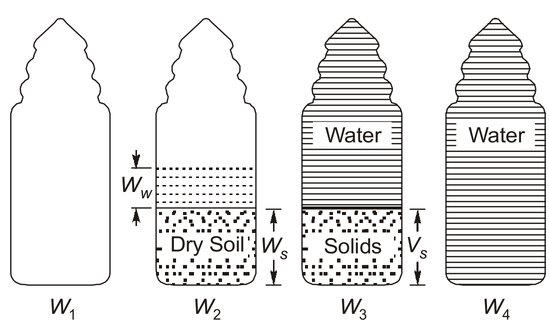
- Simplest and most accurate method
- Soil sample is dried in a controlled temperature (105-110°C)
- For organic soils, temperature is about 60°C.
- Sample is dried for 24 hrs.
- For sandy soils, complete drying can be achieved in 4 to 6 hrs.
- Water content is calculated as:

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

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:

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

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

From (1) and (2)

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

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

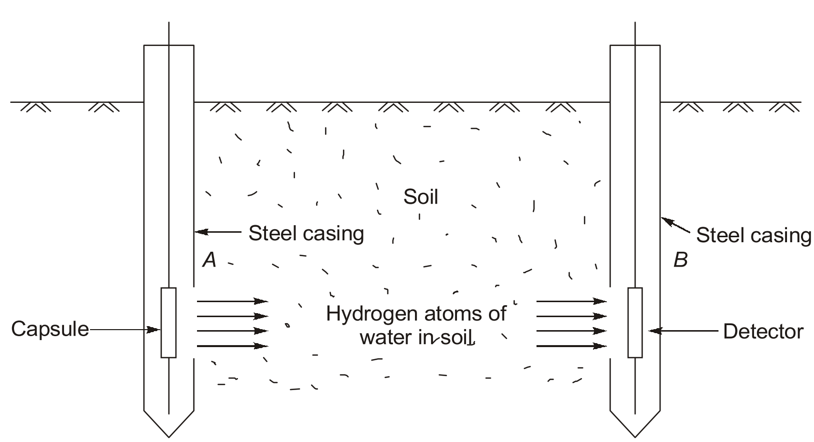
- quick, field method
- used when electric oven is not available.
- soil sample is put in a container & dried by placing it in a sand bath, which is heated on kerosene store.
- water content is determined by using same formula as in oven drying method.

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.*



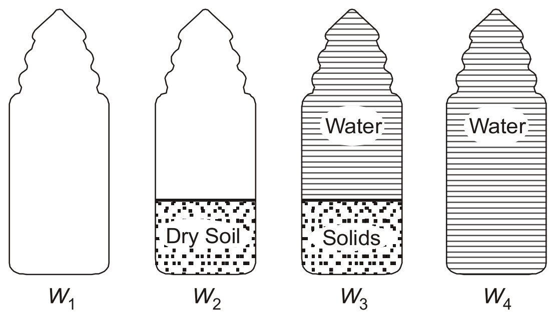
- **Principle:** The torsion wire is prestressed accurately to an extent equal to 100% of the scale reading. Then the sample is evenly distributed on the balance pan to counteract the prestressed torsion and the scale is brought back to zero. As the sample dries, the loss in weight is continuously balanced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

2.5.2 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

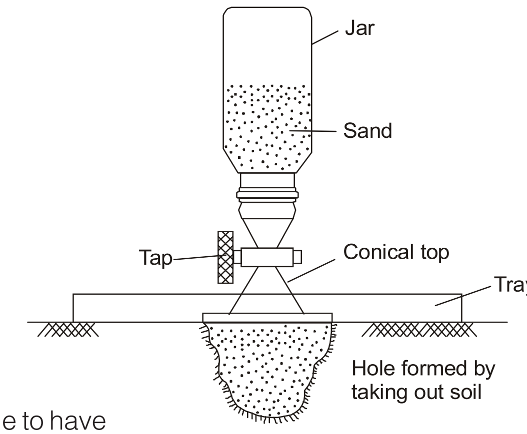
2.5.3 Methods for the determination of in-situ unit weight

