

UNIT-2 Permeability

Ref:-
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Soil water:-

* Water present in the voids of soil mass is called soil water. It can be classified in several ways given below.

a) Broad classification:-

- i) Free water or gravitational water
- ii) Held water
- iii) Structural water

b) Classification on phenomenological basis:-

- i) Ground water
- ii) Capillary water
- iii) Adsorbed water
- iv) Infiltred water

c) Classification on structural aspect:-

- i) Pore water
- ii) Solvate water
- iii) Adsorbed water
- iv) Structural water.

Capillary rise:-

* The rise of water in the capillary tubes, or the fine pores of soil, is due to the existence of surface tension which pulls the water up against the gravitational force.

* The height of capillary rise, above ground water surface depends upon the diameter of

the capillary tube.

- * The water in capillary tube hangs in tension, and is supported from the side of the tube around the edge of the meniscus.

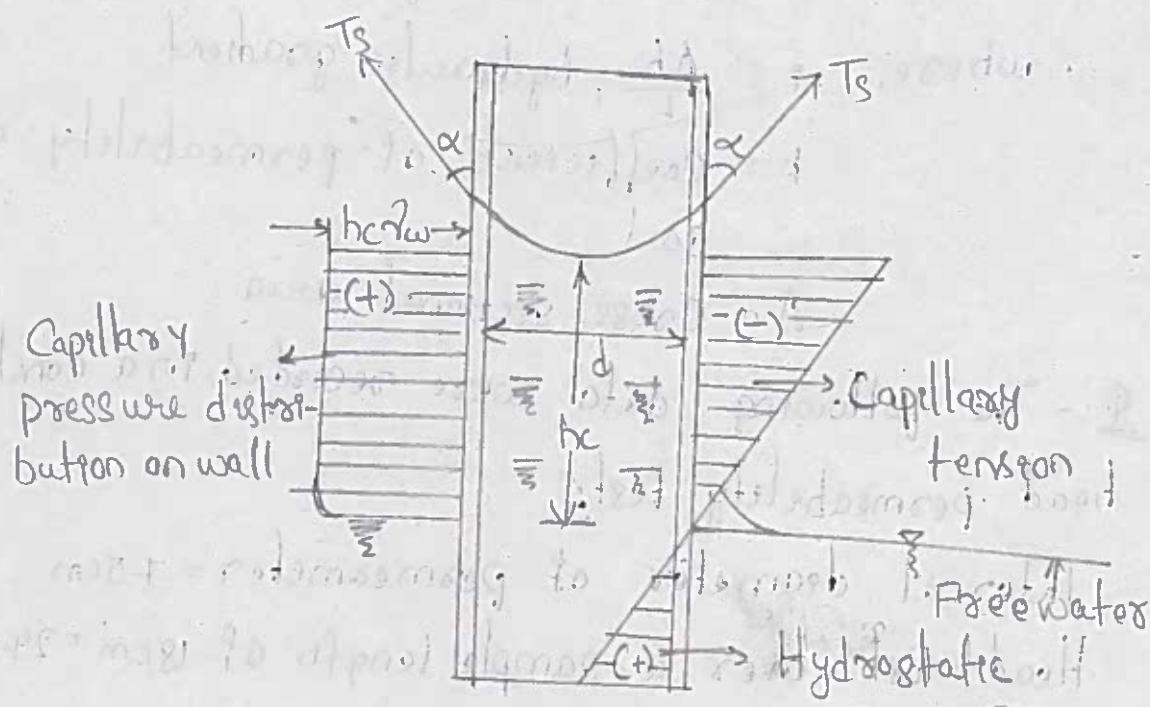


Fig:- Capillary Rise

Permeability:-

- * Soil is a particulate material and has pores that provides a passage for water such passages vary in size and are interconnected. The permeability of a soil is a property which describes quantitatively, the ease with which water flows through the soil.

Darcy's law:-

- * The flow of free water through soil is governed by Darcy's law. Darcy established that the flow occurring per unit time is directly proportional to the head causing flow and the area of cross section of the soil sample but is

inversely proportional to the length of the sample,

$$q \propto \frac{\Delta h}{L} \cdot A$$

$$q = k \cdot \frac{\Delta h}{L} \cdot A$$

$$= k \cdot i \cdot A$$

Δh = head causing flow

where, $i = \frac{\Delta h}{L}$, hydraulic gradient

k = coefficient of permeability of soil

A = cross sectional area

Q:- The following data were recorded in a constant head permeability test:

Internal diameter of permeameter = 7.5 cm

Head lost over a sample length of 18 cm = 24.7 cm

Quantity of water collected in 60 second = 626 ml

Porosity of the soil sample = 44 f

Calculate the coefficient of permeability of the soil.

$$\text{Area of soil sample} = A = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4} (7.5)^2 = 44.18 \text{ cm}^2$$

$$H = 24.7 \text{ cm}, L = 18 \text{ cm}, t = 60 \text{ sec}$$

$$\text{Hydraulic gradient } i = \frac{H}{L} = \frac{24.7}{18}$$

$$= 1.372$$

$$\text{Discharge } Q = \frac{V}{t} = \frac{626}{60} = 10.433 \text{ cm}^3/\text{s}$$

From Darcy's equation, $Q = k \cdot i \cdot A$

$$10.433 = k \times 1.372 \times 44.18$$

$$k = 0.172 \text{ cm/s}$$

Factors affecting Permeability:-

- The permeability depends on the soil properties and fluid properties both.
- The Kozeny-Carmen equation is quite useful, it reflects the effect of factors that affect permeability.

