GATE – CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

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Permeability

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8.6 Permeability of soil

Permeability is the property of soil which permits flow of water through interconnecting voids.

Permeable soil:

It is a soil containing continuous voids which permits water to pass through the soil mass.   eg: Gravel and Coarse sand.

Impermeable soil:

Soil does not allow water to pass through it.   eg: Stiff clay, rock

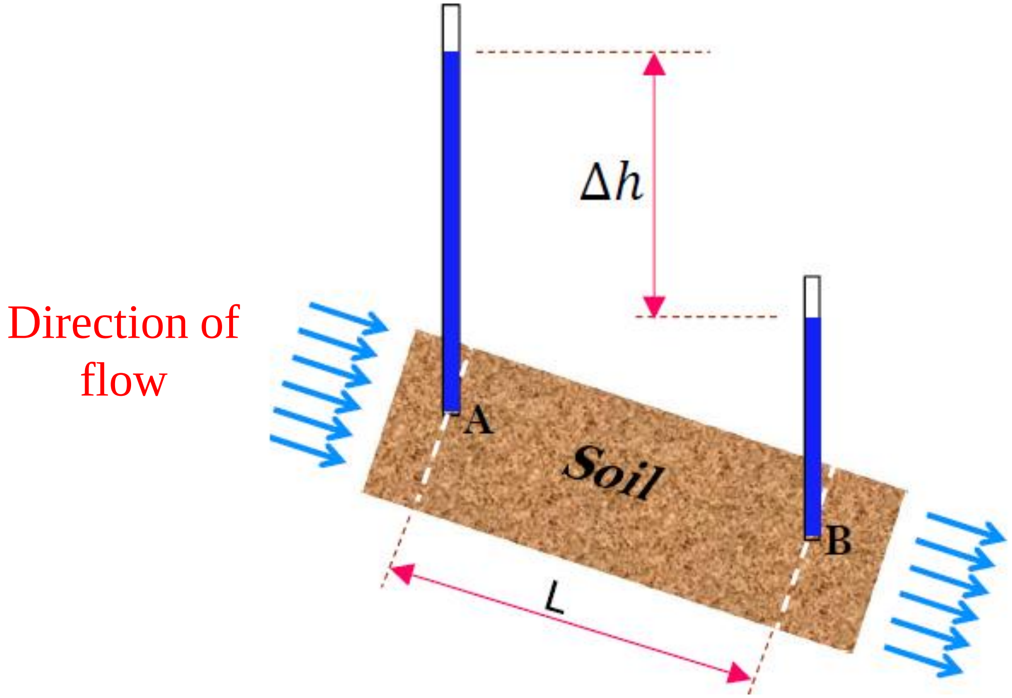
Sands, silts and medium clays falls between permeable and impermeable type of soil.

Darcy's Law:

Darcy's Law demonstrated experimentally that for laminar flow conditions in a saturated soil, the rate of flow or the discharge per unit time is proportional to the hydraulic gradient

$$q \alpha iA \quad ; \quad q = kiA \quad ; \quad \frac{q}{A} = v = ki$$

k : Coefficient of permeability expressed in cm/sec, m/day, feet/day



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A: Total cross sectional area of soil mass perpendicular to the direction of flow

$$q = A.v$$

v : Velocity of flow

i : Hydraulic gradient = $\frac{h_1 - h_2}{L}$

h_1 : Pressure head of water at top of sample

h_2 : Pressure head of water at the bottom to the sample

L : Length of the sample

- Valid only for Laminar flow conditions in saturated soil only
- For soils flow will be Laminar if Reynolds Number is <1
- Laminar flow will prevail in Clays, Silts and fine sands.
- Darcy's law is invalid for liquid flow at high velocity
- k has dimension of velocity.
- k is the velocity of flow for a unit hydraulic gradient.

Discharge Velocity or Superficial Velocity:

Discharge velocity $v = \frac{q}{A} = k.i$

- Discharge takes place throughout the entire area of soil sample.
- Flow takes place in voids only hence the velocity is not real velocity.
- v is also called superficial velocity.

Seepage Velocity or Actual Velocity:

- Seepage Velocity is the velocity obtained by considering the actual pore space available for flow.
- It is also called Actual Velocity or True Velocity.

$$v_s = \frac{Q}{A_v} \qquad Q = A.v = A_v \times v_s$$

$$v_s = v.\frac{A}{A_v} = v.\frac{A.L}{A_v.L} = v.\frac{V}{V_v} = \frac{v}{n} \qquad v_s = \frac{k.i}{n} = k_p.i$$

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v_s always greater than v, since $0 < n < 1$

k_p = Coefficient of percolation $= \dfrac{k}{n}$ $\quad k_p > k$

Energy heads :

- The velocity head in soil is negligible
- Negative pore pressure can exist
- Direction of flow is determined by the difference of total head only.
- Pressure head at a point is the height of water column in the piezometer provided at that point
- Elevation head depends on the location of the datum.

Factors Effecting Coefficient of Permeability:

Poiscuille's law for flow through the soil pores is given by $k = D_s^2 \frac{\gamma_w}{\mu} . \frac{e^3}{1+e} .C$

k : Darcy's coefficient of permeability
D_s : Effective particle size (D_{10})
γ : Unit weight of fluid
μ : Viscosity of fluid
e : Void ratio
C : Shape factor.

a. Grain size

- k is directly proportional to the square of the particle size. $k \alpha D_s^2$

b. Shape of particle

- For same void ratio the soils with angular particle are less permeable than those with rounded particle.

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- k is inversely proportional to square of the specific surface area.
- Depends on shape of soil particle and packing.

Void Ratio:

$$k \,\alpha\, \frac{e^3}{1+e}$$

- The variation of permeability with void ratio function $\left(\frac{e^3}{1+e}\right)$ is a straight line.
- The permeability of a soil at a given void ratio may not have any relationship with that of another soil.
- At the same void ratio, the soils with largest void ratio (i.e. clays) are the least pervious. This is due to fact that the individual void passages in clays are extremely small through which water current flow.

Porosity:

- Increase in porosity leads to an increase in the permeability of soil
- It causes an increase in the percentage of cross sectional area available for flow
- It causes an increase in the dimension of the pores, which increases the average velocity.

Properties of Percolating Fluid:

$$k \,\alpha\, \frac{\gamma_w}{\mu}$$

- k is proportional to the unit weight of water
- k is inversely proportional to viscosity of water
- k is reported at standard temperature of 27^0C

$$\frac{k_{27}}{k_t} = \frac{\mu_t}{\mu_{27}} \qquad \frac{k_1}{k_2} = \frac{\mu_2}{\mu_1}$$

k_t : Permeability at temperature of T^0C when viscosity is μ_t

k_{27} : Permeability at temperature of 27^0C when viscosity is μ_{27}

- Viscosity decreases with rise in temperature and vice versa.

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- Permeability increases with an increase in temperature and decreases with increase in viscosity.

$$k_1 = \frac{k.\mu}{\gamma_w}$$

$k_1 =$ Specific or Absolute or physical permeability

Degree of Saturation:

- The higher the degree of situation, the higher the permeability.

Adsorbed water:

- Adsorbed water reduces the effective pore space available for the passage of water and hence reduces the permeability of soil.

Entrapped air and other foreign matter :

- If the soil is not fully saturated, it contains air pockets formed due to entrapped air.
- The presence of air reduces the permeability of soil due to blockage of passage.

Compaction

- The influence of soil compaction on permeability is small in case of gravels, sands and silts
- Considerable effect in case of clays
- Montmorillonite has the least permeability (less than 10^{-7} cm/sec)
- Kaolinite is 100 times more permeable than montmorillonite.

The permeability parallel to stratification is much more than that perpendicular to stratification.

Effective Stress:

- The increase in effective stress causes the particles to pack more closely, decreases the void ratio.
- If the void ratio decreases, permeability decreases. Increase in effective stress decreases the permeability or vice versa.

Organic matter or Impurities:

- Organic matter reduces voids and passage of flow, thus decreasing the permeability.