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

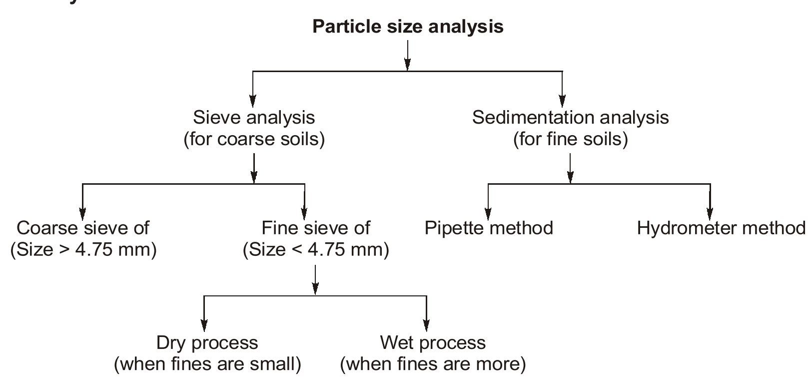
S.No.	Type of soil	Index property
1.	Coarse soil	Particle size, grain, shape, relative density
2.	Fine soil	Atterberg's limit, consistency, UCS, Thixtropy, activity

2.7 Particle Size Analysis

IS classification

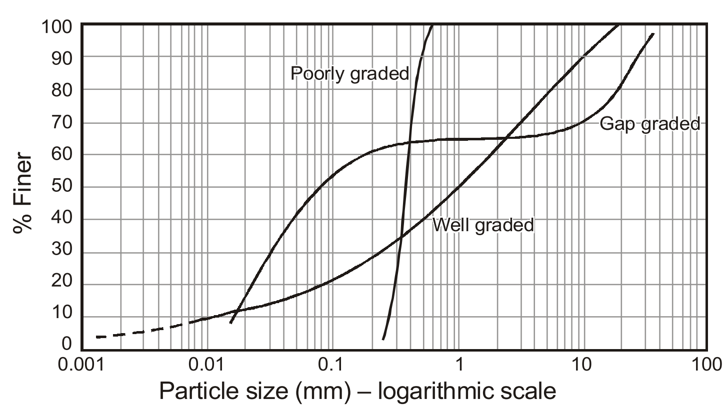
S.No.	Type of soil	Particle size	Remarks
1.	Boulder	> 300 mm	Not considered as soil
2.	Cobbles	80 mm - 300 mm	
3.	Gravel	4.75 mm - 80 mm	Coarse soils
4.	Sand	0.075 mm - 4.75 mm	
	(a) Coarse sand	2 mm - 4.75 mm	
	(b) Medium sand	0.425 mm - 2 mm	
	(c) Fine sand	0.075 mm - 0.425 mm	
5.	Silt	0.002 mm - 0.075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

$$\text{Cu} = \frac{D_{60}}{D_{10}}$$

For well graded sand, Cu > 6 ; For well graded gravel, Cu > 4 ; For poorly graded soil, Cu ≈ 1

(b) Coefficient of curvature (Cc): $C_C = \dfrac{D_{30}^2}{D_{60} \times D_{10}}$

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*' = $\dfrac{\text{Container at time '}t\text{'}}{\text{Initial container}}$
- Diameter '*d*' of following particle is given by stokes law

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

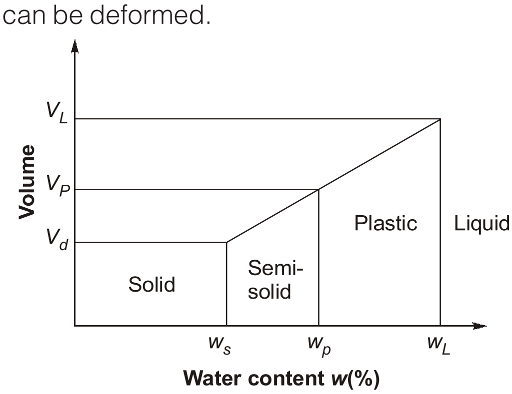
where, He = Effective depth through which particle settles.