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

a) Grain size:- The coefficient of permeability (k) includes D_{10}^2 , where D_{10} is a measure of grain size.

$$k \propto D_{10}^2$$

→ If the void ratio is same, then permeability is more in Coarse soil than in the soil.

$$k_{\text{gravel}} > k_{\text{sand}} > k_{\text{silt}} > k_{\text{clay}}$$

b) Void ratio:-

→ As per Kozeny-Carmen equation, coefficient of permeability is directly proportional to $\frac{e^3}{1+e}$

$$k \propto \frac{e^3}{1+e}$$

$$k \propto e^3$$

c) Particle size:-

→ It is expressed in terms of specific surface area and permeability relates to specific surface area as $k \propto \frac{1}{s^2}$.

→ The angular particles have greater specific surface than the rounded particles.

d) Degree of saturation:-

→ Permeability is directly proportional to the

degree of saturation i.e., $k \propto$ Degree of saturation (s).

→ In partially saturated soils, entrapped air causes blockage in the flow of water.

e) Structure of soil particles:-

→ For stratified soils, permeability is more in horizontal direction as compared to the vertical direction.

Laboratory determination of coefficient of the

Permeability:-

a) Constant head permeability test

b) Variable head permeability test

c) Capillary permeability test

d) Constant head permeability test:-

This test is preferred for coarse grained soils, such as gravels and sands. The complete set up for constant head permeameter.

An observation is taken by collecting a quantity of water in a graduated jar for a known time.

Let volume of water collected in time t is V

$$\text{Discharge, } Q = \frac{V}{t}$$

$$k \cdot i \cdot A = \frac{V}{t} \quad [\text{By Darcy's law}]$$

$$k \cdot \frac{b}{L} \cdot A = \frac{Q}{t} \quad [i = \frac{H_L}{L} = \frac{b}{L}]$$

$$k = \frac{Q L}{A b}$$

where,

L = distance between manometer taping

Point -

A = cross sectional area of sample

h = difference in manometric levels

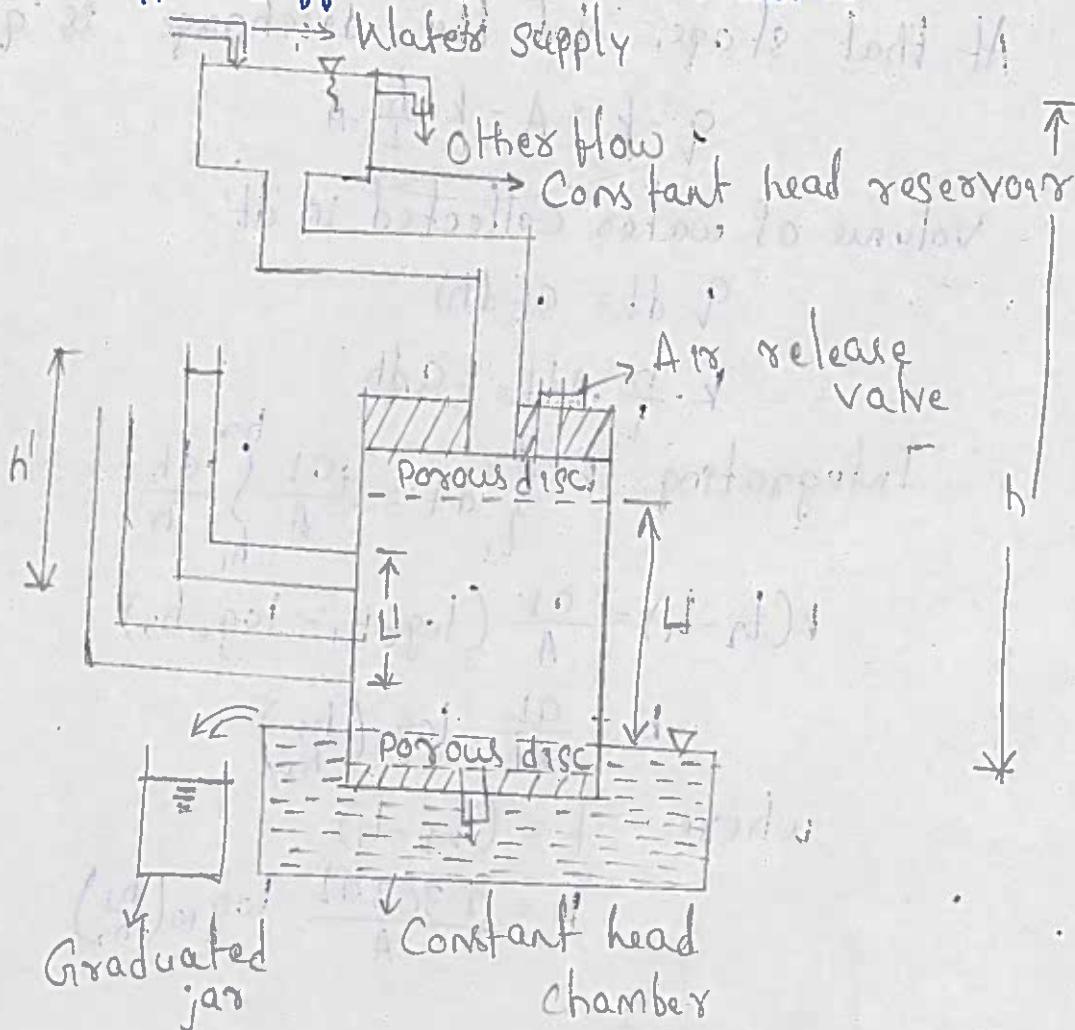


Fig:- Constant head Permeameter

b) Variable head permeability test:-

→ Variable head permeability test is used for fine sand and silt which have relatively low permeability. The complete setup for variable head permeability.