Determination of Permeability of Soil:

Laboratory methods:

a. Constant head permeability test - used for coarse grained soils.

b. Falling head or variable head permeability test - used for fine grained soils. .

Field methods:

a. Pumping out tests -used for large engineering projects.

b. Pumping in tests - used for finding the permeability of individual layers of soil

Indirect Methods:

a. Consolidation test- suitable for impermeable soils

b. Capillary permeability test - used for partially saturated soils. .

c. Considering particle size by Hazen formula.

d. Considering specific surface of the soil by Kozeny's Formula

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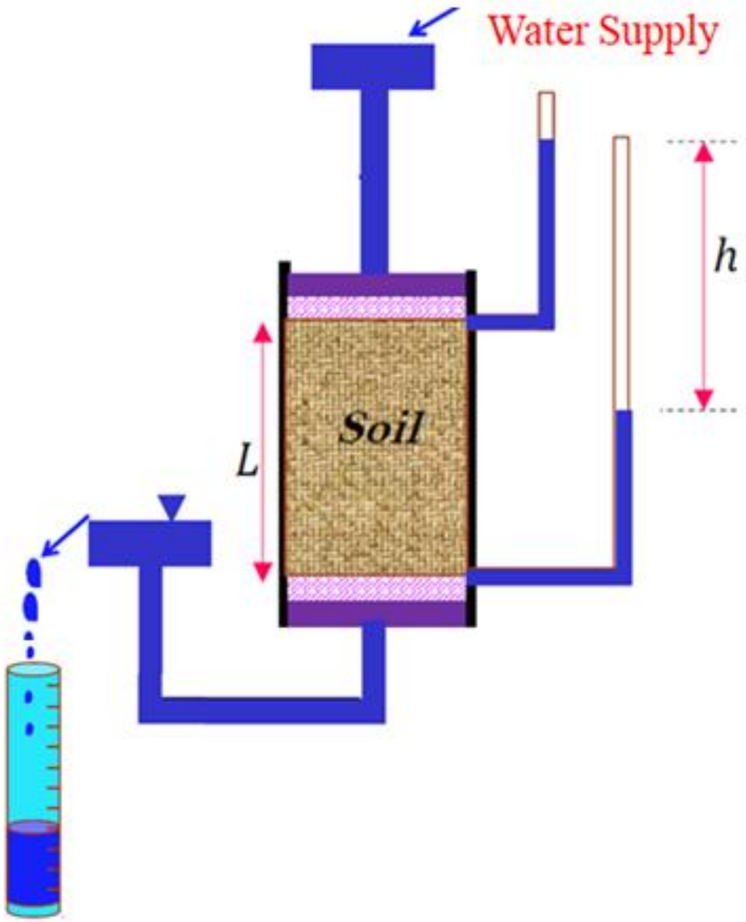
a. Constant Head Permeability Test:

- used for relatively pervious soils
- Suitable for coarse grained soils like gravel, sand with $k>10^{-1}$ cm/sec
- Head is kept constant and the discharge is measured knowing the head causing flow.



$$q = \frac{Q}{t} = k.i.A = k.\frac{h}{L}.A \qquad k = \frac{Q.L}{A.t.h}$$

Q : Discharge collected in time

A : Cross sectional area of soil sample.

L : Length of soil sample.

h : Hydraulic head causing flow.

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- Constant head permeameter test in widely used due to its simplicity in principle.

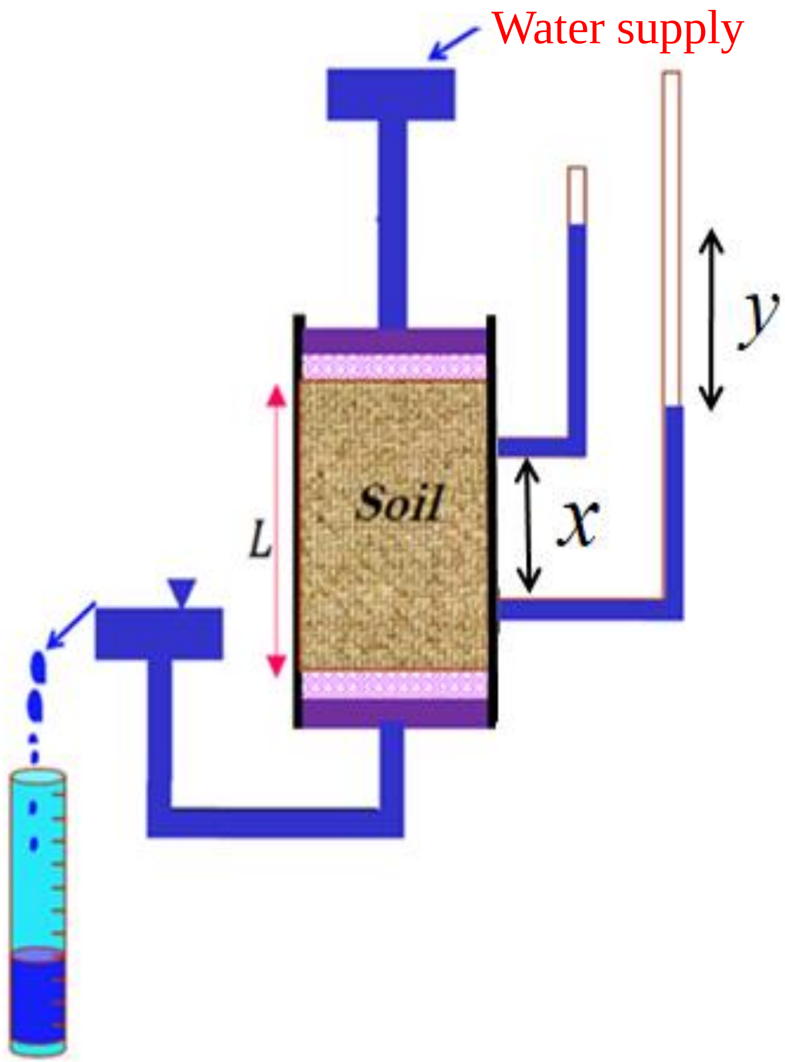
Difference in water levels:

x : Distance between manometer tapping in cm.

y : Difference in manometer levels

$$i = \frac{h}{L} = \frac{y}{x}; \qquad \frac{Q}{t} = k.i.A = k.\frac{y}{x}.A$$

$$k = \frac{Q.x}{A.t.y}$$



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Falling or Variable Head Permeameter test:

- Used for relatively less permeable soil where the discharge is small.
- For fine sands and silts with $k = 10^{-2}$ *to* 10^{-4} cm/sec
- Discharge is not required to be measured.

$$k = \frac{a.L}{A.t}\log_e\left(\frac{h_1}{h_2}\right) = 2.303\frac{a.L}{A.t}\log_{10}\left(\frac{h_1}{h_2}\right)$$

