Soil :-

- Soil is defined as a composite material which consists of five (5) major components. They are

i) minerals
ii) water
iii) Air (voids)
iv) organic matter &
v) micro-organisms.

- mainly, minerals, air & water constitutes major portions of soil structure.
- soil is formed by weathering / disintegration / decomposition of rocks by physical, chemical and biological action.

Soil Engineering :-

- It's defined as the branch of geotechnical engg. which deals with understanding the characteristics / properties & mechanics of soil.

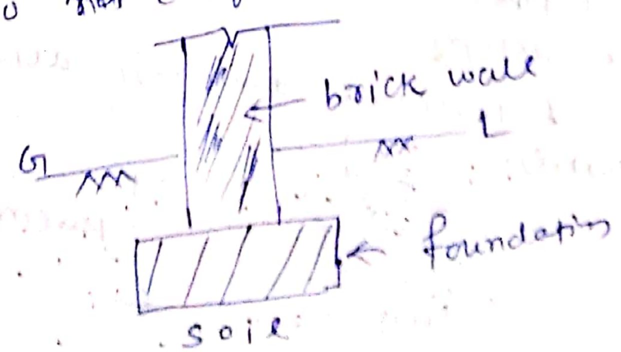
Scope of soil Engineering :-

- It deals with various engg. applications of soil particularly in civil engg. construction works. Ex:-

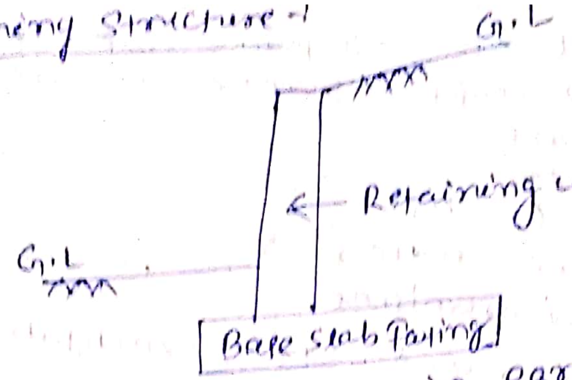
i) foundation
ii) Retaining structure
iii) stability of slopes
iv) underground structures
v) pavement design
vi) Earthen dam.

i) Foundation :- every civil engg. structure whether it's a building or bridge requires a foundation which transmits total load of superstructure to the soil below.

- Hence, soil below should have sufficient bearing capacity to carry the load from foundation.

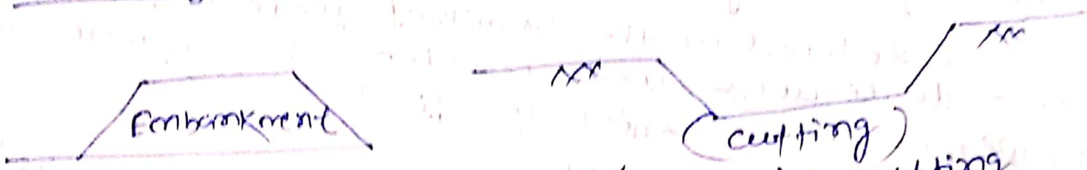


ii) Retaining structure :-



- These are used to retain earth/soil or to keep di soil surface at two different levels.
- Design of such retaining structures requires a great knowledge of soil properties.

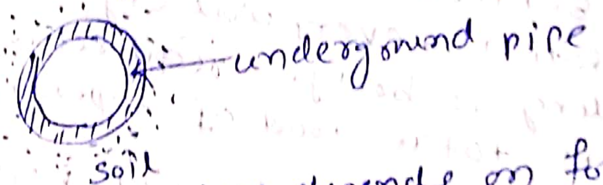
iii) Stability of slopes :-



- side slopes of embankment/earth in cutting requires a great knowledge of soil properties.

iv) Underground structures :-

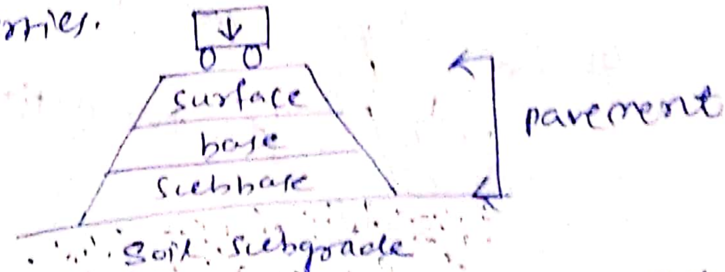
- design of underground structures requires a great knowledge of forces exerted by soil on them from surroundings.
- Hence, forces exerted also depends on soil properties. Ex:- underground pipes.



- Thickness of these pipes depends on force exerted by soil on pipe.

v) Pavement design :-

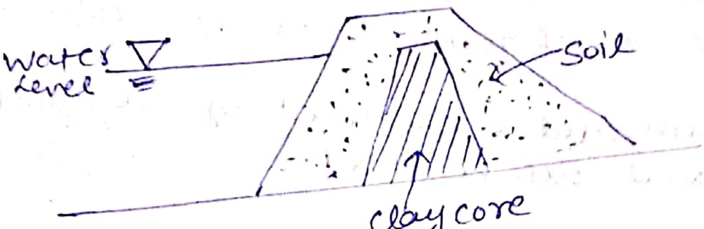
- design of pavement thickness also depends on soil properties.



- The whole structure consisting subbase, based surface is called pavement.

vi) Earthen dam-:

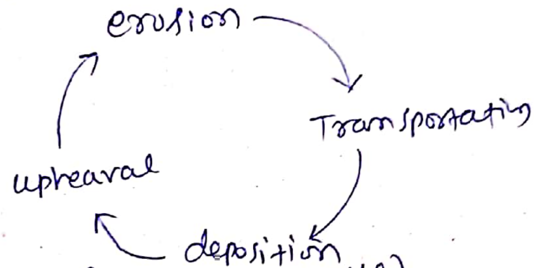
- Structures made of soil used to retain water.
- Hence, design of these soil structures also requires a great knowledge of soil properties.



(earthen dam)

Origin & formation of soil-:

- Soil are formed by weathering/disintegration of rocks by in geological cycle.
- Geological cycle consists of following stages-:



(geological cycle)

erosion-:

- It means disintegration of rocks by physical or chemical weathering. physical weathering means breakdown of rocks into smaller pieces under the action of water, wind, ice, gravity, temp. change etc whereas chemical weathering involves breakdown of rocks due to various chemical process/reactions.
- Physical weathering produces coursegrained ~~materials~~ soil
chemical " produces finegrained soil.

Transportation-:

- Now, the smaller pieces of rocks get transported under the action of water, wind, gravity etc.
- Soil which get transported by water and deposited along the streams are called alluvial soils.
- Soils which get transported & deposited by wind are called aeolian soils. Ex-: loess.
- Soils which get deposited in lakes are called lacustrine soils.
- Soils which get deposited in seas are called marine soil.

- soils which are formed under the action of gravity are called colluvial soils. Ex:- talus.

Deposition:-

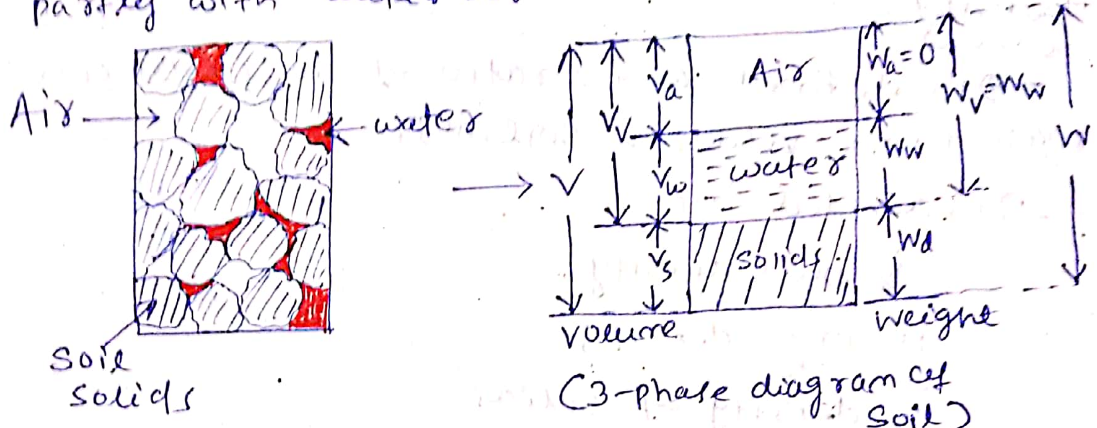
- Then, the transported soils gets deposited at some places and such continuous deposition of soils over a period of years forms an upheaval.

[Imp-: Soils transported & deposited by ice/glaciers are called Glacial soils. Ex-: till.

Chapter-2 preliminary definitions & Relationship

Soil as a 3-phase system-:

- Soil as a 3-phase system consists of soil solids (soil grains), water & air. The void space between soil solids is filled ~~with~~ partly with water and partly with ~~water~~ air.



(3-phase diagram of soil)

where,

V = total volume of soil mass.

V_a = volume of air.

V_w = volume of water.

V_s = volume of solids.

V_v = volume of voids = vol. of air + vol. of water

$= V_a + V_w$.

W_a = negligible $\simeq 0$ = weight of air.

W_w = weight of water.

W_d or W_s = weight of solids.

W = total weight of soil mass

$= W_a + W_w + W_d$ (with $W_a \simeq 0$)

$= W_w + W_d$.

$V = \underbrace{V_a + V_w}_{V_v} + V_s = V_v + V_s$.

Water content-:

- It's denoted by w. (small w)
- It's defined as the ratio of weight of water (W_w) to weight of solids (W_d) or W_s.

$$w = \frac{W_w}{W_d} \times 100.$$

- expressed in percentage.

- It's also called moisture content.

Again, $w = \frac{W_w}{W_d} \times 100$

$= \frac{W - W_d}{W_d} = \left(\frac{W}{W_d} - 1\right) \times 100$

Density :-

- It's defined as the ratio of mass of soil mass to the volume of soil mass.
- It's divided into,
  i) bulk density
  ii) Dry density
  iii) density of solids
  iv) saturated density
  v) submerged density.

i) bulk density :-
- It's defined as the ratio of total mass of soil (M) to total vol. of soil (V).
- also called moist density.
- denoted by ρ (rho).

$$\rho = \frac{M}{V}$$

- expressed in g/cm^3 or Kg/m^3.

ii) Dry density :-
- It's defined as the ratio of mass of solids (M_d) to total vol. of soil (V)
- denoted by ρ_d

$$\rho_d = \frac{M_d}{V}$$

iii) Density of solids :-
- It's defined as the ratio of mass of soil solids (M_d) to vol. of solids (V_s)
- $\rho_s = \frac{M_d}{V_s}$

iv) saturated density :-
- It's defined as the bulk density of

soil, when soil mass is saturated

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

v). Submerged density-:

- It's defined as the ratio of submerged mass of soil solids $(M_d)_{sub}$ to total vol. of soil mass.
- denoted by ρ_{sub} or ρ'
- $\rho' = \frac{(M_d)_{sub}}{V}$

$= \rho_{sat} - \rho_w$.