(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

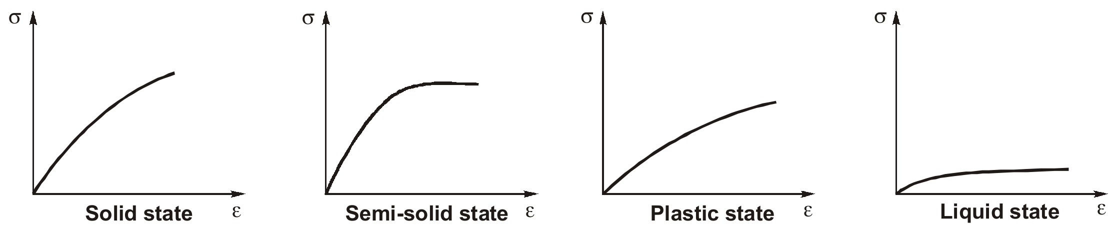


- The boundary between any two states is called consistency limit. They are also known as Atterberg's limits after Swedish scientist Atterberg, who first demonstrated the significance of these limits.

where, V_d = Volume of dry soil mass
= Volume of soil at shrinkage limit
V_P = Volume of soil at plastic limit
V_L = Volume of soil at liquid limit
w_L = Liquid limit
w_P = Plastic limit
w_S = Shrinkage limit

Slope, $\frac{dy}{dx}$ = constant

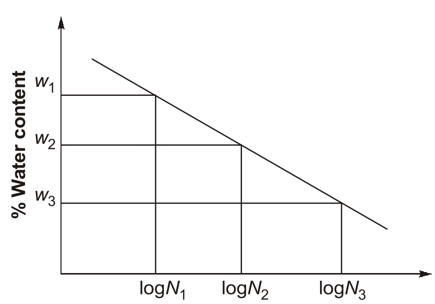
$$\Rightarrow \quad \boxed{\frac{V_L - V_P}{w_L - w_P} = \frac{V_P - V_d}{w_P - w_s}}$$



Determination of Liquid Limit

(a) Casagrande's apparatus

- About 120 g oven dried soil is taken and mixed with water (say w_1 %) to attain putty like consistency.
- Paste is placed inside casagrande apparatus cup and levelled.
- A groove of 2 mm size is cut and apparatus is given blows over a rubber pad and no. of blows required to close the 2 mm groove is noted as N_1.
- Now same soil is mixed with water content w_2 and no. of blows required to close the 2 mm groove is noted say N_2.
- Same process is repeated with different water content.
- A graph is plotted between % water content and No. of blows in semi log scale.
- The above curve is called flow curve and the slope of above curve is called flow index (I_f).



Number of blows
(Flow curve)

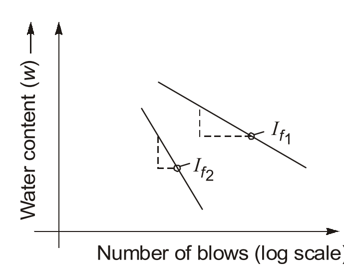
$$\boxed{I_f = \tan\theta = \frac{w_1 - w_2}{\log_{10} N_2 - \log_{10} N_1}}$$

- Flow index I_f, represents the rate of loss of shear strength of soil with increase in its water content.

$$I_{f_2} > I_{f_1}$$

$$I_f \propto \frac{1}{\text{Shear strength of soil}}$$

$\propto$ Rate of loss of shear strength of soil



- Liquid limit is the water content corresponding to **25 Number of Blows**.

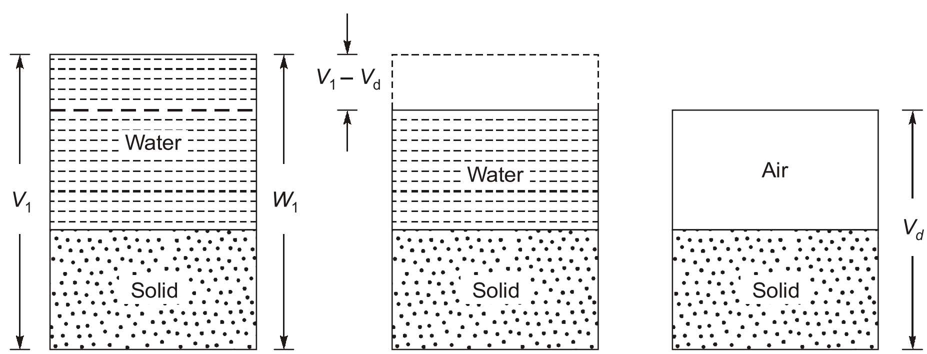
(b) Cone penetration method

Plastic limit (w_p)

- The water content at which soil sample changes from semi-solid to plastic state is known as Plastic Limit.
- Plastic limit is also defined as the water content at which soil would just begin to crumble when rolled into a thread of approximately 3 mm diameter.