k : Coefficient of permeability

a : Cross sectional area of standpipe

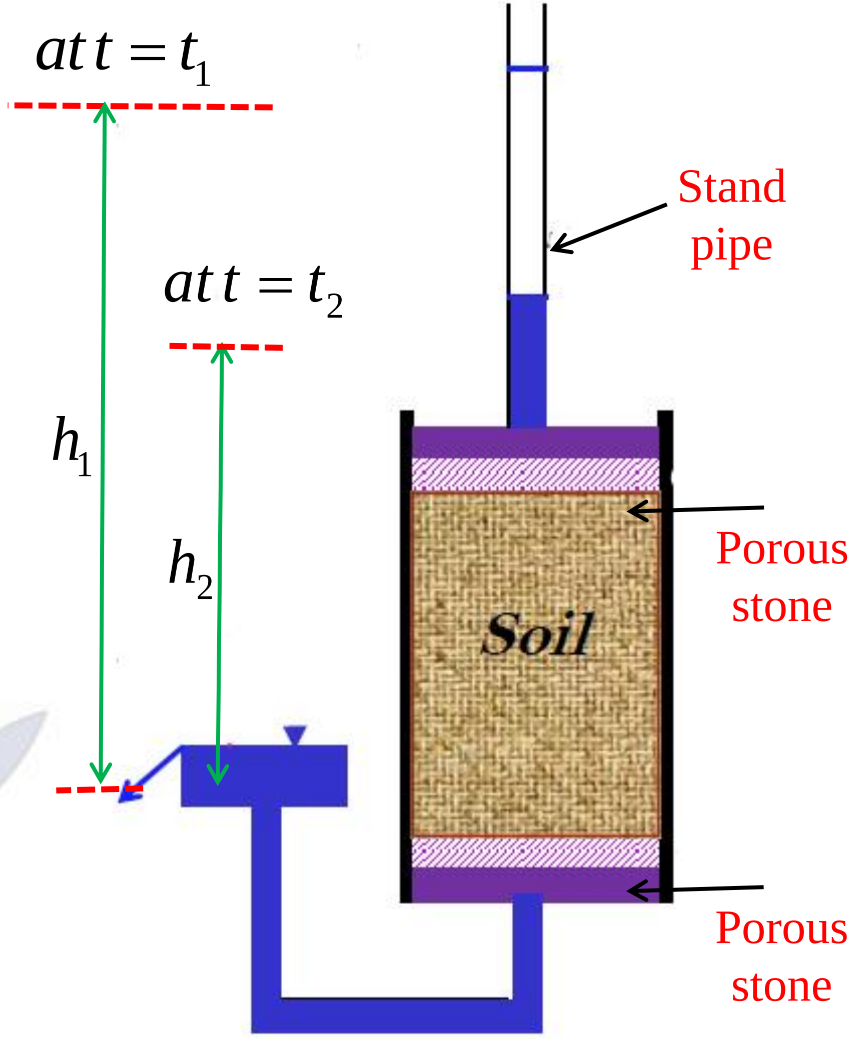
L : Length of soil sample

h_1 :Initial height of water in stand pipe at time t_1

h_2 :Final height of water in stand pipe at time t_2

Let t be the time required to drop the head from h_1 and h_2 and then h_2 to h_3

$$h_2 = h_1.h_3$$



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Range of coefficient of permeability (k) for different soils.

Soil	k , cm./sec	Degree
Coarse gravel	10^{-1}	High
Fine sand	10^{-1} to 10^{-3}	Medium
Loess	10^{-3} to 10^{-5}	Low
Silt, clay	10^{-5} to 10^{-7}	Very low
Clay	$< 10^{-7}$	Impervious

a. Consolidation or Odeometer test

Suitable for stiff clays with $k < 10^{-6}$ cm/sec.

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b. Horizontal capillary test:

- Suitable to measure permeability of partially saturated soil.
- Capillarity and permeability both can be found.

c. Particle size by Hazen formula

$$k = C.D_{10}^2 \qquad k = 100 D_{10}^2$$

D_{10} : Effective size in cm

k : Coefficient of permeability in cm/sec

- more appropriate for sands and silts
- smaller the grain size, smaller the voids and thus lower the permeability

d. Specific surface by kozeny formula

$$k = \frac{1}{k_o S^2} . \frac{\gamma}{\mu} . \frac{e^3}{1+e}$$

e : Void ratio

γ : Unit weight of fluid

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μ : Viscosity of fluid

S : Specific surface area

k_0 : a factor, depending on pore shape and ratio of length of actual flow path to the thickness of soil bed

Pumping Out test:

- Most accurate among all tests, since loose area surrounding the well is influenced.
- Used for large engineering projects - it is expensive.

Pumping in test:

- Commonly used for testing rocks and individual stratum

  eg: Open - end test, Packer test (for rocks)

Permeability of stratified soil deposits:

a. Flow parallel to the bedding planes

Loss of head or hydraulic gradient is same for all layers.

$$v = k.i$$

$$v_1 = k_1.i \quad , \quad v_2 = k_2.i \quad \text{etc.,}$$

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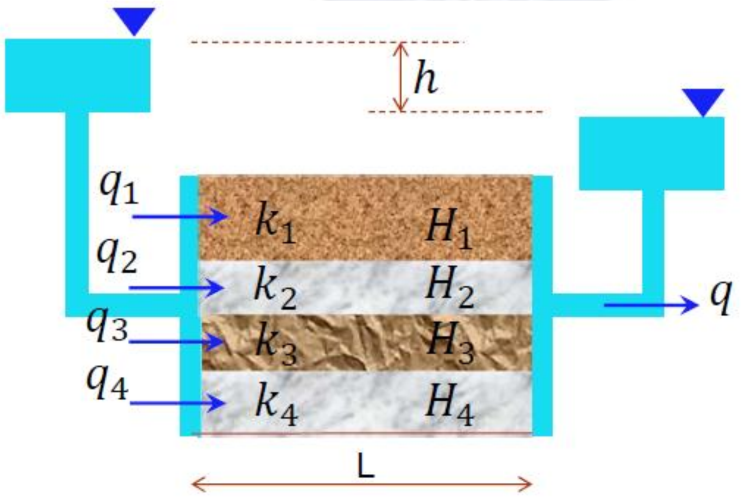
Let $H_1, H_2, \ldots\ldots\ldots H_n$ be the thickness of each of the layers

H: Total thickness of the deposit

$$H = H_1 + H_2 + H_3 + \ldots\ldots\ldots + H_n$$



Flow parallel to the bedding planes

- The discharge though the entire deposit is equal to the sum of the discharge through the individual layers.

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

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$$k_x.i.H = k_1.i.H_1 + k_2.i.H_2 + k_3.i.H_3 + ... + k_n.i.H_n$$

$$k_n = \frac{k_1 H_1 + k_2 H_2 + ... + k_n H_n}{H}$$

- k_x is the weighted mean value, the weights being the thickness for each layer.

b. Flow Perpendicular to the bedding planes:

Discharge is same through all the layers

Total loss of head : $\Delta h = \Delta h_1 + \Delta h_2 + \Delta h_3 + ... + \Delta h_n$

$$i = \frac{\Delta h}{H}; \quad \Delta h = i.H$$

$$\Delta h_1 = i_1.H_1; \quad \Delta h_2 = i_2.H_2; \quad \Delta h_3 = i_3.H_3; ....; \Delta h_n = i_n.H_n$$

Since q is same in all layers, the cross sectional area of the flow is same, the velocity is same is all layers.

$$k_z.i = k_1.i_1 = k_2.i_2 = ... = k_n.i_n = v$$

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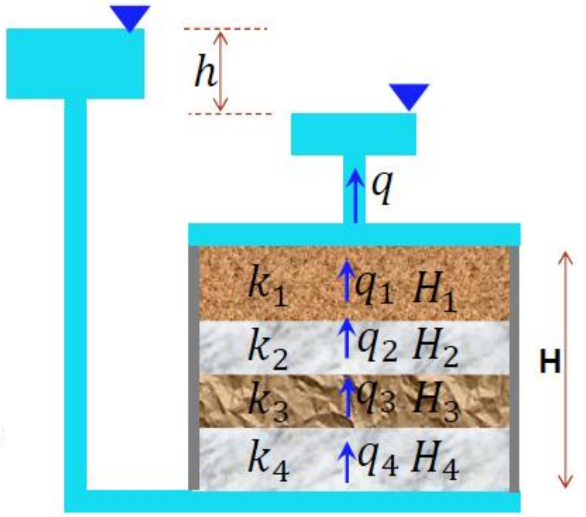
$$k_z.\frac{\Delta h}{H} = k_1.\frac{\Delta h_1}{H_1} = k_2.\frac{\Delta h_2}{H_2} = ... = k_n.\frac{\Delta h_n}{H_n} = v$$

$$\frac{v.H}{k_z} = \frac{v.H_1}{k_1} + \frac{v.H_2}{k_2} + ... + \frac{v.H_n}{k_n}; \qquad k_z = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + ... + \frac{H_n}{k_n}}$$



Flow Perpendicular to the bedding planes

k_z is always less than k_x since the joints in perpendicular bedding plane are more and hence water will not enter easily.

k_e = Equivalent Coefficient of permeability

$$k_e = \sqrt{k_x.k_z}$$

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- Flow occurs in soil when there is a difference in the total heads between the two points.
- The difference of pressure head alone or the difference of elevation head alone will not cause the flow through soil.
- In case of soils, the velocity head is neglected.