→ After saturation, the sand pipe of area $\text{cross-section } 'a'$ is filled with water and time t is taken for the water level to fall by h . Now water

is allowed to fall to h_2 , and time t_2 is noted
Let at any intermediate stage water level
be ' h ' which falls by ' dh ' in time ' dt '. So the
head difference is h .

At that stage, let the discharge is ' q'

$$q = k \cdot i \cdot A = k \cdot \frac{h}{L} \cdot A$$

Volume of water collected in ' dt '

$$q \cdot dt = a(-dh)$$

$$k \cdot \frac{h}{L} \cdot A dt = -adh$$

Integrating, $k \cdot \int_{t_1}^{t_2} dt = -\frac{aL}{A} \int_{h_1}^{h_2} \frac{dh}{h}$

$$k(t_2 - t_1) = \frac{aL}{A} (\log_e h_1 - \log_e h_2)$$

$$k = \frac{aL}{Af} \log_e \left(\frac{h_1}{h_2} \right)$$

where, $f = (t_2 - t_1)$

$$k = \frac{9.303 aL}{A} \log_{10} \left(\frac{h_1}{h_2} \right)$$

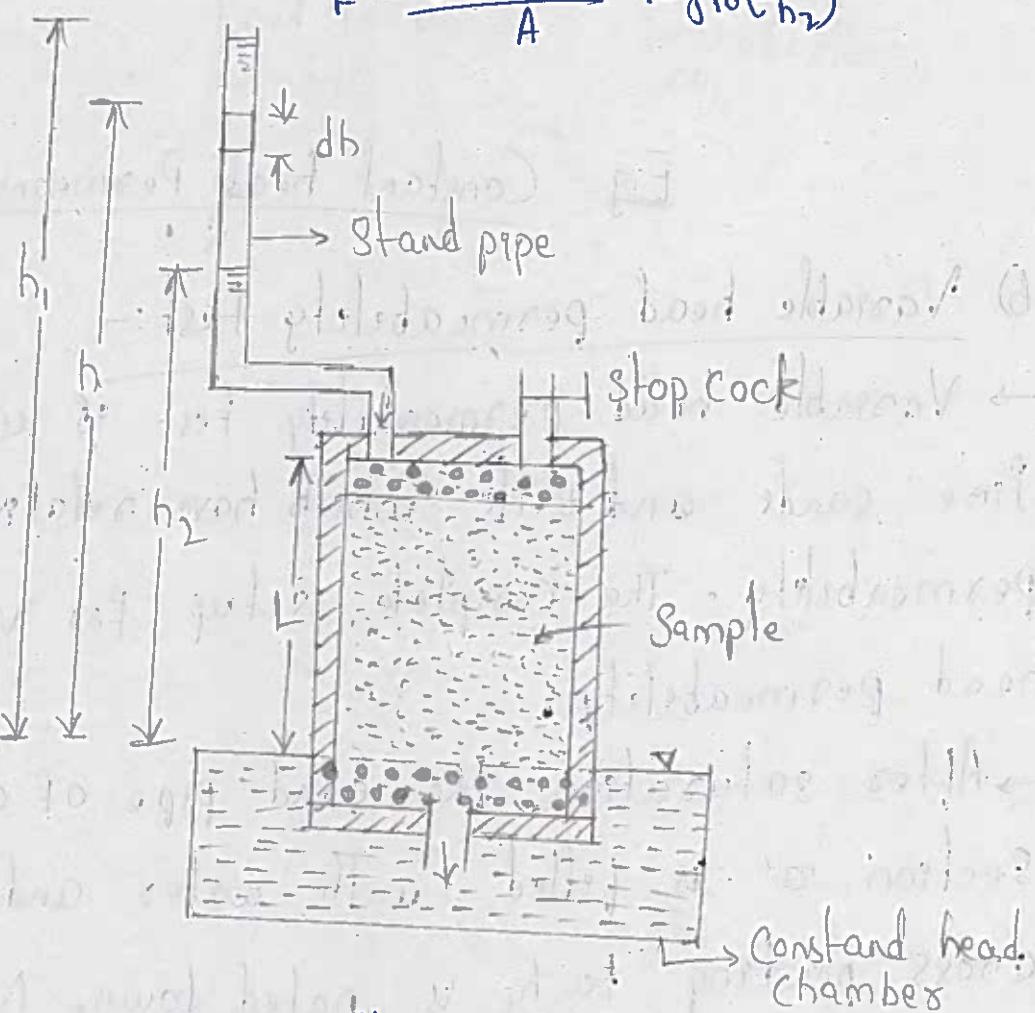
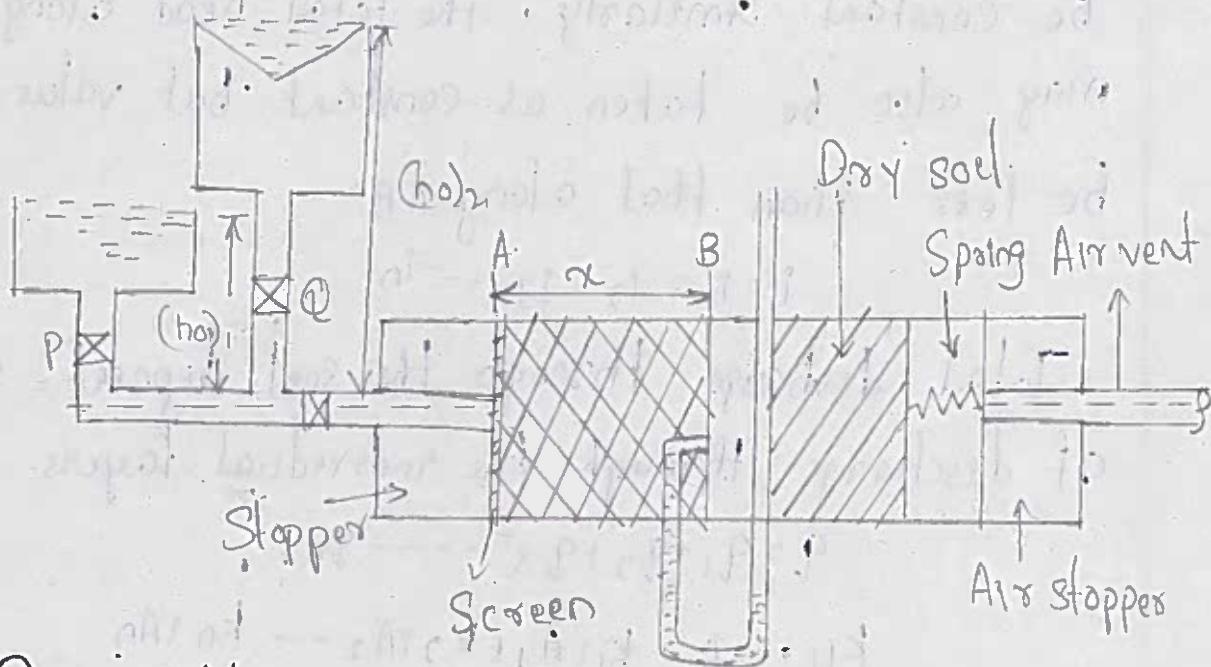