Shrinkage Limit (w_s)

- A state when the decrease in moisture content leads to solid state, no change in volume of soil mass is observed, the consistency of soil changes from semi-solid to solid state. The boundary water content is called shrinkage limit.
- Shrinkage limit is the smallest value of water content at which soil mass is completely saturated. It means that below shrinkage limit, soil is partially saturated.



(a) Original Soil **(b) Soil at shrinkage limit** **(c) Dry Soil**

$$w_s = w_1 - \left(\frac{V_1 - V_d}{W_d}\right) \times \gamma_w = \frac{1}{R} - \frac{1}{G}$$

- Shrinkage limit test can be used to determine sp.gravity of soil solids

$$G = \frac{1}{\left(\frac{\gamma_w}{\gamma_d} - \frac{w_s}{100}\right)}$$

where, γ_w = unit weight of water ; γ_d = dry unit weight of soil ; w_s = % shrinkage limit

- If specific gravity G and void ratio e are known, then

$$w_s = \frac{Se}{G} = \frac{e}{G} \qquad (\because S = 1)$$

- **Shrinkage ratio (R) :** It is defined as the ratio of a given volume change in a soil, expressed as a percentage of the dry volume to the corresponding change in water content above the shrinkage limit.

$$R = \frac{\left(\frac{V_1 - V_2}{V_d}\right) \times 100}{w_1 - w_2}$$

where,
V_1 = Volume of soil mass at water content w_1%
V_2 = Volume of soil mass at water content w_2%
V_d = Volume of dry soil mass.

STUDENT'S ASSIGNMENTS

Q.1 Which of one of the following gives the correct sequence of decreasing order of densities of a soil sample?
(a) saturated, submerged, wet, dry
(b) saturated, wet, submerged, dry
(c) saturated, wet, dry, submerged
(d) wet, saturated, submerged, dry

Q.2 Which of the following correctly defines the term activity of clay?
(a) Plasticity index / % of clay
(b) Plastic limit / liquidity index
(c) UCS/cohesion
(d) Strength of remoulded sample unconfined compressive strength of undisturbed sample.

Q.3 The difference between maximum void ratio and minimum void ratio of sand sample is 0.30. If the relative density of sample is 66.6% at the void ratio of 0.40, then the void ratio of the sample at its too rest state will be
(a) 0.40 (b) 0.60
(c) 0.50 (d) 0.75

Q.4 A sample has natural moisture content *w*, void ratio '*e*', specific gravity of solids 'G_s'. The bulk unit weight of soil '*g*' is given by (y_w is unit weight of water)
(a) $\frac{(1-w)G_s\gamma_w}{1-e}$ (b) $\frac{(1+w)G_s\gamma_w}{1-e}$
(c) $\frac{(1+w)G_s\gamma_w}{1+e}$ (d) $\frac{(1-w)G_s\gamma_w}{1+e}$

Q.5 If the specific gravity of the soil sample is represented by G_s and void ratio is '*e*', the hydraulic gradient is expressed as
(a) $\frac{G_s-1}{1+e}$ (b) $\frac{G_s+1}{1-e}$
(c) $\frac{1-G_s}{1+e}$ (d) $\frac{1+G_s}{1+e}$
[SS-JE-2007]

Q.6 Uniformity coefficient of well graded sand is
(a) less than 2 (b) greather than 2
(c) greater than 6 (d) None of these
[SS-JE-2008]

Q.7 If the plasticity index of soil mass is zero, the soil is
(a) Clay (b) Clayed silt
(c) Sand (d) Silt
[SS-JE-2012]