- also called buoyant density.

[Note-: density of water = 1000 kg/m³ or 1 gm/cm³].

Specific gravity: -

1. It is defined as the ratio of density or unit weight of soil solids (excluding the voids) to density or unit weight of water of equal volume at a given temperature (normally 27°C)
2. It is also called true or absolute specific gravity (G)

$$G = \frac{\gamma_s}{\gamma_w}$$

3. Bulk/mass/apparent specific gravity (G_m) is defined as the unit weight of total soil mass (including the voids) to the unit weight of water. i.e.

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

Voids ratio: -

- It is defined as the ratio of volume of voids to the volume of soil solids in the given soil mass.

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

Porosity: -

- It is defined as the ratio of volume of voids to the total volume of the given soil mass.

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

Percentage of air voids: -

- It is defined as the ratio of volume of air voids to the total volume of soil mass and it is expressed in percentage
- It is denoted by n_a

$$na = \frac{V_a}{V}$$

Air content: -

- It is defined as the ratio of volume of air voids to the volume of voids
- It is denoted by a_c

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

Degree of saturation: -

- It is defined as the ratio of volume of water present in a given soil mass to the total volume of voids in it and expressed in percentage.

$$s = \frac{V_w}{V_v}$$

- For a fully saturated soil sample, Vw = Vv and hence S = 1.
- For a fully dried soil sample, Vw = zero, and hence S = 0.

Density index: -

- It is defined as the ratio of the difference between the voids ratio of soil in its loosest state (e_{max}) and its natural voids ratio (e) to the difference between the void ratio in the loosest and densest states.

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

Fundamental relationships: -

- $n = e/(1+e)$
- $e = n/(1-n)$
- $n_a = n.a_c$
- $Se = Gw$
- $\Upsilon_{bulk} = (G+Se)\ \Upsilon_w / (1+e)$

where, Υ is the unit weight which is equal to weight per unit volume and similar to density (ρ). $\Upsilon_w = 9.81\ kN/m^3$

- $\Upsilon_{dry} = G\ \Upsilon_w / (1+e)$
- $\Upsilon_{sat} = (G+e)\ \Upsilon_w / (1+e)$
- $\Upsilon_{sub} = (G-1)\ \Upsilon_w / (1+e)$
- $\Upsilon_{dry} = \Upsilon_{bulk} / (1+w)$
- $\Upsilon_{dry} = (1-n_a)\ G\ \Upsilon_w / (1+Gw)$

PROBLEMS ON CHAPTER 2: - PRELIMINARY DEFINITIONS AND RELATIONSHIP

1. Given, Volume of soil mass = 1m^3

   Weight of soil mass at moist condition = 100 gram

   Weight of soil mass after oven drying = 80 gram

   Determine, a) moist density & moist unit weight of soil

   b) dry density & dry unit weight of soil

   c) water content (w)

2. Given, Volume of soil mass = 0.028 m^3

   Weight of soil mass at moist condition = 45.5 kg

   Weight of soil after oven drying = 36.4 kg

   Determine, a) moist density &moist unit weight of soil

   b) dry density & dry unit weight of soil

   c) water content

3. Given, Volume of soil mass = 0.06m^3

   Weight of soil mass at moist condition = 70 kg

   Weight of soil mass after oven drying = 45 kg

   Specific gravity of soil solids = 2.65

   Determine, a) voids ratio b) porosity

   c) degree of saturation d) air content

   e) percentage air voids f) saturated and submerged density

4. Given, Volume of soil mass = 0.0283m^3

   Weight of soil mass at moist condition = 56.6 kg

   Weight of soil mass after oven drying = 45.5 kg

   Specific gravity of soil solids = 2.65

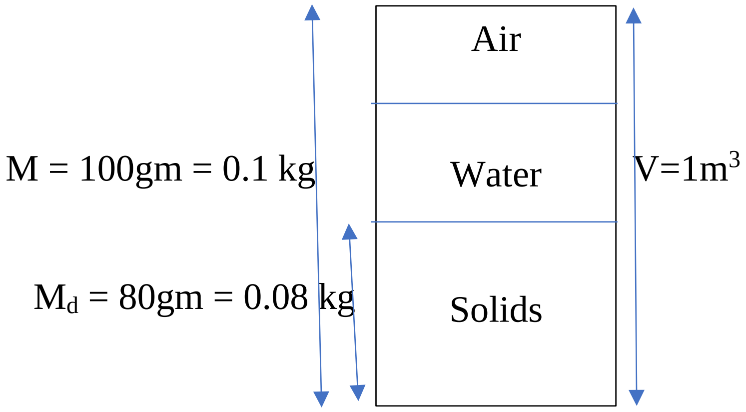
   Determine, a) voids ratio b) porosity

   c) degree of saturation d) air content

   e) percentage air voids f) saturated and submerged density

(draw three phase diagram for all questions which is compulsory)

1.



a) moist density (ρ) = M /V = 0.1 / 1 = 0.1 kg/m^3

moist unit weight (Υ) = ρ x g = 0.1 x 9.81 = 0.981 N/m^3

b) dry density (ρ_d) = M_d / V = 0.08 / 1 = 0.08 kg/m^3 or, $\rho_d = \rho$ / (1 + w) = 0.1 / (1+0.25) = 0.08 kg/m^3

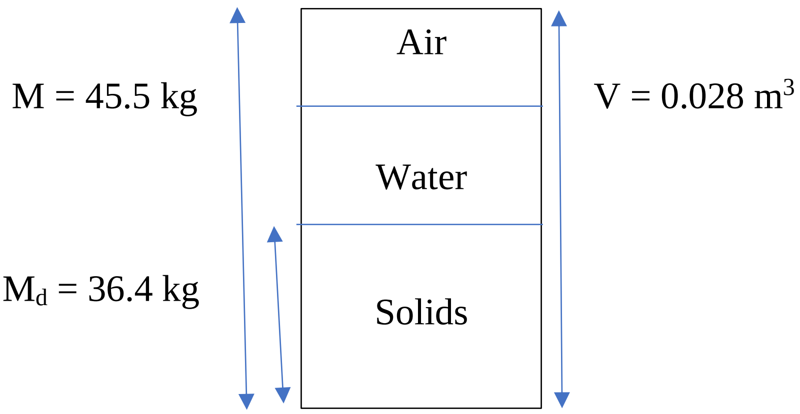
moist unit weight (Υ_d) = ρ_d x g = 0.08 x 9.81 = 0.7848 N/m^3

c) water content (w) = (Ww / Wd) x100 or (Mw /Md) x 100

so, Mw = M – M_d = 0.1kg – 0.08kg = 0.02 kg

w = (Mw /Md) x 100 = (0.02 / 0.08) x 100 = 25%. (ans)

2.



a) moist density (ρ) = M /V = 45.5 / 0.028 = 1625 kg/m^3

moist unit weight (Υ) = ρ x g = 1625 x 9.81 = 15941 N/m^3 = 15.94 kN /m^3

b) dry density (ρ_d)= M_d / V = 36.4 kg / 0.028 m^3 = 1300 kg/m^3

dry unit weight (Υ_d) = ρ_d x g = 1300kg/m^3 x 9.81 m/s^2 = 12753 N/m^3

= 12.753 kN/m^3

c) water content (w) = (M_w / M_d) x 100

PROBLEMS ON CHAPTER 2: - PRELIMINARY DEFINITIONS AND RELATIONSHIP

M_w = mass of water = mass of soil in moist condition – mass of soil in dry condition

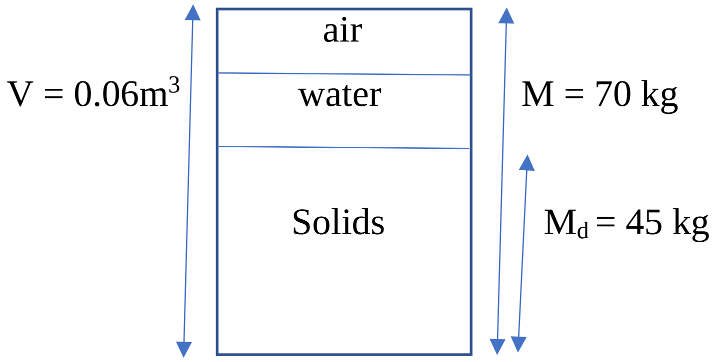
= 45.5 kg – 36.4 kg = 9.1 kg

M_d = 36.4 kg

Water content (w) = (9.1 kg / 36.4 kg) x100

= 25 %

3. G/G_s = 2.65



G = $\rho_s / \rho_w = (M_d / V_s) / \rho_w$

- ⇨ $2.65 = (45\text{ kg} / V_s) / (1000\text{ kg/m}^3)$
- ⇨ $2.65 = (45) / (V_s \times 1000)$
- ⇨ $2.65 \times (V_s \times 1000) = 45$
- ⇨ $V_s = 45 / (2.65 \times 1000)$
- ⇨ $V_s = 45 / 2650 = 0.017\text{ m}^3$

V_v = volume of voids = $V - V_s = 0.06\text{ m}^3 - 0.017\text{ m}^3 = 0.043\text{ m}^3$

a) voids ratio (e) = $V_v / V_s = 0.043 / 0.017 = 2.53$

b) porosity (n) = $\frac{e}{1+e}$ = 2.53 / (1+2.53) = 0.716

c) we know, $\rho_w = M_w / V_w$

=> $1000 = (M - M_d) / V_w$

- ⇨ $1000 = (70 - 45) / V_w$
- ⇨ $1000\ V_w = 25$
- ⇨ $V_w = 25 / 1000 = 0.025\text{ m}^3$

Degree of saturation (S) = (V_w / V_v) *100 = (0.025 / 0.043) * 100 = 58.13 %

Or,

Water content (w) = $M_w / M_d = (M - M_d) / M_d = (70 - 45) / 45 = 0.55$

As we know,

$Gw = Se$

⇨ $2.65 * 0.55 = S * 2.53$

⇨ $S = (2.65 * 0.55) / 2.53 = 0.576 = 57.6\ \%$.