At point A: Pressure head, $\frac{p}{\gamma} = y$

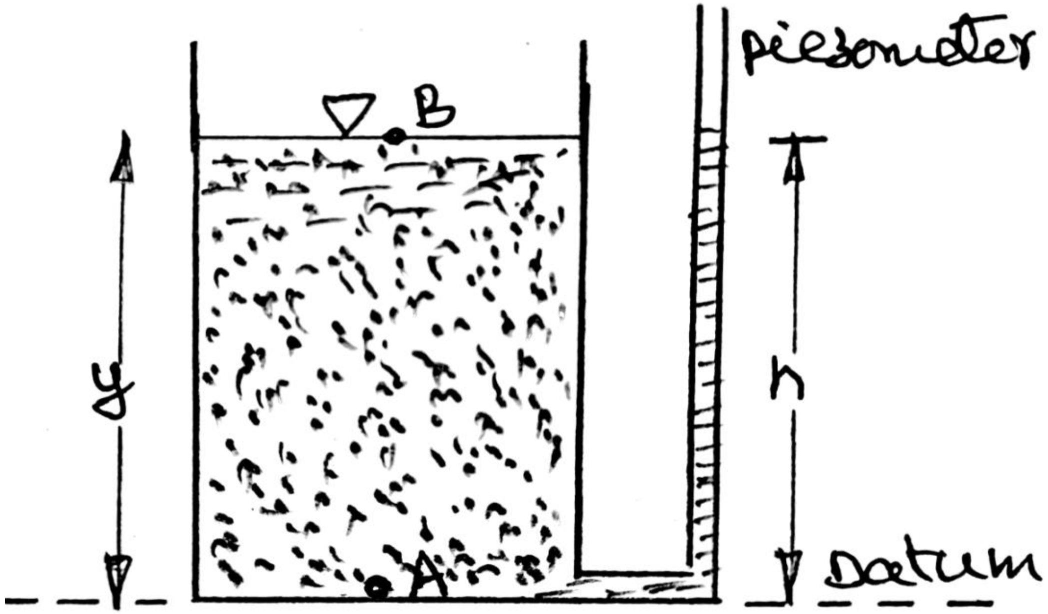
Datum Head, $z = 0$

Total Head, $h = y + 0 = y$

At point B: Pressure head, $\frac{p}{\gamma} = 0$

Datum Head, $z = y$

Total Head, $h = y + 0 = y$



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- The total head is same at points A and B and hence there is no flow between the two points A and B.
- When the two piezometers are connected at the two points of the soil mass, the total head difference or total head loss is equal to the difference in the elevation of water in piezometers kept at those two points.

$$h = h_1 - h_2$$

If $k > 10^{-1} cm/s \Rightarrow$ Permeable soils

If $k < 10^{-7} cm/s \Rightarrow$ Impermeable soils

The flow in soils is laminar, if $R_e \leq 1$

$$R_e = \frac{\rho v d}{\mu} \Rightarrow R_e \alpha v \Rightarrow R_e \alpha k$$

As k decreases, R_e decreases and hence the flow becomes laminar.

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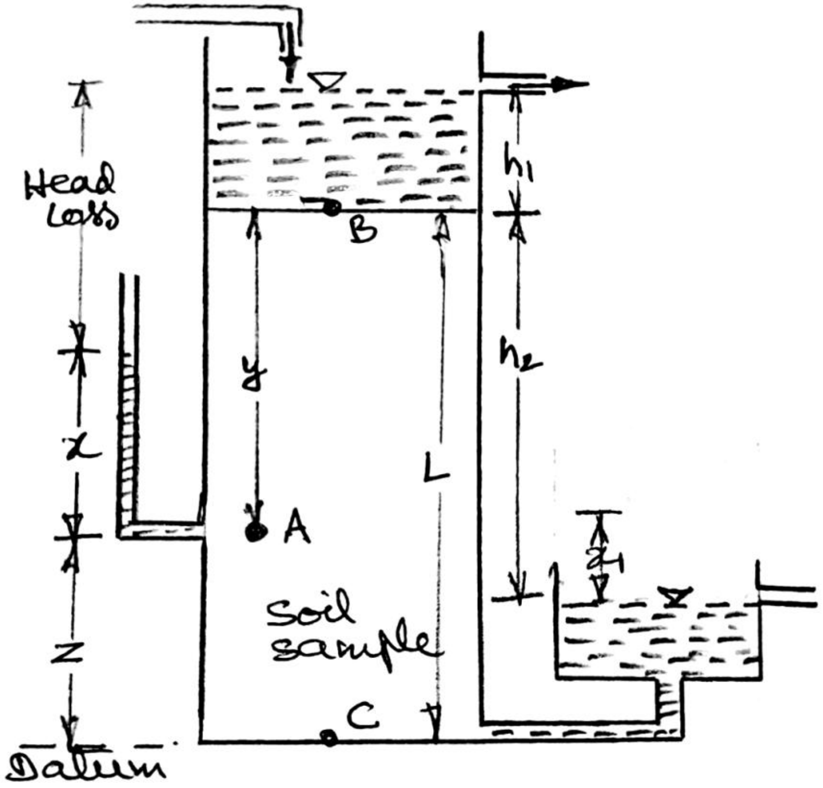

Total head loss, $h = h_1 + h_2$

Total seepage length $= L$

Hydraulic gradient, $i = \dfrac{h}{L}$

At point A:

Seepage Length $= y$

Head loss $= i.y = \dfrac{h}{L}.y$

Pressure head = Total head – Head loss at A

$$P_A = h - \frac{h}{L}.y$$

Datum head $= z$

Total head $= P_A + z$

At point B:

Pressure head, $P_B = h - 0$

Datum head $= L$

Total head = Pressure head + Datum head

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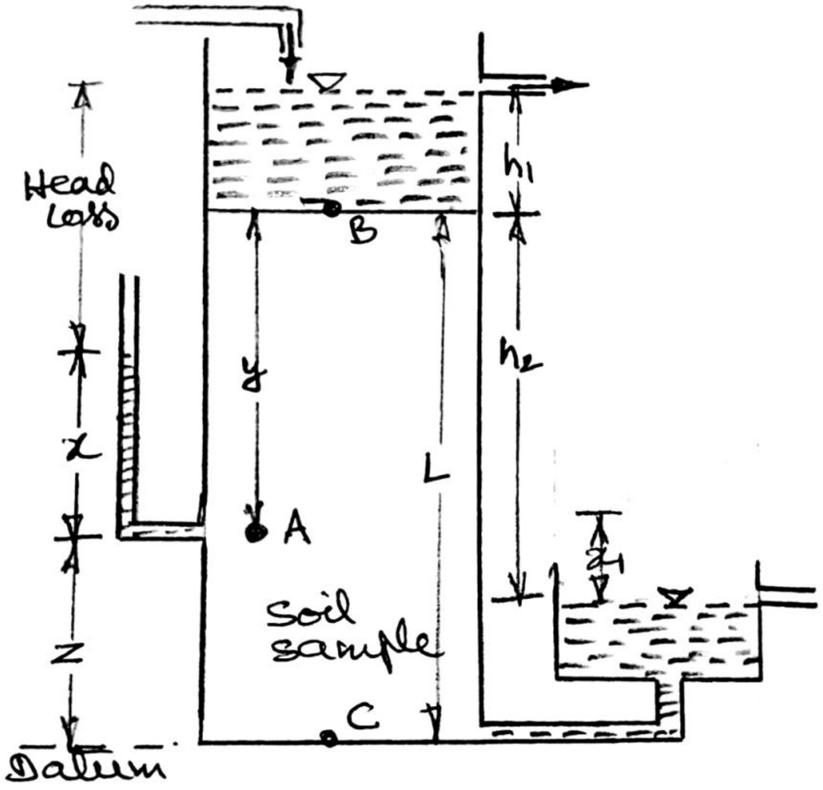
At point C:

Pressure head, $P_C = h - \frac{h}{L}.L = h - h = 0$

Datum head = 0

Total head = 0



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eg. Assuming datum head at the surface of the downstream water

At Point A:

Pressure head, $h_A = h - i.y$

Datum head $= x_1$

Total head $= h_A + x_1$

At point B:

Pressure head, $h_B = h$

Datum head $= h_2$

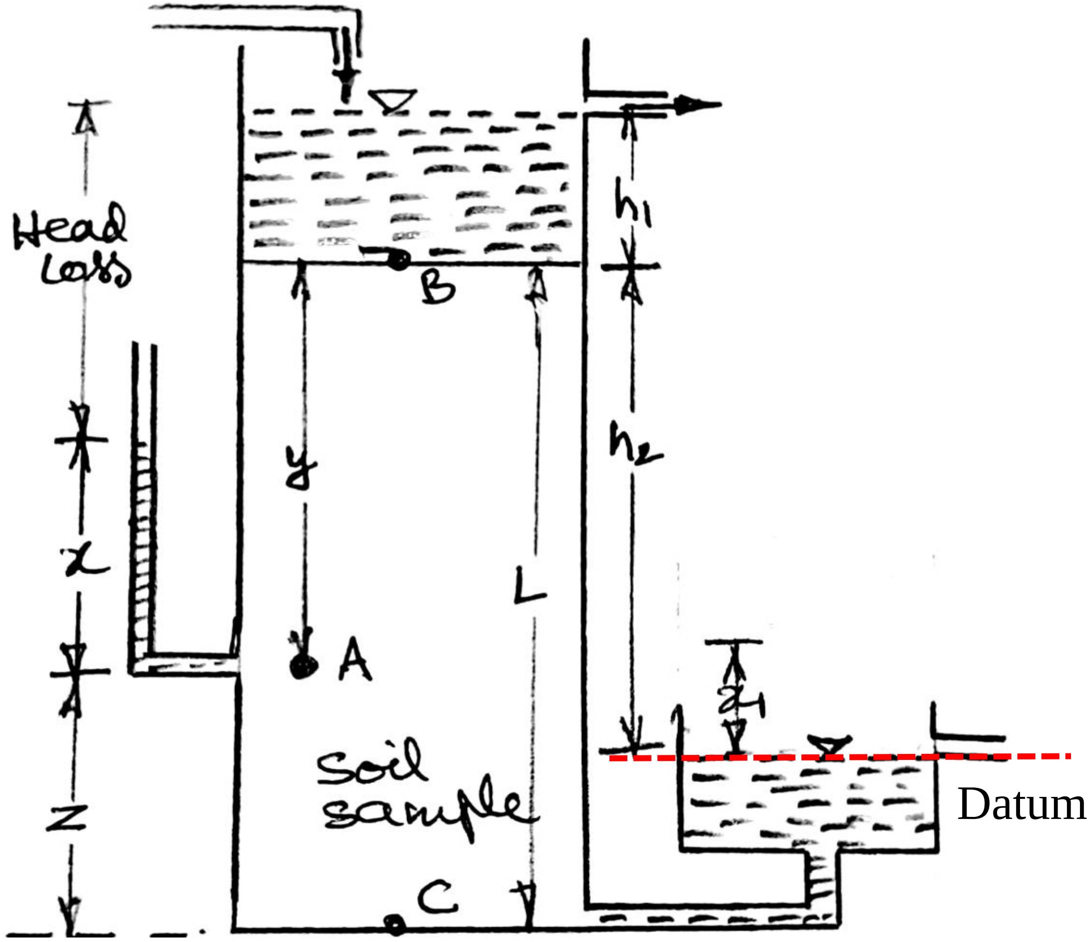
Total head $= h + h_2$

At point C:

Pressure head, $h_C = 0$

Datum head $= -(z - x_1)$

Total head $= 0 - (z - x_1) = -(z - x_1)$



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Total head $= h_1$

$$h_A + h_B = h_1$$

$$h_B = c.h_A$$

$$Q_A = Q_B$$

$$(k.i.A)_A = (k.i.A)_B$$

At Point P:

Pressure head, $= h_1$

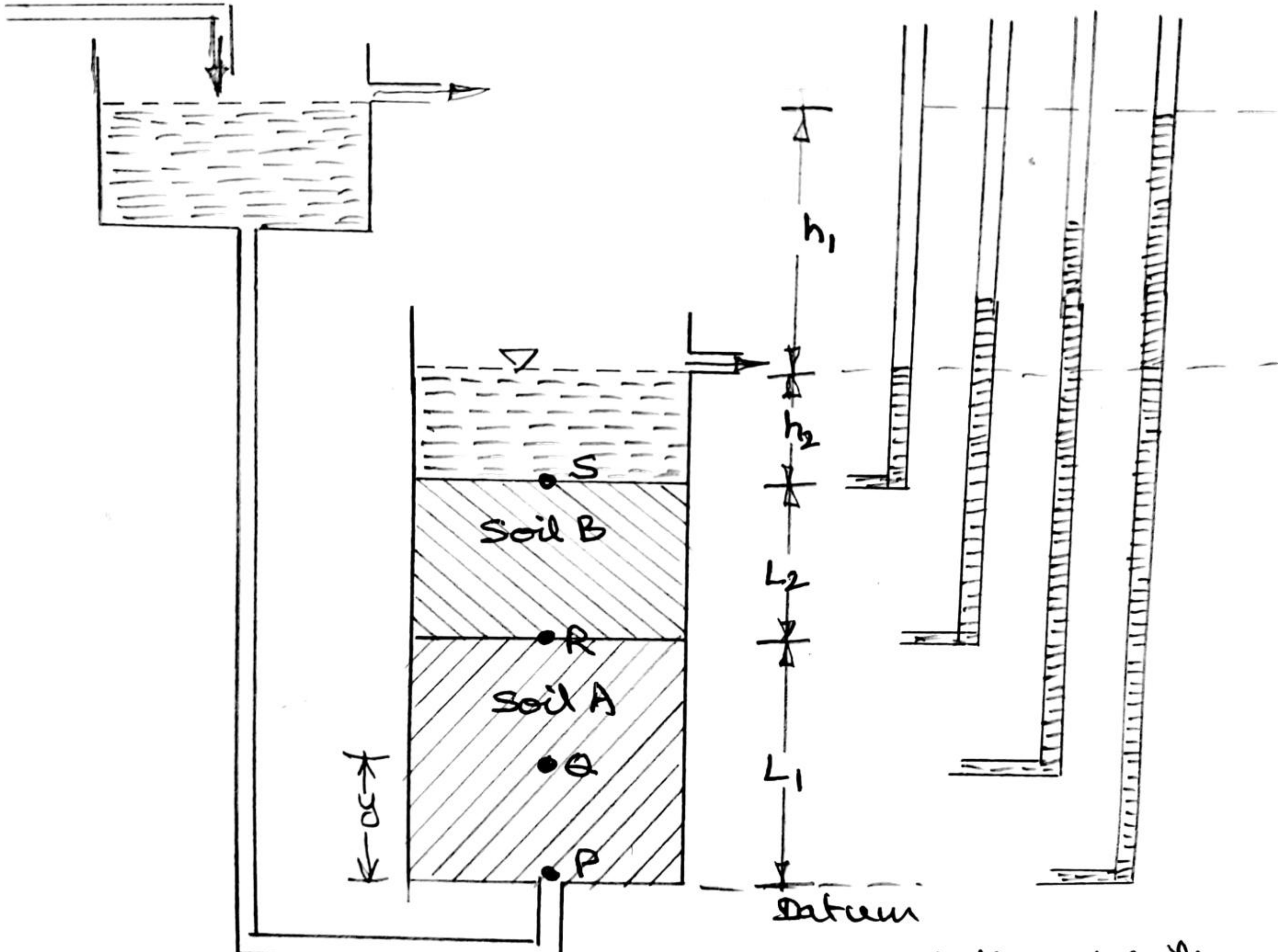
Datum head $= 0$

Total head $= h_1 + 0 = h_1$

At point Q:

Pressure head, $= h_1 - i_A.y$

Datum head $= y_1$



Permeability through two different soils.