Fig :- Falling head permeameter

c) Capillary permeability test:-

→ It is also known as horizontal capillary test. This result helps us to evaluate the coefficient of permeability (k) as well as value of capillary head ((h_c)) of the soil sample. The above two test are suitable for saturated soil conditions whereas this test can be used for partially saturated soil also.



Permeability of layered soils:-

* In nature, soils are usually deposited in successive layers. Even if the different layers of the deposit are homogeneous within themselves, they may lead to a considerable disparity in the average permeability parallel to the bedding plane and normal to the bedding planes.

Horizontal flow:-

Consider the soil profile, shown in figure, below consisting of n number of layers with $H_1, H_2, H_3 \dots H_n$ in thickness with their permeability $k_1, k_2, k_3 \dots k_n$, respectively.

Let, H = Total thickness of deposit

$$= H_1 + H_2 + H_3 + H_4 \dots H_n$$

K_H = Average permeability in the horizontal direction.

Assume the total head along the line AB to be constant. Similarly, the total head along CD may also be taken as constant but value will be less than that along AB

$$i = i_1 = i_2 = i_3 = \dots i_n$$

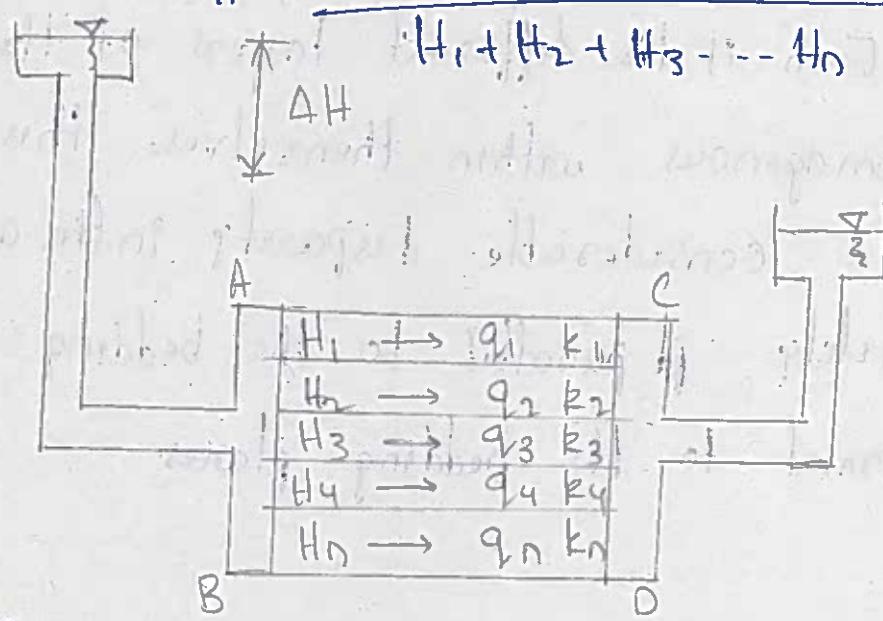
Total discharge through the soil deposit = sum of discharge through the individual layers.