d) Air content (a_c) = $V_a / V_v = (V - (V_w + V_s)) / V_v$

$= (0.06\ m^3 - (0.025\ m^3 + 0.017\ m^3)) / 0.043\ m^3$

$= 0.018 / 0.043 = 0.4186 = 41.86\ \%$

$\Rightarrow S = 100 - 41.86 = 58.14\ \%$

e) percentage air voids (n_a) = $V_a / V = 0.018 / 0.06 = 0.3$

or,

as we know, $n_a = n \times a_c$

⇨ $n_a = 0.716 \times 0.4186 = 0.3$

f) saturated & submerged density (ρ_{sat} & ρ_{sub})

$\rho_{sat} = ((G + e)\ \rho_w) / (1+e)$

$= ((2.65 + 2.53) \times 1000) / (1+ 2.53)$

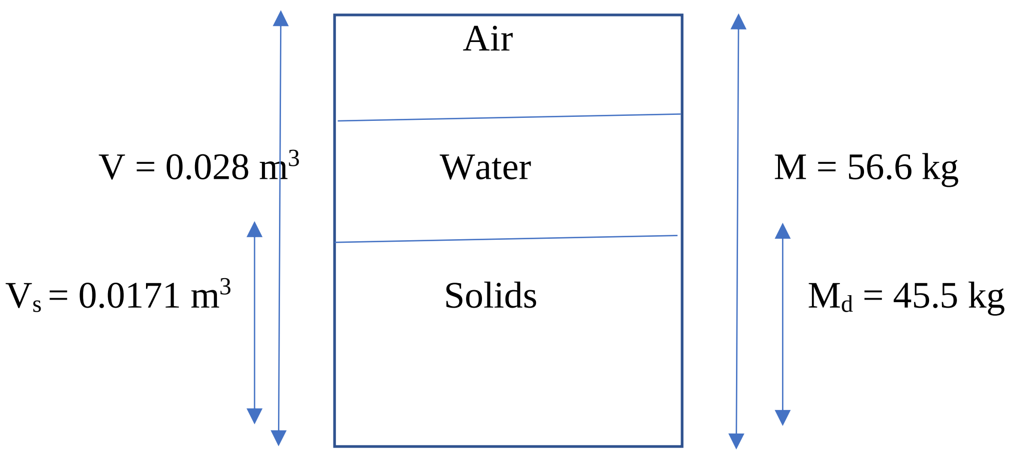
$= 1467.42\ kg/m^3$

$\rho_{sub} = ((G - 1)\ \rho_w) / (1+e)$

$= ((2.65 - 1) \times 1000) / (1+ 2.53)$

$= 467.42\ kg/m^3$ or, $\rho_{sub} = \rho_{sat} - \rho_w = 1467.42 - 1000 = 467.42\ kg/m^3$

4.



PROBLEMS ON CHAPTER 2: - PRELIMINARY DEFINITIONS AND RELATIONSHIP

$G_S = 2.65$

a) voids ratio (e) = V_v / V_s

$G_s = \rho_s / \rho_w = (M_d / V_s) / \rho_w$

⇨ $2.65 = (45.5 / V_s) / 1000$

⇨ $V_s = 0.0171\ m^3$

V_v = Volume of voids = $V – V_s = 0.028 – 0.017 = 0.011\ m^3$

Voids ratio (e) = 0.011 / 0.017 = 0.647

b) porosity (n) = e / (1+e) = 0.647 / (1+0.647) = 0.393

Or,

Porosity (n) = $V_v / V = 0.011 / 0.028 = 0.393$

c) degree of saturation (S) = V_w / V_v

$\rho_w = M_w / V_w$

⇨ $1000 = (M – M_d) / V_w$

⇨ $1000 = (56.6 – 45.5) / V_w$

⇨ $V_w = 0.011\ m^3$

Degree of saturation (S) = 0.011 / 0.011 = 1 or 100%

Or,

Water content (w) = $M_w / M_d = (56.6 – 45.5) / 45.5 = 0.244$

As we know, Gw = Se

⇨ 2.65 x 0.244 = S x 0.647

⇨ S = 1 or 100%

d) air content (a_c) = 100 – S(%) = 100 – 100 = 0

e) percentage air voids (n_a) = $V_a / V = (V_v – V_w) / V = (0.011 – 0.011) / 0.028 = 0$

Or,

As we know, $n_a = n \times a_c$

⇨ $n_a = 0.39 \times 0 = 0$

f) saturated density (ρ_{sat}) = $(G + e)\ \rho_w / (1+e)$

$= (2.65 + 0.647) \times 1000 / (1+0.647)$

$= 2001.82 \text{ kg/m}^3$

Submerged density (ρ_{sub} / $\rho^{/}$) = $\rho_{sat} - \rho_w$ = 2001.82 – 1000 = 1001.82 kg/m^3

Or,

As we know,

$$\rho_{sub} = (G - 1)\ \rho_w / (1+e)$$
$$= (2.65 - 1) \times 1000 / (1+0.647)$$
$$= 1001.82 \text{ kg/m}^3.$$

Extra problems

1. For a moist soil sample, the following are given:

   Total volume = 1.2 m^3

   Total mass = 2350 kg

   Moisture content = 8.6 %

   Specific gravity of soil solids = 2.71

Determine the following.

i) moist density

ii) dry density

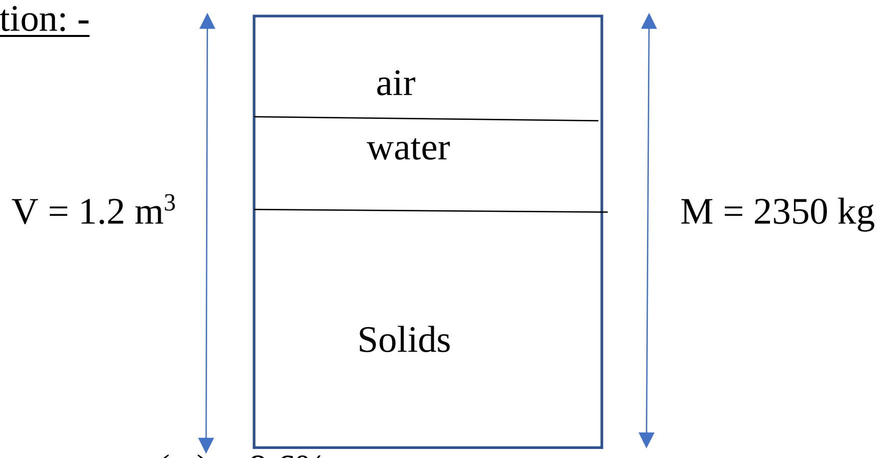
iii) void ratio

iv) porosity

v) degree of saturation

vi) volume of water in the soil sample

solution: -



Water content (w) = 8.6%

PROBLEMS ON CHAPTER 2: - PRELIMINARY DEFINITIONS AND RELATIONSHIP

G or G_s = 2.71

i) moist density / bulk density (ρ) = M / V = 2350 / 1.2 = 1958.33 kg/m^3

ii) dry density (ρ_d) = M_d / V

water content (w) = M_w / M_d

- ⇨ 0.086 = (M – M_d) / M_d
- ⇨ 0.086 = (2350 – M_d) / M_d
- ⇨ M_d = 2163.9 kg

Now, dry density (ρ_d) = M_d / V

= 2163.9 / 1.2 = 1803.2 kg/m^3

Or,

As we know from fundamental relationships,

Dry density (ρ_d) = ρ / (1+w)

= 1958.3 / (1+0.086)

= 1803.2 kg/m^3

iii) void ratio (e) = ?

we know, e = V_v / V_s

again, G = 2.71

- ⇨ ρ_s / ρ_w = 2.71
- ⇨ (M_d / V_s) / 1000 = 2.71
- ⇨ (2163.9 / V_s) / 1000 = 2.71
- ⇨ V_s = 0.8 m^3

Now, volume of voids (V_v) = V - V_s = 1.2 – 0.8 = 0.4 m^3

So, void ratio (e) = V_v / V_s = 0.4 / 0.8 = 0.5

Or,

From fundamental relationships, we know

ρ_d = (G x ρ_w) / (1 + e)

⇨ 1803.2 = (2.71 x 1000) / (1 + e)

⇨ e = 0.5

iv) porosity (n) = ?

we know, n = V_v / V

= 0.4 / 1.2 = 0.33

Or,

From fundamental relationships, we know

$$n = e / (1 + e)$$

$$= 0.5 / (1 + 0.5)$$

$$= 0.33$$

v) degree of saturation (S) = ?

we know, $S = (V_w / V_v) \times 100$

again, $\rho_w = M_w / V_w$

$= (M – M_d) / V_w$

- ⇨ $1000 = (2350 – 2163.9) / V_w$
- ⇨ $V_w = 0.18\ m^3$

So, degree of saturation (S) = $(V_w / V_v) \times 100$

$= (0.18 / 0.4) \times 100 = 45\%$

Or,

From fundamental relationships we know,

$$Gw = Se$$

- ⇨ $2.71 \times 0.086 = S \times 0.5$
- ⇨ $S = 46\%$

Or,

From fundamental relationships, we know

$$\rho = ((G + Se)\ \rho_w) / (1 + e)$$

- ⇨ $1958.3 = ((2.71 + 0.5S) \times 1000) / (1 + 0.5)$
- ⇨ $1958.3 \times 1.5 = (2.71 + 0.5S) \times 1000$
- ⇨ $2937.45 / 1000 = 2.71 + 0.5S$
- ⇨ $2.937 – 2.71 = 0.5S$
- ⇨ $0.227 / 0.5 = S$
- ⇨ $S = 0.454 = 45\%$

Vi) volume of water in the soil sample = $0.18\ m^3$

Chapter 3: Index properties of soil

Soil properties are broadly divided into two types: they are,

1. Index properties
2. Engineering properties

1. Index properties: - properties of soil used for classification and identification purpose are called index properties of soil. These are also used as indicative to engineering properties of soil. They are,
   a. Water content
   b. Specific gravity
   c. In-situ density
   d. Particle size distribution
   e. Relative density/ density index
   f. Consistency limits also known as Atterberg limits and plasticity indices
2. Engineering properties: - properties of soil used for quantifying the engineering behavior of soil under the application of load are called engineering properties of soil. They are,
   a. Shear strength
   b. Compressibility or consolidation
   c. Compaction
   d. Permeability or hydraulic conductivity
   e. Swelling potential etc.