Pressure head = Height of water column in piezometer

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At Point R:

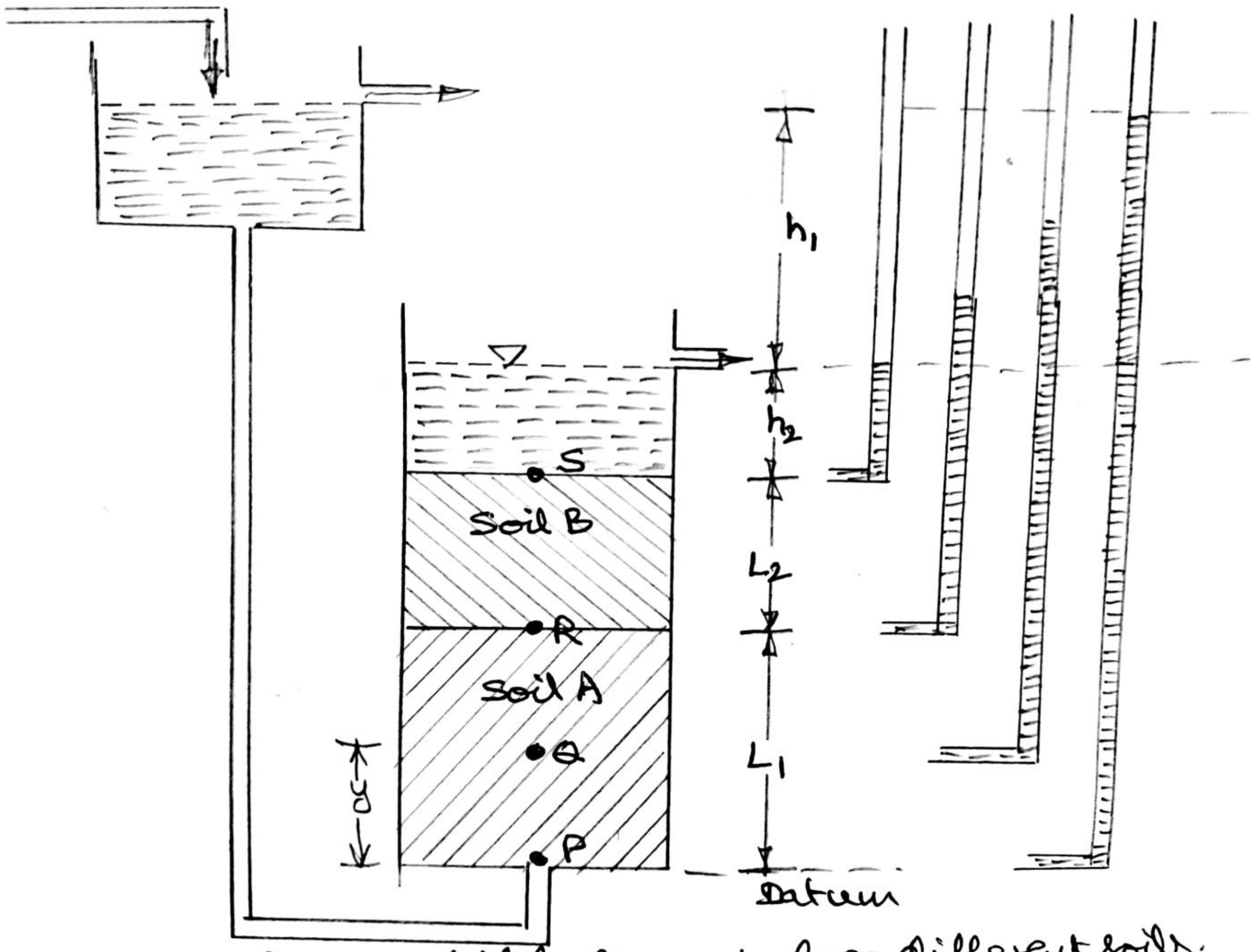
Pressure head, $= h_1 - i_A.L_1$

Datum head $= L_1$

At point S:

Pressure head, $= h_1 - i_A.L_1 - i_B.L_2$

Datum head $= L_1 + L_2$



Permeability through two different soils.

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Permeability

(Numerical Questions)

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PERMEABILITY OF SOIL

01. The quantity of water passing through a sample 6 cm height and 50 cm^2 cross sectional area in 10 minutes is 480 cm^3 under an effective constant head of 48 cm. The coefficient of permeability of soil is

a. 2×10^{-4} m/sec **b.** 2×10^{-5} m/sec c. 12×10^{-3} m/sec d. 12×10^{-4} m/sec

Ans. b

Length of the specimen, $L = 6$ cm

Cross sectional area, $A = 50\ cm^2$

Quantity of water, $Q = 480\ cm^3$

Time of flow, $t = 10 \times 60 = 600$ sec.

Constant head, $H = 48$ cm

$$q = kiA \Rightarrow \frac{Q}{t} = k\frac{H}{L}A \Rightarrow k = \frac{QL}{AtH}$$

$$k = \frac{480 \times 6}{50 \times 600 \times 48} = 0.002\ \text{mm/sec} = 2\times10^{-5}\ \text{m/sec.}$$

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02. The coefficient permeability of the soil sample 6 cm height and 50 cm^2 cross sectional area under an effective constant head of 48 cm is 2×10^{-5} m/sec. If the void ratio of the soil is 0.57, the discharge velocity and seepage velocity respectively are

a. 2×10^{-5} m/sec, 5.6×10^{-5} m/sec.
b. 2×10^{-5} m/sec, 3.5×10^{-5} m/sec.
c. 16×10^{-5} m/sec, 44.4 m/sec.
d. 16×10^{-5} m/sec, 28.1×10^{-5} m/sec.

Ans. c

Length of sample, L = 60 mm
Cross sectional area, A = 5000 mm^2.
Constant head, H = 480 mm
Coefficient of permeability, $k = 2 \times 10^{-5}$ m/sec.
Void ratio of the soil, e = 0.57

Discharge velocity, $v = k.i = k.\frac{H}{L} = 2\times10^{-5}\times\frac{480}{60} = 16\times10^{-5}$ m/sec

Porosity, $n = \frac{e}{1+e} = \frac{0.57}{1+0.57} = 0.36$

Seepage velocity, $v_s = \frac{v}{n} = \frac{16\times10^{-5}}{0.36} = 44.4\times10^{-5}$m/sec

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03. A cylindrical mould of 50 cm^2 cross sectional area contains 18.0 cm length of sand sample. When water flows through the soil under constant head at a rate of 48 cm^3/minute, the loss of head between two points 8 cm apart is found to be 12.8 cm. The coefficient of permeability of soil is

a. 0.1 cm/sec **b**. 0.01 cm/sec c. 0.001 cm/sec d. 0.0001 cm/sec.