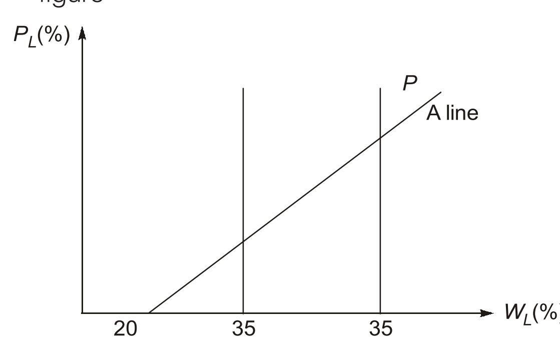
Q.8 Coefficient of curvature for a well graded soil must be in the range:
(a) 0.5 - 1.0 (b) 3.0 - 4.0
(c) 4.0 - 5.0 (d) None of the above
[SS-JE-2010]

Q.9 The moisture content of a soil, below which the soil volume becomes constant, is called
(a) Liquid limit (b) Plastic limit
(c) Shrinkage limit (d) None of the above
[SS-JE-2010]

Q.10 A soil has a liquid limit of 45% and lies above A-line when plotted on a plasticity chart. The group symbol of the soil as per is soil classification is
(a) CH (b) CI
(c) CL (d) ML [ESE-1997]

Q.11 The value of porosity of soil sample in which the total volume of soil grains is equal to twice the total volume of void would be
(a) 75% (b) 66.66%
(c) 50% (d) 33.33%
[ESE-2000]

Q.12 The standard plasticity chart by cassagrande to classify fine grained soil is shown in the figure



The area marked P represents:
(a) Inorganic clays of high plasticity
(b) Organic clays and highly plastic organic silts
(c) Organic and in organic silts
(d) Clays [ESE-2016]

Q.13 The mass specific gravity of a fully saturated specimen of clay having a w/c of 40% is 1.88. On overn drying if mass specific gravity drops to 1.74 then the specific gravity of clay will be

(a) 1.95 (b) 2.90
(c) 2.67 (d) 2.85

[DMRC-JE-2018]

Q.14 Soil samples A and B have void ratios of 0.5 and 0.7 respectively. If 1.5 m^3 of soil sample A and 1.7 m^3 of soil sample B are mixed to form sample C having a volume of 3.2 m^3, which one of the following correctly represents the porosity of sample C ?

(a) 0.375 (b) 0.60
(c) 1.66 (d) 2.66

Q.15 In Casagrande's liquid limit device, the material of the test specimen is harder than the standard rubber. This hardness indicates that the liquid limit, plasticity index, flow index and toughness index, respectively, of the specimen, are

(a) more, less more and same
(b) same, less, same and more
(c) less, less, same and less
(d) less, same, less and more

Q.16 Which one of the following is the water content of the mixed soil made from 1 kg of soil (say A) with water content of 100% and 1 kg of soil (say B) with water content of 50%?

(a) 66 % (b) 71%
(c) 75 % (d) 82 %

Q.17 Given for a sample of a river sand :

Void ratio at the densest state = 0.40

Void ratio at the loosest state = 1.20

Which one of the following correctly represents the relative density of a sample prepared with a void ratio of 1.0 ?

(a) 12.5 % (b) 25 %
(c) 75 % (d) 87.5 %

Q.18 A saturated sand deposite have natural moisture content of 30%. It was noticed that the maximum and minimum void ratios are 0.95 and 0.40 respectively. Assume specific gravity of sand solids are 2.7, the sand deposite will be classified as

(a) Medium (b) Dense
(c) Loose (d) Very dense

Q.19 Two soil samples A and B have porosities n_A = 40% and n_B = 60%, respectively. What is the ratio of void ratio $e_A : e_B$?

(a) 2:3 (b) 3:2
(c) 4:9 (d) 9:4

[ESE: 2004, DMRC-JE-2018]

Q.20 A clay sample has a void ratio of 0.54 in dry state. The specific gravity of soil solids is 2.7. What is the shrinkage limit of the soil?

(a) 8.5% (b) 10.0%
(c) 17.0% (d) 20.0%

[ESE: 2005]

Q.21 Consider the following properties of clay X and Y.

S. No.	Properties	Clay (X)	Clay (Y)
1.	LL(%)	42	56
2.	PL(%)	20	34
3.	Natural W/C(%)	30	50

Which of the days, X or Y experiences larger settlement under identical loads; is more plastic; and is softer in consistency?