Water content: -

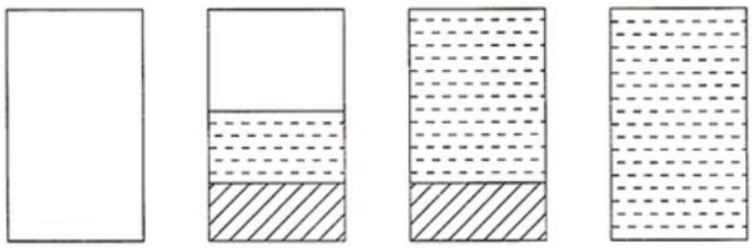
- it is defined as the ratio of mass or weight of water to mass or weight of soil solids in a soil mass. i.e. water content (w) = (M_w / M_s) x100
- different methods to determine water content in a soil mass are,
  - oven drying method ✓ – **most accurate method**
  - pycnometer method ✓
  - sand bath method ✓
  - calcium carbide method – **quickest method**
  - torsion balance method
  - alcohol method
- oven drying method: - it is the standard and most accurate method of determination of water content in the laboratory. In this method, wet soil is taken in a container with lid and weighed (Fig. b), let say the weight is W_2 gm. Then the container

without lid and wet soil is placed in an oven maintained at a temp of 105-110^0 C for a period of 24h. Then the dried soil with container is taken out from oven and placed in desiccator to cool with lid closed. The weight of dried soil with container and lid is noted, let say W_3 gm (Fig. c). If the weight of empty container with lid is let say W_1 gm (Fig. a).


(a) (b) (c)

Then, water content (w) = weight of water in soil mass / weight of soil solids in soil mass = $(W_2 – W_3) / (W_3 – W_1) \times 100$

- <u>pycnometer method: -</u> this method of water content determination is suitable only when specific gravity (G) of soil is accurately known. Pycnometer is a density bottle of 900 mL capacity with a brass conical cap screwed at top and a rubber washer inside the cap to prevent the leakage of water. In this method, first the empty weight of pycnometer is noted let W_1 gm (Fig. a), then approx. 200-400 g of wet soil is placed inside the pycnometer and pycnometer along with wet soil is weighed and noted let W_2 gm (Fig b). Then, water is added into the pycnometer and wet soil up to the top and stirred with a glass rod to remove the entrapped air and the weight of pycnometer along with wet soil and water up to top is noted let W_3 gm (Fig c) and finally, the weight of pycnometer filled only with water up to top is noted let W_4 gm (Fig. d).

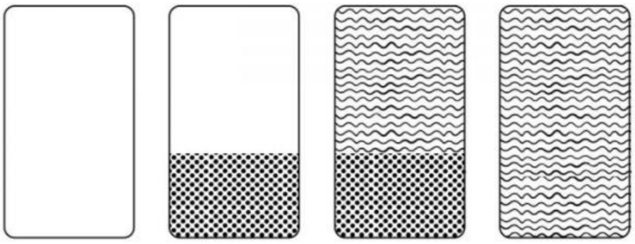

(a) (b) (c) (d)

Then, water content (w) = $\left\{\left[\frac{(W_2 - W_1)}{(W_3 - W_4)}\frac{(G-1)}{G}\right] - 1\right\}$

- Sand bath method: - this is a rapid field method of water content determination compared to oven drying method. It gives less accurate results compared to oven drying method. It is similar to oven drying method except drying of wet soil is done in sand bath for a period of about 0.5-1 hr. until the water gets fully evaporated instead of oven.

Specific gravity: -

- it is defined as the ratio of density/ unit weight of soil solids to the density/ unit weight of water at a standard temperature and pressure. i.e. $G = \rho_s / \rho_w$.
- different methods for determination of specific gravity of soil mass are: -
  - pycnometer method
  - density bottle method
- pycnometer method: - in this method, approx. 200-300 gm of oven dried soil is taken in a pycnometer and then following measurements are taken.



W_1 W_2 W_3 W_4

Where,

W_1 = weight of empty pycnometer in gm

W_2 = weight of pycnometer + dry soil in gm

W_3 = weight of pycnometer + soil + water up to top in gm

W_4 = weight of pycnometer + water only in gm

Then, specific gravity $(G) = (W_2 – W_1) / [(W_2 – W_1) – (W_3 – W_4)]$

- density bottle method: - density bottle with a stopper of capacity 50ml is used for calculation of specific gravity. The density bottle is cleaned and dried at a temperature of 105 to 110 degree Celsius and cooled. About 5-10g of oven dried sample soil is taken and following measurements are recorded.

Chapter 3: Index properties of soil

Let, W_1 = weight of empty bottle in gm

W_2 = wt. of bottle + dry soil in gm

W_3 = wt. of bottle + dry soil + water filled up to mark in gm

W_4 = wt. of bottle + water only (up to same mark) in gm

Then, specific gravity (G) = $(W_2 - W_1) / [(W_2 - W_1) - (W_3 - W_4)]$

Sometimes, kerosene is used in place of water in that case,

specific gravity (G) = $[G_K (W_2 - W_1)] / [(W_2 - W_1) - (W_3 - W_4)]$

Particle size distribution: - soil particles of size greater than 75 microns are called **coarse grained soil** and soil particles finer than 75 microns are called **fine grained soil**. To classify a soil, it is important to know the grain size distribution of soil. There are two ways of measuring the particle size distribution: -

- Sieve analysis
- Wet mechanical analysis / sedimentation analysis

Sieve analysis: - this method is suitable for classifying coarse grained soils. In this method, soil sample approx. 1kg is placed on a set of sieves arranged in decreasing order of size from top to bottom i.e. largest sieve size at top with a receiving pan at bottom. The soil sample is shaken for at least 10 minutes with the help of shaking machine or manually. The sieve sizes used normally for sieve analysis are 4.75mm, 2.36mm, 1.18mm, 600μ, 425μ, 300μ, 150μ, 75μ and receiving pan. After shaking the soil sample for 10 mins, soil mass retained on each sieve is measured and percentage finer is calculated for each sieve. Then, particle size distribution curves are drawn on a semi-log paper by taking sieve size along x-axis in log scale and percentage finer along y-axis in arithmetic scale. Using the curve, D_{10}, D_{30}, D_{60} are determined and C_u, C_c are calculated from following formulas. ($1\ \mu = 10^{-3}$ mm)

$C_u = D_{60} / D_{10}$

$C_c = (D_{30})^2 / (D_{60} \times D_{10})$

Where,

D_{10}, D_{30} and D_{60} represents the sieve size corresponding to 10%, 30% and 60% finer

C_u = uniformity coefficient

C_c = coefficient of curvature

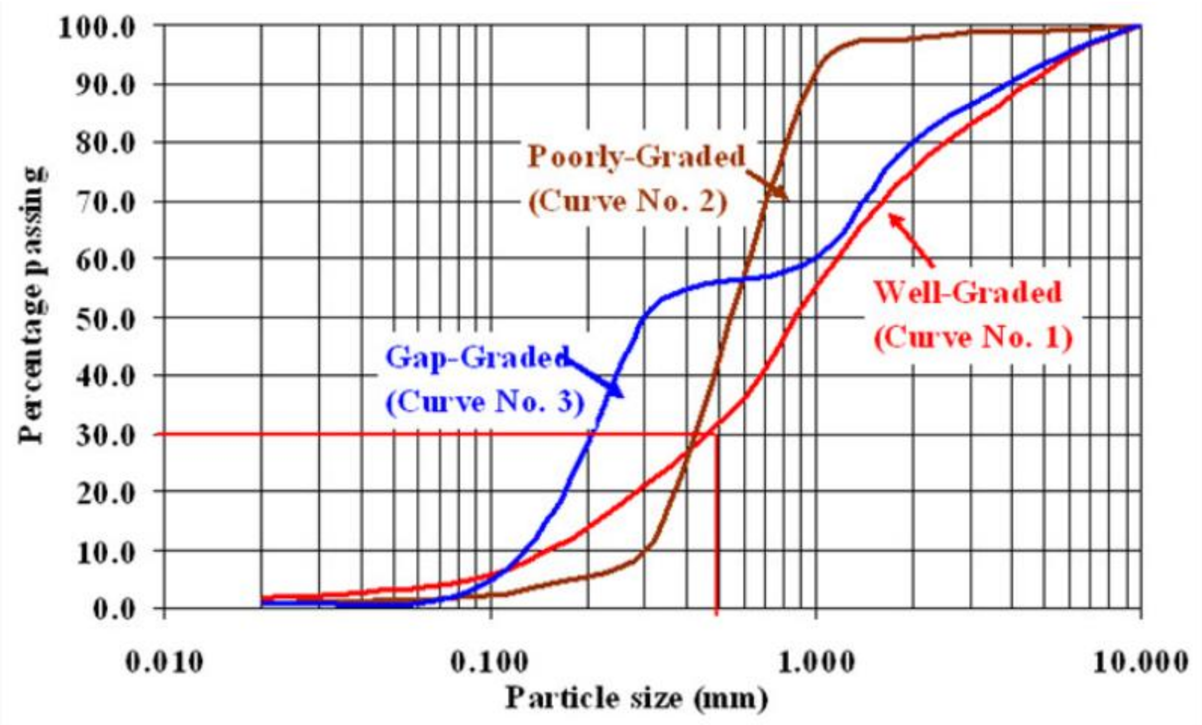
Sample calculation

Sieve Number	Sieve Size (mm)	Mass of each sieve (g) (M1)	Mass of each sieve + soil retained (M2)	Mass of soil (M2-M1)	Percentage retained on each sieve $\left(\frac{(M2-M1)}{M}\right)$ X 100	Cumulative % retained	Percent finer
4	4.750	765.5	786.5	021	4.2	4.2	95.8
10	2.360	738.25	764.25	026	5.2	9.4	90.6
16	1.180	672	716.5	044.5	8.9	18.3	81.7
30	0.600	602.5	649	046.5	9.3	27.6	72.4
40	0.425	572	684	112	22.4	50	50
60	0.300	554.5	701.5	147	29.4	79.4	20.6
100	0.150	523.5	585.5	062	12.4	91.8	8.2
200	0.075	509.5	530.5	021	4.2	96	4
Receiving pan		485	505	020	4	100	0
Total				500 (M)			

M --> Mass of specimen	M2 – M1 --> Mass of soil
M1 --> Sieve Size	Zr --> Cumulative % retained
M2 --> Mass of each sieve + soil retained	Zr - 100 --> Percent finer

Calculate the Cc and Cu using the plotted graph for the above details.