$$q = q_1 + q_2 + q_3 \dots q_n$$

$$K_H \cdot i \cdot A = k_1 A_1 + k_2 A_2 \dots k_n A_n$$

$$K_H \cdot H = k_1 H_1 + k_2 H_2 + \dots k_n H_n$$

$$K_H = \frac{k_1 H_1 + k_2 H_2 \dots k_n H_n}{H_1 + H_2 + H_3 \dots H_n} = \frac{\sum k_i H_i}{\sum H_i}$$



Vertical flow:

- * In this case, flow takes place in the direction perpendicular to the stratification.
- * In this case, to satisfy the continuity equation.

$$q = q_1 = q_2 = q_3 = \dots = q_n$$

- * Let head loss through different layers be $h_1, h_2, h_3, \dots, h_n$

∴ Total head loss,

$$\Delta H = h_1 + h_2 + h_3 + \dots + h_n$$

Also let k_v be the average permeability in vertical direction.

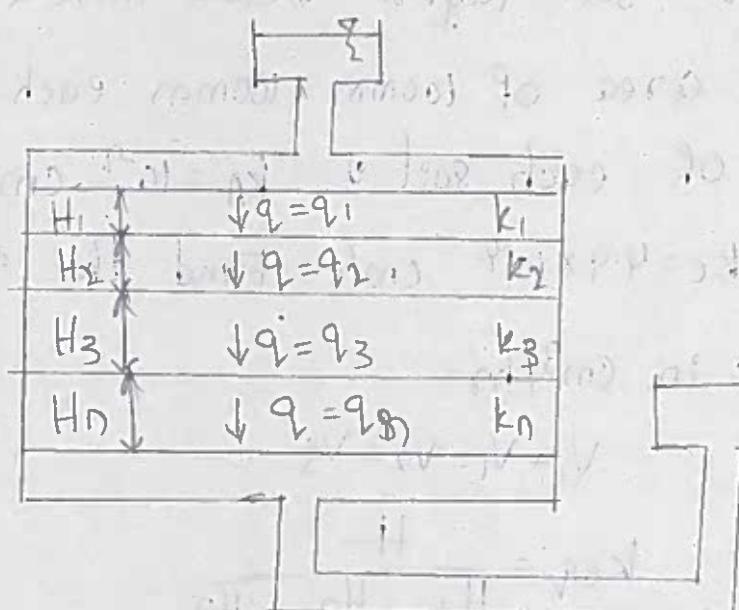
$$q = k_v \cdot i \cdot A = k_v \cdot \frac{\Delta H}{H} \cdot A$$

$$\Delta H = \frac{q \cdot H}{k_v \cdot A}$$

$$h_1 = \frac{q \cdot H_1}{k_1 \cdot A}, h_2 = \frac{q \cdot H_2}{k_2 \cdot A},$$

$$\frac{q \cdot H}{k_v \cdot A} = \frac{q \cdot H_1}{k_1 \cdot A} + \frac{q \cdot H_2}{k_2 \cdot A} + \dots + \frac{q \cdot H_n}{k_n \cdot A}$$

$$k_v = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3} + \dots + \frac{H_n}{k_n}}$$



Q:- A horizontal stratified soil deposit consists of three layers, each uniform in itself. The permeability of layers are 8×10^{-4} , 50×10^{-4} and 15×10^{-4} cm/s, and their thickness are 6m, 3m and 12m respectively. Find the effective average permeability of the deposit in horizontal and vertical directions.

$$k_x = \frac{k_1 H_1 + k_2 H_2}{H_1 + H_2}$$

$$k_x = k_n = \frac{8 \times 10^{-4} \times 6 + 50 \times 10^{-4} \times 3 + 15 \times 10^{-4} \times 12}{6 + 3 + 12}$$

$$k_n = \frac{378}{21} = 18 \times 10^{-4} \text{ cm/s}$$

Permeability in vertical direction,

$$k_y = \frac{H_1 + H_2 + H_3}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}}$$

$$k_y = k_v = \frac{6 + 3 + 12}{\frac{6}{8 \times 10^{-4}} + \frac{3}{50 \times 10^{-4}} + \frac{12}{15 \times 10^{-4}}} \\ = \frac{21}{1.61} \times 10^{-4}$$

$$k_v = 13.04 \times 10^{-4} \text{ cm/s}$$

Q:- The soil layers below have a cross-sectional area of 100mm x 100mm each. The permeability of each soil is $k_A = 10^{-2}$ cm/s, $k_B = 3 \times 10^{-3}$ cm/s, $k_C = 4.9 \times 10^{-4}$ cm/s. Find the rate of water supply in cm^3/hr .