(a) X, Y and X (b) Y, X and X
(c) Y, X and Y (d) X, X and Y

[ESE: 2009]

ANSWER KEY — STUDENT'S ASSIGNMENTS

1. (c)	**2.** (a)	**3.** (b)	**4.** (c)	**5.** (a)
6. (c)	**7.** (c)	**8.** (d)	**9.** (c)	**10.** (b)
11. (d)	**12.** (a)	**13.** (b)	**14.** (a)	**15.** (c)
16. (b)	**17.** (b)	**18.** (c)	**19.** (c)	**20.** (d)
21. (c)				

HINTS & SOLUTIONS — STUDENT'S ASSIGNMENTS

1. (c)

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

For dry soil, $w = 0$

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

and for submerged condition

$$\gamma_{sub} = \gamma_{sal} - \gamma_w$$

$$= \frac{G_s - 1}{1+e}\gamma_w$$

Thus, $\gamma_{sat} > \gamma > \gamma_{chy} > \gamma_{sub}$

2. (a)

$$\text{Activity of clay} = \frac{I_P}{\%\,\text{clay}}$$

Higher the plasticity index, higher is the activity.

3. (b)

As we know, $R_D = \dfrac{e_{max} - e_{nat}}{e_{max} - e_{min}}$

Given, $e_{max} - e_{min} = 0.30$

and $R_D = 0.666$

$e_{nat} = 0.40$

Then, $0.666 = \dfrac{e_{max} - 0.40}{0.30}$

$\Rightarrow$ $e_{max} = 0.1948 + 0.40$

$\Rightarrow$ $e_{max} = 0.5998 \approx 0.6$

4. (c)

$$g = \frac{(G_s - es)}{1+e}\gamma_w$$

and $es = w\,G_s$

$$\Rightarrow \quad g = \frac{G_s(1+w)}{1+e}\gamma_w$$

5. (a)

Hydraullic gradient (i)

$$i = \frac{G-1}{1+e}$$

6. (c)

For well graded sand Cu > 6

For well graded gravel, Cu > 4

7. (c)

Plasticity index of sand is '0'.

8. (d)

For well graded soil,

$$1 \le C_c \le 3$$

9. (c)

Below the shrinkage limit of soil, there is no change in volume.

10. (b)

Above A-ling = Clay,

$w_L = 45\%\ (35\% < w_L < 50\%)$

$\Rightarrow$ Intermediate plasticity

$\therefore$ Group symbol is CI.

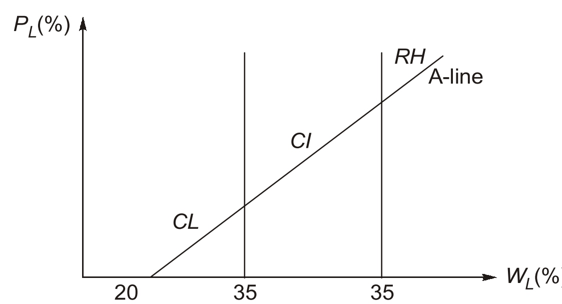
11. (d)

$$\text{Porosity} = \frac{\text{Volume of voids}}{\text{Total volume}}$$

$$n = \frac{Vv}{V_s + V_v} = \frac{Vv}{2V_v + V_v} = \frac{1}{3}$$

$= 33.33\%$

12. (a)



$\therefore$ P lies in the area of inorganic clays of high plasticity.

13. (b)

$w = 40\%$

$\gamma = 1.88$

$\gamma_{dry} = 1.74$

Since soil is fully saturated,

At $w = 40\%$

Thus, $es = wG_s$

$\Rightarrow$ $ex1 = 0.4\,G_s$

$\Rightarrow$ $e = 0.4\,G_s$

and $\gamma_d = \dfrac{G_s\gamma_w}{1+e}$

and $\gamma = \dfrac{G_s + e_s}{1+e}\gamma_w$

$\Rightarrow$ $1.88 = \dfrac{G_s + 0.4G_s}{1+0.4G_s} \times 1\gamma_w$

$\Rightarrow$ $1.88(1 + 0.4G_s) = 1.4\,G_s$

$\Rightarrow$ $G_s = 2.901$