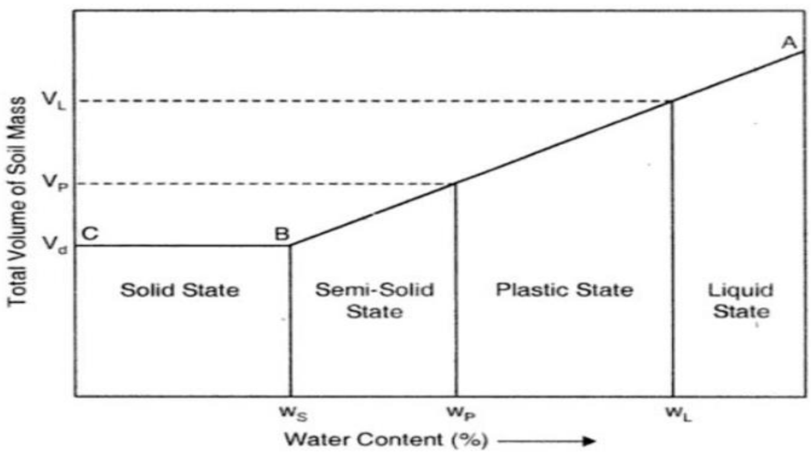
Chapter 3: Index properties of soil



Wet mechanical analysis: - this method is suitable for fine grained soils i.e. soils finer than 75 microns. This method is also known as sedimentation analysis. This can be done by two ways:

- Hydrometer analysis **(explain and submit in classroom folder)**
- Pipette analysis **(explain and submit in classroom folder)**

Consistency of soils: - it represents the plasticity or stiffness of soil, which depends on the water content of soil. It can also be defined as the change of state of a soil mass with change in its water content. The boundaries of change in state of soil mass with change in water content are called consistency limits or Atterberg limits.



CONSISTENCY LIMITS

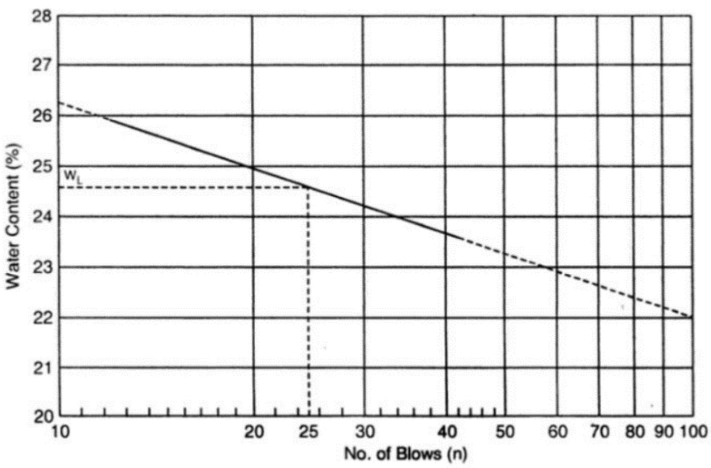
Where, w_L = liquid limit

w_P = plastic limit

w_S = shrinkage limit

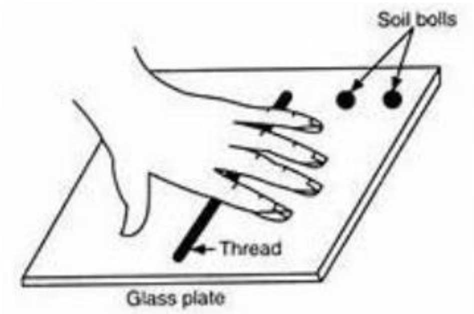
Liquid limit: - it is defined as the water content at which soil mass changes from plastic state to liquid state or it is defined as the water content which is sufficient to close a gap of 12.7mm in the soil sample made using a standard tool after 25 blows. Casagrande apparatus used to obtain liquid limit of soil. Slope of the flow curve is called flow index.

$$I_F = \frac{w_1 - w_2}{\log\left(\frac{N_2}{N_1}\right)}$$



FLOW CURVE.

Plastic limit: - it is defined as the water content at which soil mass changes from semi-solid state to plastic state or it is the water content at which a thread crumbles when it reaches just a diameter of 3mm.



Chapter 3: Index properties of soil

Shrinkage limit: - it is defined as the water content at which soil mass changes from solid state to semi-solid state.

Plasticity index: - it is defined as the difference between liquid limit and plastic limit.

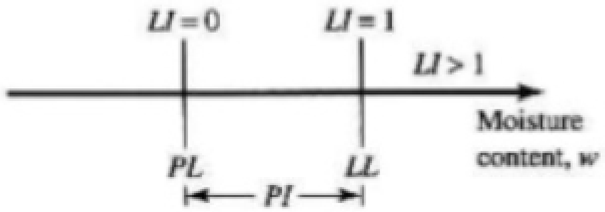
$$I_P = w_L - w_P$$

S. No.	Plasticity index	Plasticity
1.	0	Non-plastic
2.	Less than 7	Low plastic
3.	7–17	Medium plastic
4.	Greater than 17	Highly plastic

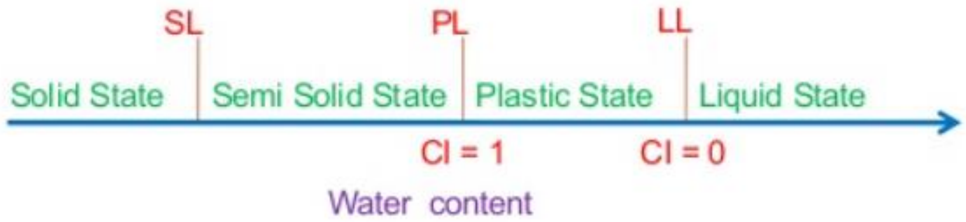
liquidity index: -

$$I_L = \frac{\text{Natural water content} - \text{Plastic limit}}{\text{Plasticity index}}$$

if natural water content (w) = w_L, then $I_L = 1$ and similarly, if w = w_P, then $I_L = 0$



Consistency index: - $I_C = \frac{\omega_L - \omega}{I_P}$ Where, w is the natural water content



CH. 4 CLASSIFICATION OF SOIL

Soils are classified in order to sort them into various groups showing similar behaviour based on following two criteria: -

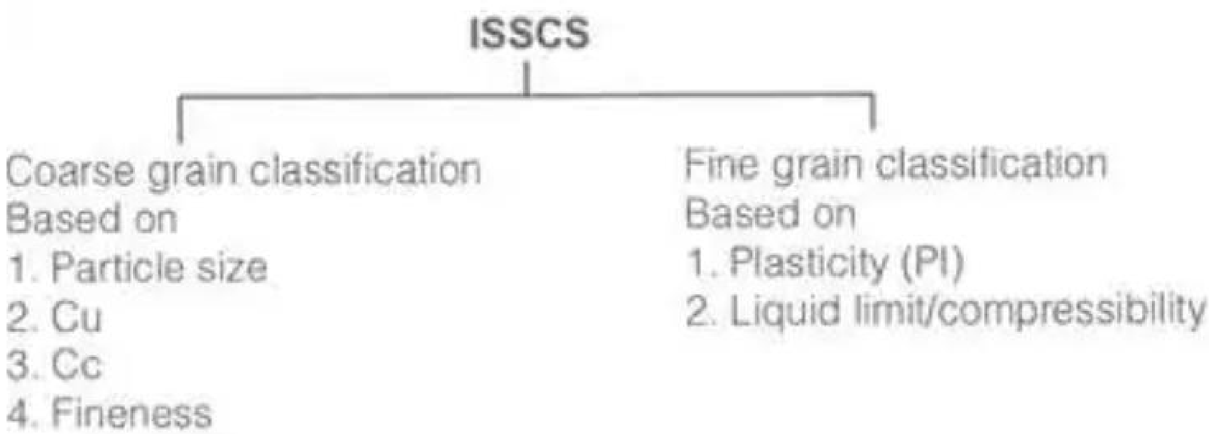
1. Grain size
2. Plasticity

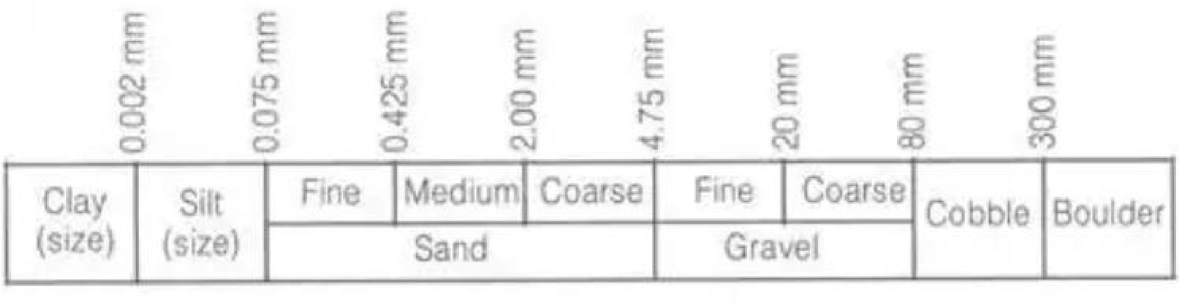
There are 4 methods of soil classification, they are: -

1. Textural classification
2. Unified soil classification system (USCS)
3. AASTHO soil classification system
4. Indian soil classification system (ISCS)

Indian soil classification system (ISCS)

Soil particles retained on 75 micron IS sieve are called coarse grained soil and soil particles passing through 75 micron sieve are called fine grained soil. Indian soil classification system uses the following criteria for soil classification.





Classification of soils based on grain size.

On the basis of fineness (percentage passing through 75 μ IS sieve), coarse grain soils are further classified into following types: -

Case-1 ï when fineness < 5%

1. GW ï well graded gravel

   $C_u > 4$

   $1 \leq C_c \leq 3$

2. GP ï poorly graded gravel

   Above values of C_u & C_c are not satisfied

3. SW ï well graded sand

   $C_u > 6$

   $1 \leq C_c \leq 3$

4. SP ï poorly graded sand

   Above values of C_u & C_c are not satisfied

Case-2 ï when fineness lies between 5% - 12%, dual symbols are used

1. GW-GC ï well graded gravel containing clay

   $C_u > 4$

   $1 \leq C_c \leq 3$

   Clay > silt and gravel > sand

2. GW-GM ï well graded gravel containing silt

   $C_u > 4$

   $1 \leq C_c \leq 3$

   Silt > Clay and gravel > sand

3. SW- SC ï well graded sand containing clay

   $C_u > 6$

   $1 \leq C_c \leq 3$

   Clay > silt and sand > gravel

4. SW-SM ï well graded sand containing silt

   $C_u > 6$

   $1 \leq C_c \leq 3$

Silt > Clay and sand > gravel

Similarly, for poorly graded soils dual symbols like GP-GC, GP-GM, SP-SC, and SP-SM are used when C_u and C_c are not satisfied.