Ans. b

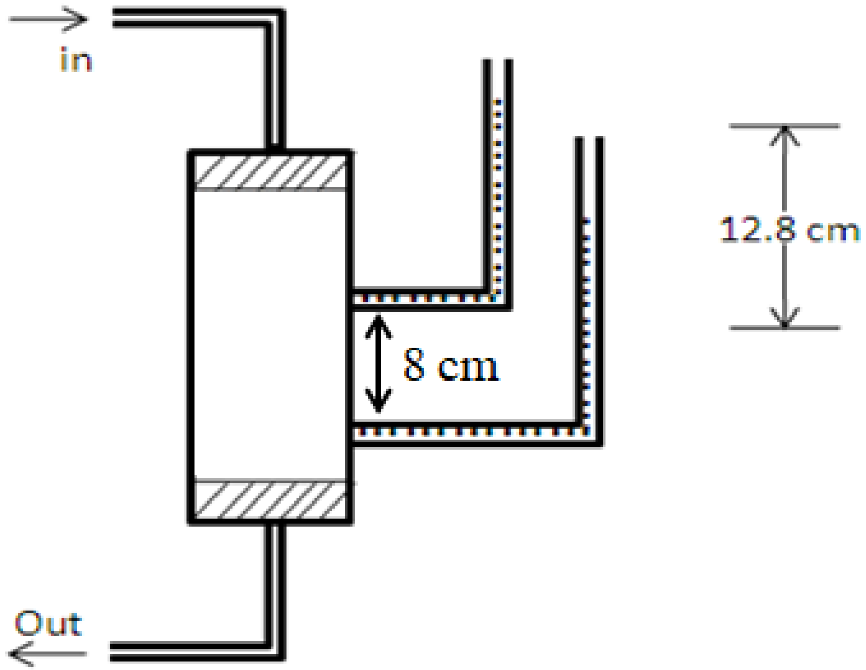
Cross sectional area of specimen, A = 50 cm^2.

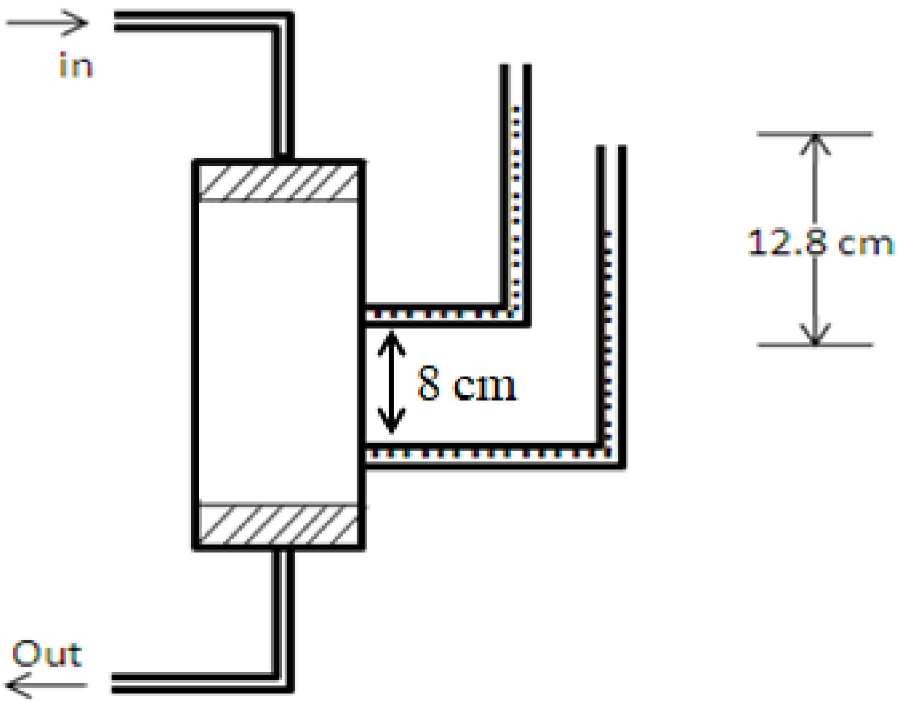
Length of soil specimen, L = 18 cm.

Rate of flow, q = 48 cm^3/minute = 0.8 cm^3/sec.

Length of sample, x = 8 cm.

Loss of head, y = 12.8 cm





Hydraulic gradient, $i = \frac{x}{y} = \frac{12.8}{8} = 1.6$

$$Q = kiA$$

$$k = \frac{0.8}{1.6 \times 50} = 0.01 \text{cm/sec}$$

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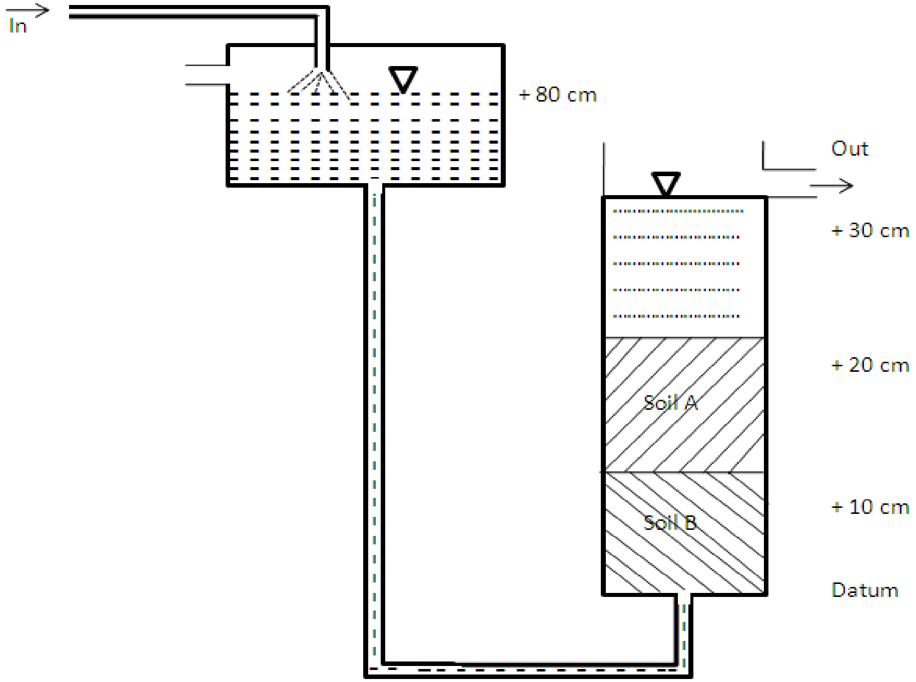
04. Two soils samples A and B each of 50 cm^2 cross sectional area arranged in a constant head permeability test as shown in fig. The loss of head in soil B is 4 times that of the loss of head in soil A. If the coefficient of permeability of soil A is 2×10^{-3} cm/sec. then the coefficient of permeability of soil B is

a. 8×10^{-3} cm/sec. b. 2×10^{-3} cm/sec. c. 5×10^{-3} cm/sec. **d.** 5×10^{-4} cm/sec.



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04 Ans. d

Let H_A and H_B be the head losses in soils A and B respectively.

$$H_B = 4H_A$$

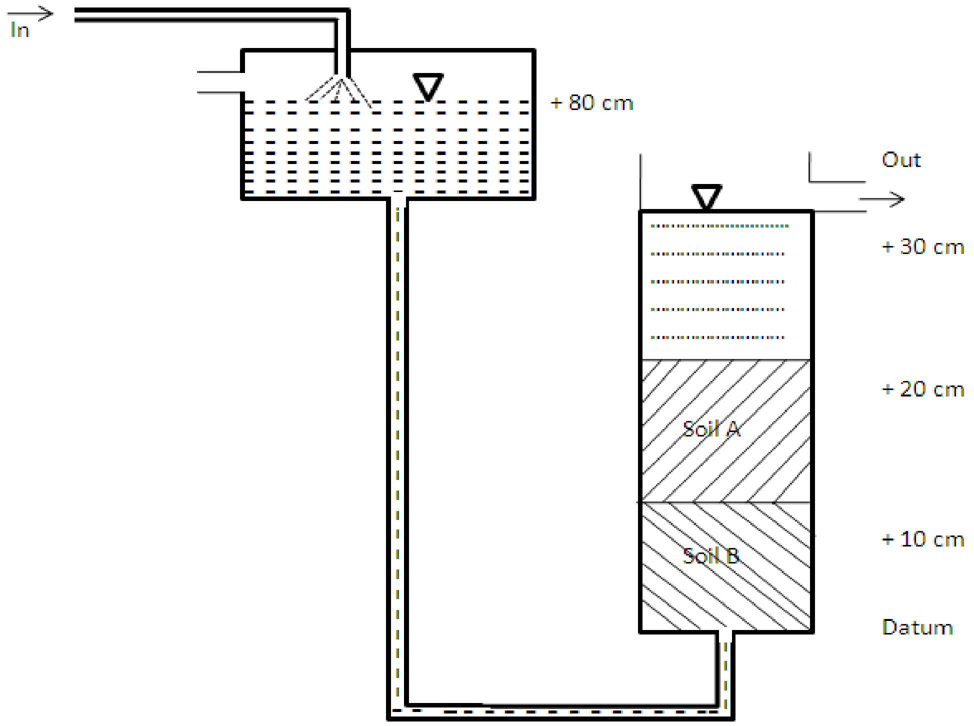
Total head loss, H = 80-30 = 50 cm.

$$H_A + H_B = 50$$

$$H_A + 4H_A = 50$$

H_A= 10 cm, H_B= 40 cm.