$$V = V_1 = V_2 = V_3$$

$$k_{eq} = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}}$$

$$= \frac{450}{\frac{150}{1 \times 10^{-2}} + \frac{150}{3 \times 10^{-3}} + \frac{150}{4.9 \times 10^{-4}}} \\ = 1.2 \times 10^{-3} \text{ cm/s}$$

Head loss during flow, $H_L = 300 \text{ mm}$

Hydraulic gradient, $i = \frac{H_L}{L}$

$$= \frac{300}{450} = \frac{2}{3}$$

By Darcy's equation, $Q = k_{eq} \cdot i \cdot A$

$$= 1.2 \times 10^{-3} \times \frac{2}{3} \times (10 \text{ cm} \times 10 \text{ cm}) \times \frac{3600}{1} \\ = 291 \text{ cm}^3/\text{hr}$$

Effective stress & Seepage through soils

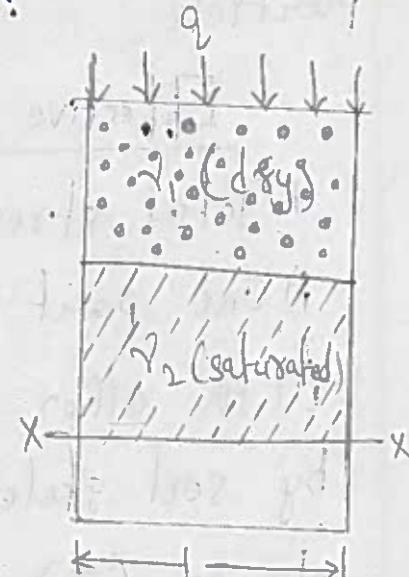
Total stress:-

* Normal stress is defined as the sum of the normal component of the forces (ΣN) over a plane ($x-x$) divided by the area of plane (A).

* Generally, it is denoted by σ .

$$\sigma = \frac{\Sigma N}{A}$$

Let us consider a stratified soil sample of unit width and unit length for the plane over which normal stress is to be computed.



$$\sigma = \frac{q \cdot A + \gamma_{t_1} \times h_1 \cdot A + \gamma_{t_2} \times h_2 \cdot A}{A}$$

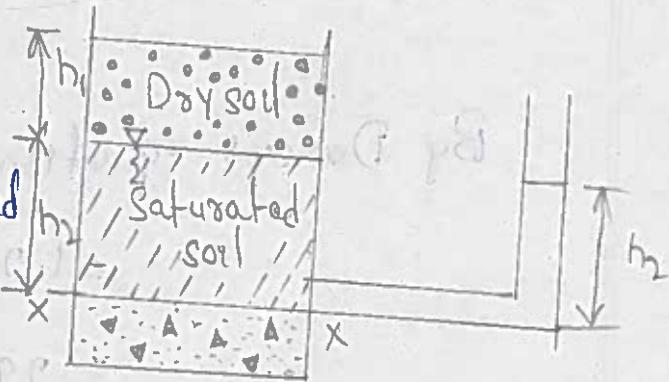
$$= q + \gamma_d h_1 + \gamma_s g f h_2$$

* If external pressure is zero, the total stress caused due to the over burden alone are known as 'Geostatic stress'

$$\sigma = \gamma_d h_1 + \gamma_{sat} h_2$$

Pore pressure:-

* It is the pressure exerted by pore water filled in the void of soil skeleton. It is denoted by u and equal to depth (h_2) below the ground water table upto the point (A) where it is measured and multiplied by the unit weight of water γ_w .



$$u = h_2 \gamma_w$$

* Pore pressure is also called the neutral stress because it acts on all sides of the particle.

Effective stress:-

* Total stress (σ) is made up of two parts
 i) One part is due to pore water pressure (u)
 ii) the other part is due to pressure exerted by soil skeleton which is called effective stress ($\bar{\sigma}$).

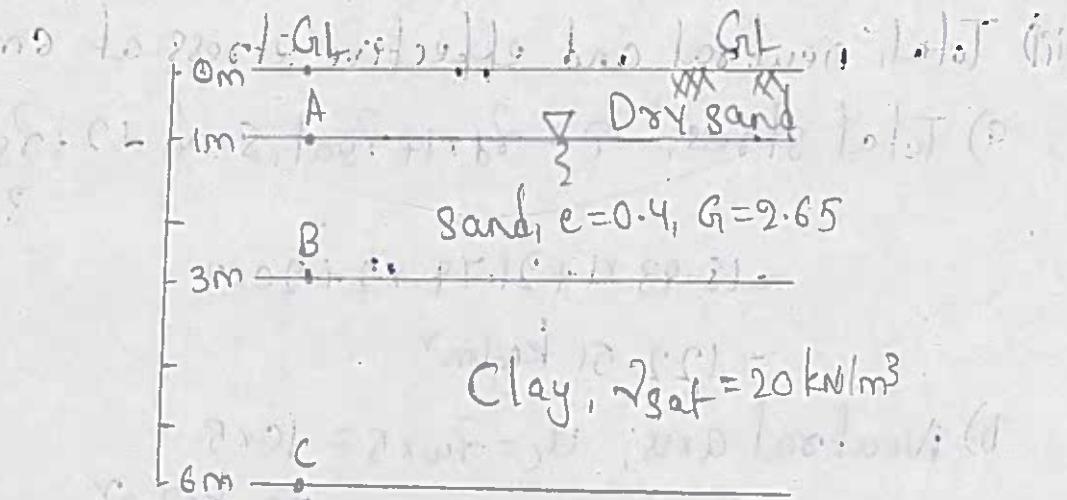
$$\sigma = u + \bar{\sigma}$$

$$\bar{\sigma} = \sigma - u$$

$$\bar{\sigma} = \gamma_d h_1 + (\gamma_{sat} - \gamma_w) h_2$$

$$\bar{\sigma} = \gamma_d h_1 + \gamma' h_2$$

Q:- For the subsoil condition shown in figure below, calculate the total, neutral and effective stress at 1m, 3m and 6m below the ground level. Assume $\gamma_w = 10 \text{ kN/m}^3$.