Case-3 ï when fineness > 12%

1. GC ï Clayey gravel

   gravel > sand

   clay > silt, $I_p > 7\%$

2. GM ï silty gravel

   gravel > sand

   silt > clay, $I_p < 4\%$

3. SC ï clayey sand

   Sand > gravel

   silt > clay, $I_p > 7\%$

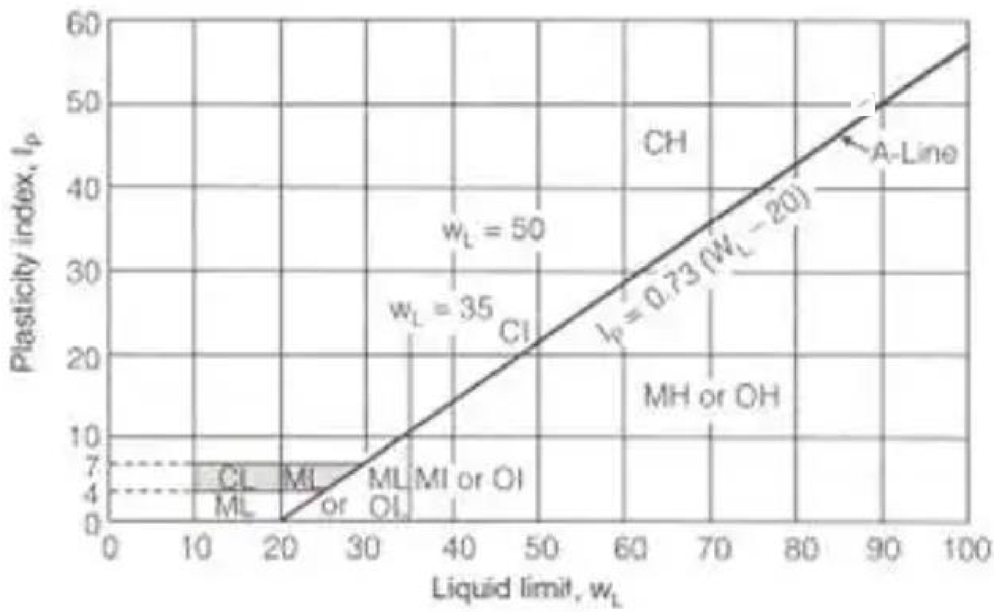
4. SM ï silty sand

   Sand > gravel

   silt > clay, $I_p < 4\%$

For I_p between 4% and 7%, dual symbols are used.

For classifying fine grained soils, following plasticity chart is used.



(i) Low plastic soils (LL < 35%)

CL → Low plastic inorganic clay

ML → Low plastic silt

OL → Low plastic organic clay

(ii) Medium plastic soils (35% < 50%)

CI → Medium plastic inorganic clay

MI → Medium plastic silt

OI → Medium plastic organic clay

(iii) High plastic soils (LL > 50%)

CH → High plastic inorganic clay

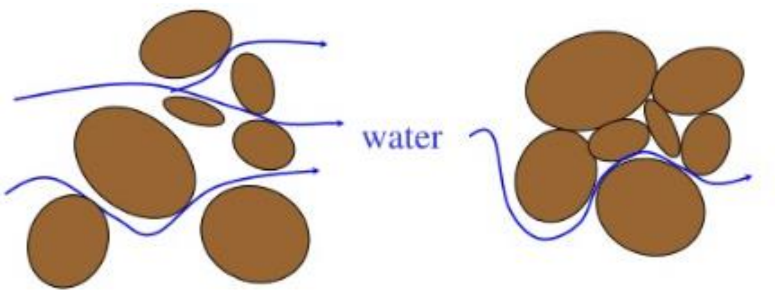
MH → High plastic silt

OH → High plastic organic clay

CH 5 PERMEABILITY AND SEEPAGE

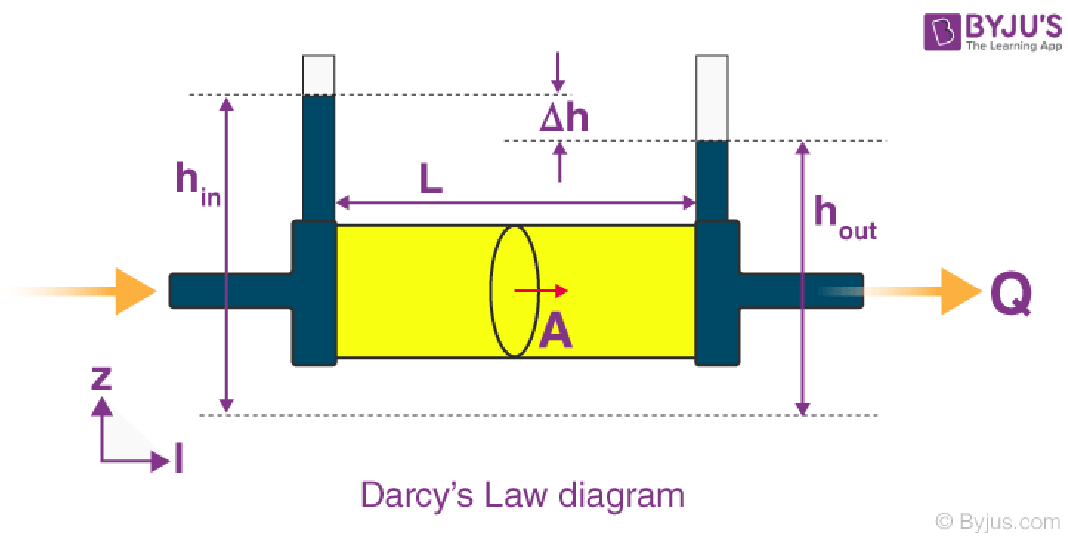
Concept of permeability: -

- ✓ The ability of soil to allow flow of water through it is called as **permeability** of soil.
- ✓ Flow of water in soil takes place through void spaces, which are interconnected.



- ✓ Importance of permeability = in Estimating the quantity of underground seepage, Stability analysis of earth structures and earth retaining walls etc.

Darcy's Law: -



- ✓ It states that the rate of flow i.e. volume of water per unit time (Q) is directly proportional to the head causing the flow and the c/s area of the soil sample but is inversely proportional to the length of soil sample. i.e.

$$Q \propto \frac{\Delta h}{L} \text{ x } A \text{ or}$$

$$Q = kiA \text{ or } \frac{Q}{A} = ki \text{ or } \boxed{V = ki}$$

CH 5 PERMEABILITY AND SEEPAGE

Where, V = discharge velocity = $\frac{Q}{A}$

k = coefficient of permeability

i = hydraulic gradient i.e. $\frac{\Delta h}{L} = \frac{h_{in}-h_{out}}{L}$

- ✓ So, coefficient of permeability can be defined as the velocity of flow of water through soil mass per unit hydraulic gradient.
- ✓ Unit of coefficient of permeability i.e. k is same as velocity as m/sec, cm/sec etc.
- ✓ Value of k for different soils is given below

  Gravel – 10^0 cm/s

  Sand – $10^0 - 10^{-2}$ cm/s

  Silt – $10^{-2} - 10^{-4}$ cm/s

  Clay – $10^{-4} - 10^{-6}$ cm/s

Factors affecting Permeability: -

$$k = C\, D_{10}^2 \frac{\gamma_w}{\mu} \frac{e^3}{1+e}$$

- ✓ Shape of the particles
- ✓ Grain size or Particle size ($k = 100\, D_{10}^2$, given by Allen Hazen)
- ✓ Void Ratio
- ✓ Presence of foreign particles / Impurities in soil
- ✓ Degree of saturation
- ✓ Adsorbed water
- ✓ Entrapped air and organic matter

To determine the value of k i.e. coefficient of permeability, there are two laboratory tests as discussed below, they are: -

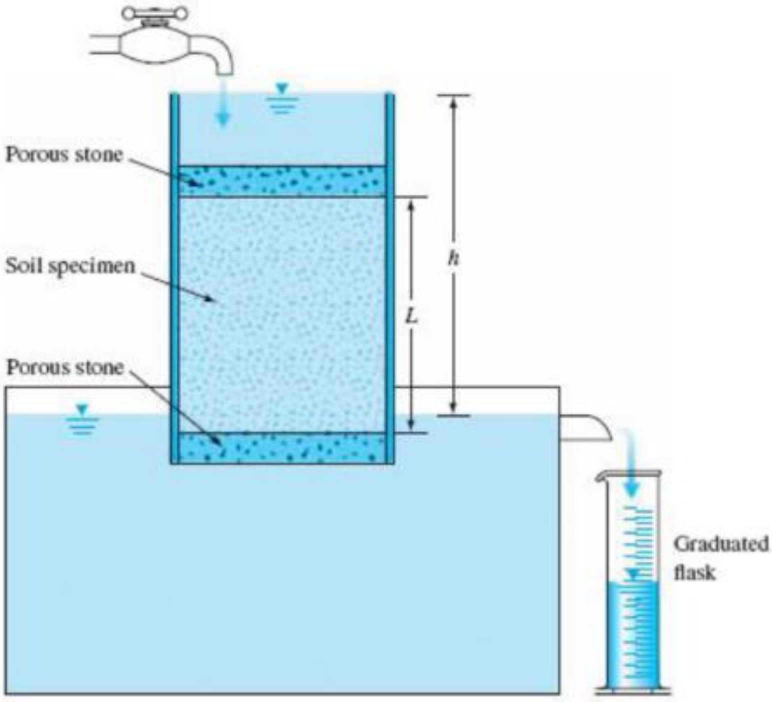
1. Constant-head permeability test
2. Falling-head permeability test

Constant-head permeability test: - for coarse grained soils

- ✓ A typical arrangement for this test is shown in figure below. In this test, the water supply at inlet is adjusted such as to keep the head difference between inlet and outlet remains constant during the whole test.