Given data,

$$e = 0.4$$

$$G_i = 2.65$$

$$\gamma_d = \frac{G_i \gamma_w}{1+e} = \frac{2.65 \times 10}{1+0.4}$$

$$\gamma_d = 18.93 \text{ kN/m}^3$$

$$\gamma_{sat} = \frac{(G_i+e)\gamma_w}{1+e} = \frac{(2.65+0.4) 10}{1+0.4}$$

$$\gamma_{sat} = 21.79 \text{ kN/m}^3$$

i) Total, neutral and effective stress at 1m depth

a) Total stress, $\sigma_A = \gamma_d \cdot z = 18.93 \times 1$

$$= 18.93 \text{ kN/m}^3$$

b) Neutral stress, $u_A = 0$

c) Effective stress, $\sigma'_A = \sigma_A - u_A$

$$= 18.93 - 0 = 18.93 \text{ kN/m}^2$$

ii) Total, neutral and effective stress at 3m depth

a) Total stress, $\sigma_B = \gamma_d \times 1 + \gamma_{sat, sand} \times 2$

$$= 18.93 \times 1 + 21.79 \times 2$$

$$= 62.57 \text{ kN/m}^3$$

b) Neutral stress, $u_B = \gamma_w \times 2$
 $= 10 \times 2 = 20 \text{ kN/m}^2$

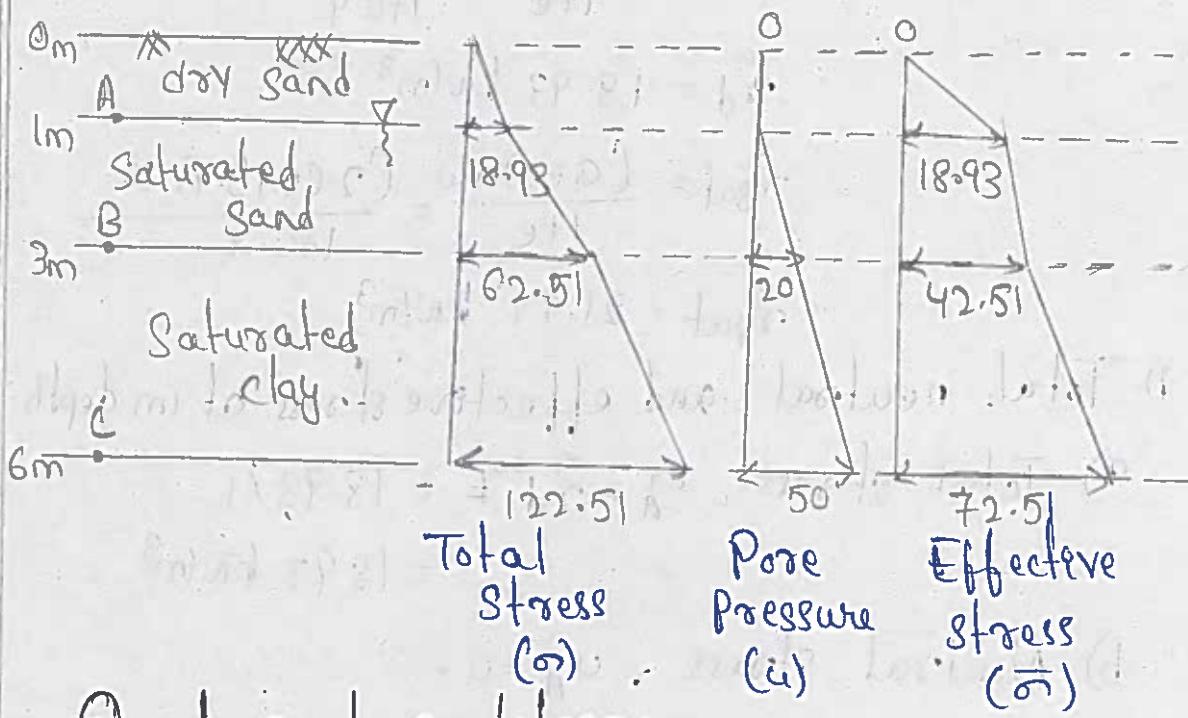
c) Effective stress, $\sigma_B = \sigma_B - u_B$
 $= 182.51 - 20 = 162.51 \text{ kN/m}^2$

iii) Total, neutral and effective stress at 6m

a) Total stress, $\sigma_c = \gamma_d \times 1 + \gamma_{sat, sand} \times 2 + \gamma_{sat, clay} \times 3$
 $= 18.93 \times 1 + 21.79 \times 2 + 20 \times 3$
 $= 122.51 \text{ kN/m}^2$

b) Neutral axis, $u_c = \gamma_w \times 5 = 10 \times 5$
 $= 50 \text{ kN/m}^2$

c) Effective stress, $\sigma_c = \sigma_c - u_c$
 $= 122.51 - 50$
 $= 72.51 \text{ kN/m}^2$



Quick sand condition:-

* For upward flow condition, effective stress at any point within soil mass is given by

$$\bar{\sigma} = \bar{\sigma} - p_g$$

$$= \gamma_2 - p_g$$

→ It is clear from above equation, upward

Seepage pressure decreases effective stresses in the soil mass.

* If the seepage pressure is such that it equals the submerged weight of the soil mass, then effective stress at that location reduces to zero. Under such condition, cohesionless soil mass loses all shear strength. Now soil mass has a tendency to move also with the flowing water in the upward direction.

* The process in which soil particles are lifted over the soil mass is called quick sand condition. It is also known as boiling of sand as the surface of sand looks it is boiling.

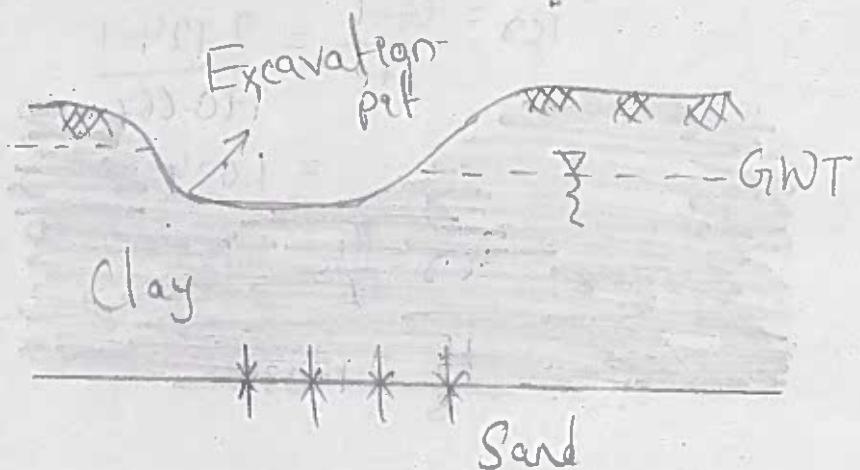
* At quick sand condition, net effective stress is reduced to zero.

$$\overline{\sigma} = 0$$

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

$$i_{cr} = \frac{G_t - 1}{1 + e}$$

$$FoS = \frac{i_{cr}}{i}$$



Q:- A 3m thick soil stratum has coefficient of permeability 3×10^{-7} m/s. A separate test have porosity 40% and bulk unit weight 21 kN/m³ at a moisture content of 31%. Determine the head at which upward seepage will cause quick sand condition. What is the flow required to maintain critical conditions?

$$k = 3 \times 10^{-7} \text{ m/s}$$

$$n = 0.4$$

$$\gamma = 21 \text{ kN/m}^3$$

$$\omega = 0.31$$

$$n = \frac{e}{1+e}$$

$$0.4 = \frac{e}{1+e}$$

$$e = 0.667$$

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

$$\gamma_d = \frac{21}{1+0.31}$$

$$\gamma_d = 16.03 \text{ kN/m}^3$$

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

$$16.03 = \frac{G_r \times 9.81}{1+0.667}$$

$$G_r = \frac{16.03 \times 1.667}{9.81} = 2.724$$

$$i_{cr} = \frac{G_r - 1}{1+e} = \frac{2.724 - 1}{1+0.667} \\ = 1.034$$

$$i_{cr} = \frac{H_L}{L}$$

$$\frac{H_L}{3} = 1.034$$

$$H_L = 1.034 \times 3 = 3.1 \text{ m}$$

The flow required to cause quick sand condition can be obtain by Darcy's equation.

$$Q = k \cdot i \cdot A$$

$$= 3 \times 10^{-7} \times 1.034 \times 1$$

$$Q = 3.1 \times 10^{-7} \text{ m}^2/\text{s}/\text{m}^2$$

Seepage through soils:-

* Seepage may be defined as the infiltration downward and lateral movement of water into soil or substrate from a source of supply such as reservoir or irrigation canal. Such water may reappear, depending upon the topographic contours and water table rise due to seepage.

→ Characteristics of soil and strata over which the canal is laid.

→ Hydraulic characteristics of canal

→ Lining material

→ Amount of sediment in the water and sediment deposition in the canal.

Flow nets:-

→ The entire pattern of flow lines and equipotential lines is referred as a flow net.

Characteristics:-

→ Flow nets and equipotential meet each other orthogonally.

→ Flow lines and equipotential lines are smooth

continuous curves.

- There can be no flow across the flow net and velocity of flow is always perpendicular to equipotential lines
- Loss of head between two equipotential lines i.e. equipotential drop remains constant for all the equipotential lines.
- For non-isotropic medium, flow field is rectangular which may either be linear or curvilinear.
- Area bounded between two adjacent equipotential lines and adjacent flow lines is referred to a flow field.
- Area bounded between two adjacent flow lines is called flow channel.

Uses:-

- * Flow net can be used for the determination of
- Seepage
- Seepage pressure
- Hydrostatic pressure
- Exit gradient