CH 5 PERMEABILITY AND SEEPAGE

- ✓ After a constant flow rate is established, water is collected in a graduated flask for a known duration.



the total volume of water collected can be written as,

$$Q = A.v.t$$

Where, Q = volume of water collected

A = C/S area of soil specimen

t = duration of water collection

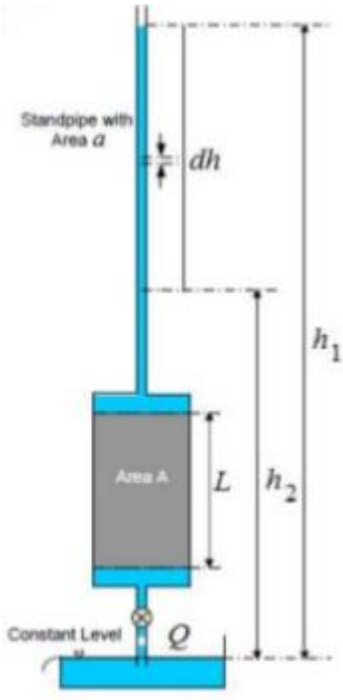
As we know, $i = \frac{h}{L}$ and from Darcy's law, v = ki

Then, $Q = A.k.\frac{h}{L}.t$ or, $\boxed{k = \frac{QL}{Aht}}$

Falling head permeability test: - for fine grained soils

- ✓ A typical arrangement for this test is shown in figure below. Water from a standpipe is allowed to flow through soil specimen. The initial head difference h_1 at time $t=t_1$ is recorded. Then, water is allowed to flow through soil specimen and after certain time interval, let say at time $t=t_2$, head difference h_2 is recorded.

CH 5 PERMEABILITY AND SEEPAGE



- ✓ Then, to calculate coefficient of permeability (k) following formula is used.

$$k = 2.303 \frac{aL}{At} \log \frac{h_1}{h_2}$$

Where, k = coefficient of permeability in m/sec or cm/sec

a = area of standpipe

L = length of soil specimen

A = area of soil specimen

$t = t_2 - t_1$ = time interval in sec

h_1, h_2 are the head differences at times t_1 and t_2 respectively.

Stresses in a soil mass: -

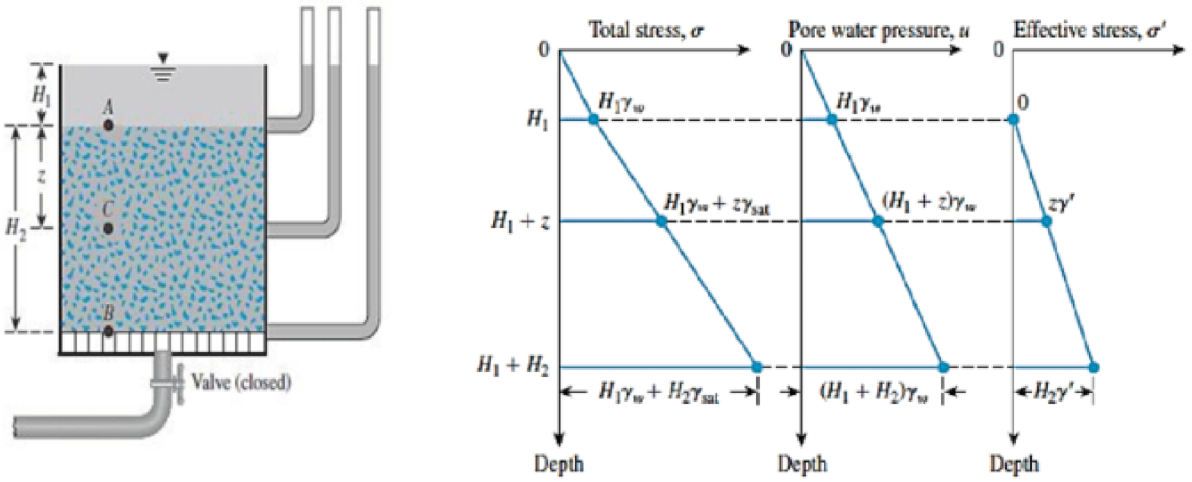
- ✓ Load applied on a soil mass is shared by soil particles and pore water/ water present in voids. Load shared by soil particles is called effective stress and load shared by pore water is called pore water pressure.
- ✓ Hence, total stress (σ) = effective stress (σ') + pore water pressure (u)

CH 5 PERMEABILITY AND SEEPAGE

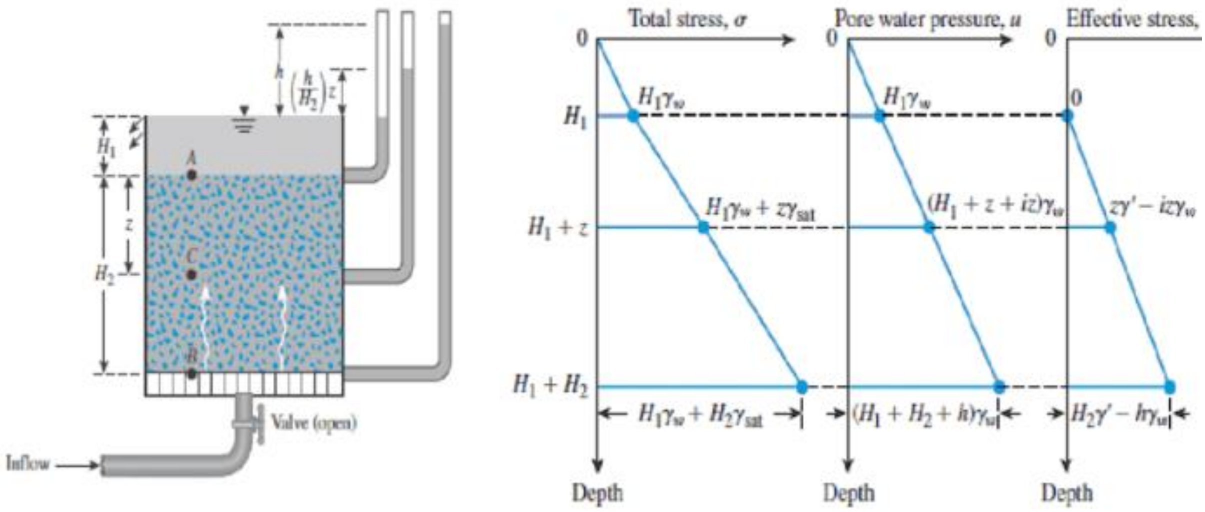
- ✓ As effective stress can't be measured directly, hence it is computed from,

  Effective stress ($\sigma^{/}$) = total stress (σ) - pore water pressure (u)

- ✓ Total stress at any depth in a soil mass depends upon the height of soil mass above the point under consideration and pore water pressure depends upon the height of water it will be raised when a piezometer is inserted at that point. i.e.



- ✓ If seepage (movement of water through a soil mass) starts taking place from bottom by opening the valve at bottom of above figure, then the distribution of total, effective and pore water pressure will be as shown below.



- ✓ Thus, we can see the effective stress at a depth z from top of soil mass is reduced by amount of $iz\gamma_w$ due to upward seepage. If the rate of seepage and hydraulic gradient is increased, a stage will be reached when effective stress will become equal to zero. i.e.

$$\sigma_c^{/} = z\gamma^{/} - i_{cr} z\gamma_w = 0$$

$$\Rightarrow i_{cr} = \frac{\gamma'}{\gamma_w}$$

- ✓ i_{cr} is called critical hydraulic condition and the phenomenon when effective stress becomes equal to zero and soil mass losses all its strength is known as **quick sand condition or boiling condition**.
- ✓ Normally, cohesion-less soils (sand)are s.t. quicksand conditions.

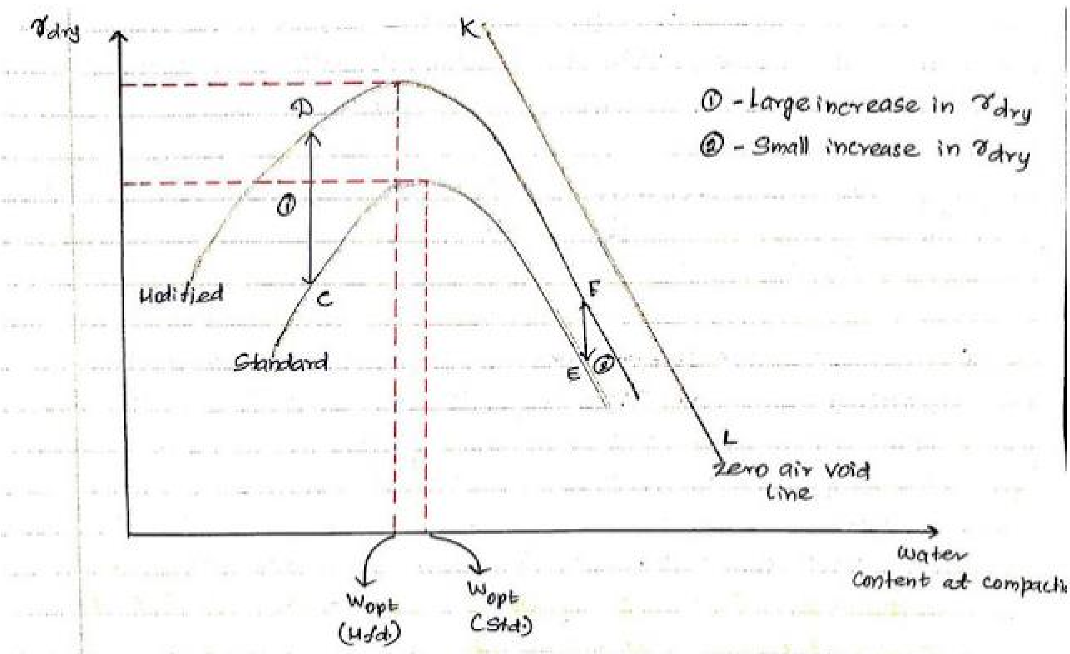
CHAPTER-6 COMPACTION AND CONSOLIDATION

Compaction: -

- ✓ Compaction is defined as a short term process of removal of air voids with the help of mechanical means.
- ✓ Compaction causes the soil grains to pack more closely, which increases the strength and stability of soil mass.
- ✓ It also increases the unit weight of soil mass.

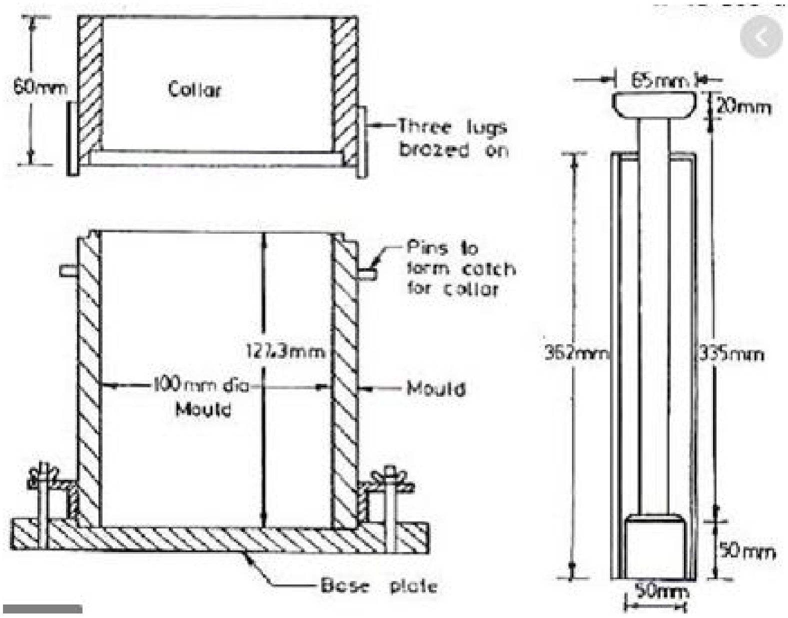
Maximum dry density (MDD) and optimum moisture content (OMC): -

- ✓ It has been observed that dry density (γ_d) increases with percentage water content in soil mass up to a certain point and then it decreases with further increase in water content. It is because water starts taking place the spaces occupied by solid particles.
- ✓ Hence, the graph showing the variation of dry density with water content is shown in following figure



- ✓ The water content at which maximum dry density occurs is known as the optimum moisture content (OMC) and corresponding dry density is called maximum dry density (MDD).
- ✓ The laboratory tests performed to obtain the values of OMC and MDD are
  - o Standard proctor test (light compaction)
  - o Modified proctor test (heavy compaction)
- ✓ In proctor test, a hammer of specified weight is allowed to fall on soil mass filled in specified no. of layers in a cylindrical mould of internal dia. 100mm and height 127.3mm. After the mould is filled, the dry density is calculated for different percentages of water content and a graph is

plotted by taking the water content along x-axis and dry density along y-axis and the values of OMC and MDD are noted.



Differences between standard and modified proctor test: -

Test	Standard Proctor	Modified Proctor
Hammer weight	2.7 kg	4.9 kg
Drop height	300 mm	450 mm
Energy imparted per blow	7.94 J	21.62 J
No. of soil layers	3	5
No. of blows per layer	25	25
Energy imparted per unit volume	596 kJ/m^3	2703 kJ/m^3

Zero air void line: -

- ✓ As we know, dry density (ɔ$_d$) can be obtained using percentage air voids (n_a) using the formula,

$$\gamma_d = \frac{(1-n_a)G\gamma_w}{1+wG}$$

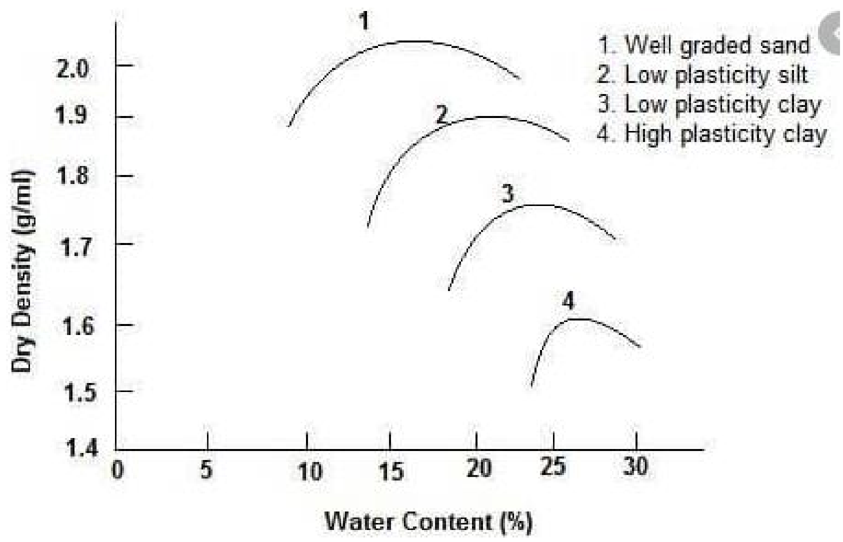
- ✓ The line corresponding to zero percent air voids (n_a =0) is called zero air void line.
- ✓ This line is also called as 100% saturation line.

Factors affecting compaction: -

- ✓ water content
- ✓ type of soil
- ✓ amount of compactive effort

Water content: - Proper control of moisture content in soil is necessary for achieving desired density. Maximum density with minimum compacting effort can be achieved by compaction of soil near its OMC (optimum moisture content).

Type of soil: - Type of soil has a great influence on its compaction characteristics. Normally, heavy clays, clays & silts offer higher resistance to compaction where as sandy soils and coarse grained or gravelly soils are amenable for easy compaction. The coarse grained soils yield higher densities in comparison to clays. A well graded soil can be compacted to higher density.



Compactive effort: - The term compactive effort or compactive energy simply means type of equipment or machinery used for compaction. Greater the compactive effort, greater will be the compaction. Higher the compactive effort, higher will be the maximum dry density (MDD) and lower will be the optimum moisture content (OMC).

Field compaction methods and their suitability: -

Various equipments used for compaction of soil and their suitability in field are listed below.

- ✓ Smooth wheel roller: - for compaction of well-graded coarse grained soils for use in highway base courses and non ï plastic fine-grained soils.
- ✓ Sheep Foot Roller: - suitable for both plastic and non-plastic fine-grained soils and for coarse-grained soils with more than 20% fines.
- ✓ Vibratory Rollers: - to compact the granular soil to a very high maximum dry density
- ✓ Impact Rammers: - can be used for all types of soils and also used for compacting in trenches.

- ✓ Vibrating Plates: -to compact granular base courses for highways and runways where the thickness of layers is small. Vibrating plates are suitable to coarse-grained soils containing up to 12 % fines.

Smooth wheel rollers

Sheep-footed roller

Vibratory roller

Vibrating plate compactor

CONSOLIDATION

Definition: -

It is defined as a process in which expulsion of pore water takes place from a saturated soil mass under long term static loading.

Difference between compaction and consolidation: -

compaction	**consolidation**
Compaction is an instantaneous process of reducing the volume of voids of soil due to the expulsion of pore air.	It is a time-dependent process of reducing the volume of voids of soil due to the expulsion of pore water.
In compaction, the air is removed from voids.	In consolidation, water is removed from voids.
It is an artificial process.	It is a natural process.
For compaction degree of saturation should be less than one which means (S < 1) soil should be partially saturated that means air and water are present in the soil voids.	For consolidation degree of saturation should be one (S = 1) which means fully saturated soil (100%), that means only water is present in the soil voids.
Compaction is done by mechanical means such as rolling, tamping and vibration.	Consolidation is done by sustained, static loading.
Loading period is short.	Loading period is long. It may take many years for 100% consolidation.
Compaction can be controlled.	Consolidation cannot be controlled. it is a natural process.
Compaction is the primary process.	Consolidation starts after compaction.
Compaction is one stage process.	Consolidation is a two-stage process that is Primary consolidation and Secondary consolidation.

Initial consolidation/settlement: -

It is defined as the settlement or consolidation due to **expulsion of air voids** during initial stages of load application.

Primary settlement/consolidation: -

It occurs due to the **expulsion of pore water** from the saturated soil mass.

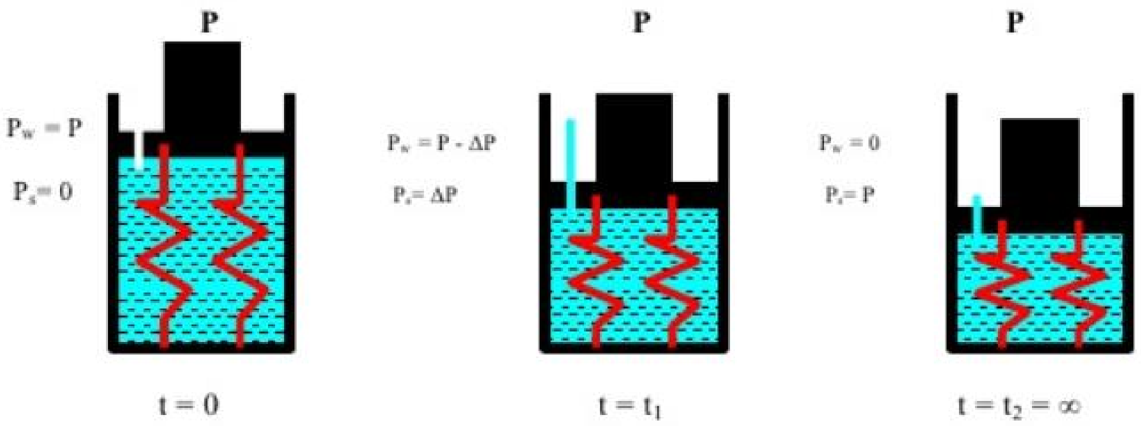
Secondary settlement/consolidation: -

CONSOLIDATION

It occurs after so many years and due to the **plastic readjustment of soil solid particles** and adsorbed water.

Terzaghiôs spring analogy model: -

- ✓ To understand the principle of consolidation, Terzaghi proposed the spring analogy model as shown in following figure.
- ✓ Figure shows a cylinder fitted with a tight fitting piston with a valve. The cylinder is filled with water and contains spring of specified stiffness.
- ✓ When load is applied on piston with valve closed, entire load will be taken up by water and spring will not share any load. Hence, P = 0 + P and $P_W = P$, $P_S = 0$
- ✓ If the valve is gradually opened, water will start escaping out. Spring starts sharing the load and reduction in its length occurs. Let, ȹP be the amount of load taken by spring then, P = ȹP + (P ï ȹP) and P_W = P - ȹP, P_S = ȹP.



- ✓ Finally, the entire load will be transferred to spring and water will not carry any load. Then, P = P + 0 and $P_W = 0$, $P_S = P$.
- ✓ The behaviour of saturated soil when subjected to steady static load is similar to the behaviour of spring-piston model as described where, soil solids behave like spring, water in voids behave like water in the cylinder and permeability of soil behaves like valve opening in the piston.
- ✓ The pore water pressure developed is similar to the pressure carried by the water in the cylinder and effective stress will be similar to the stress developed in the spring. i.e.

When load applied i.e. at t = 0, ů (total stress) = u (pore water pressure)

At $t = t_1$, ů = ȹů (effective stress) + u

At t = Ð, ů = ȹů or ů$^{/}$