For flow through soil A, $Q = kiA = 2\times10^{-3}\times\frac{10}{10}\times50$



For flow through soil B

$$Q = kiA$$

$$0.1 = k_B\times\frac{40}{10}\times50 \Rightarrow k_B = 5\times10^{-4}\,\text{cm/sec}$$

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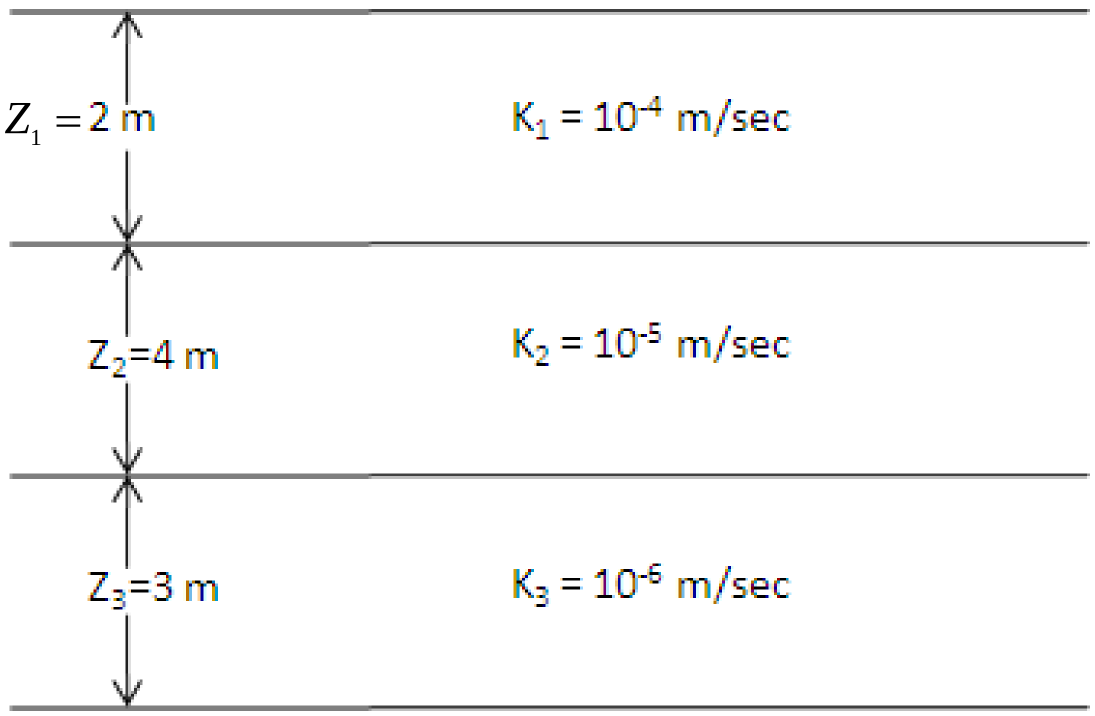
05. A soil deposit consists of three layers 2 m, 4 m and 3 m thick with permeabilities 10^{-4}, 10^{-5} and 10^{-6} m/sec respectively. The horizontal and vertical permeabilities of soil deposit respectively are

a. 2.7×10^{-5} m/sec, 3.33×10^{-7} m/sec. b. 2.43×10^{-4} m/sec, 3.33×10^{-7} m/sec.

c. 2.7×10^{-5} m/sec, 3.7×10^{-8} m/sec d. 2.43×10^{-4} m/sec, 3.7×10^{-8} m/sec

Ans. c



Average permeability parallel to bedding plane,

$$k_x = \frac{k_1.z_1 + k_2.z_2 + k_3.z_3}{z_1 + z_2 + z_3} = \frac{10^{-4} \times 2 + 10^{-5} \times 4 + 10^{-6} \times 3}{2+4+3} = 2.7\times10^{-5} \text{ m/sec}$$

Average permeability perpendicular to bedding plane,

$$k_z = \frac{z_1 + z_2 + z_3}{\frac{z_1}{k_1} + \frac{z_2}{k_2} + \frac{z_3}{k_3}} = \frac{2+4+3}{\frac{2}{10^{-4}} + \frac{4}{10^{-5}} + \frac{3}{10^{-6}}} = 3.7\times10^{-8}\text{m/sec}$$

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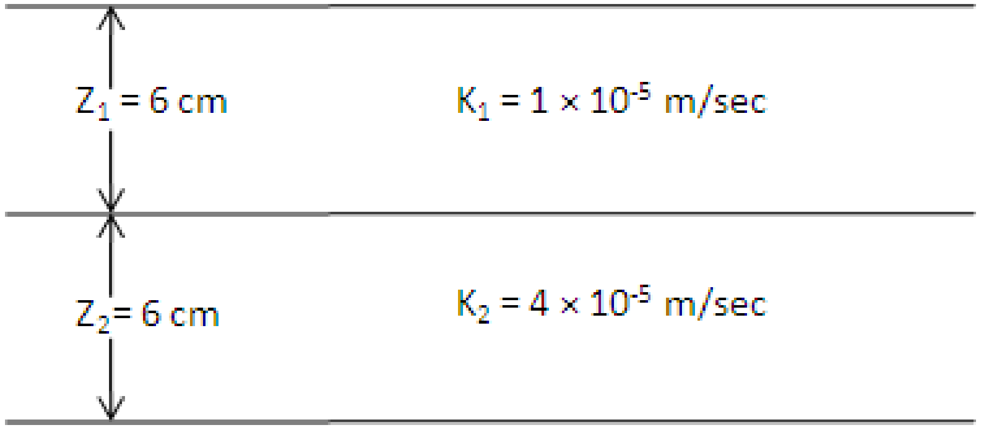
06. The soil sample in falling head permeability test consists of two layers each 6 cm thick and 50 cm^2 cross sectional area with permeabilities 1×10^{-5} m/sec and 4×10^{-5} m/sec respectively. The cross sectional area of stand pipe is 2 cm^2. If the flow takes place perpendicular to the bedding planes, the time required for the head to drop from 40 cm to 20 cm is

a. 3 min 28 sec. b. 2 min 13 sec c. 1 min 51 sec d. 1 min 7 sec.

Ans. a

$z_1 = 0.06$ m $k_1 = 1\times10^{-5}$ m/sec.

$z_2 = 0.06$ m $k_2 = 4\times10^{-5}$ m/sec.



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Length of the sample, L = 12 cm

Cross sectional area of sample = 50 cm^2.

Initial head, h_1 = 40 cm

Final head, h_2 = 20 cm

Time taken to fall from h_1 to h_2 = ?

Cross sectional area of stand pipe, a = 2 cm^2.

Average permeability perpendicular to the bedding planes,

$$k_z = \frac{z_1 + z_2}{\frac{z_1}{k_1} + \frac{z_2}{k_2}} \quad , \quad k_z = \frac{0.06 + 0.106}{\frac{0.06}{1\times10^{-5}} + \frac{0.06}{4\times10^{-5}}} = 1.6\times10^{-5}\text{m/sec} = 1.6\times10^{-3}\text{cm/sec}$$

$$k = 2.303\frac{QL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

$$t = 2.303\frac{2\times12}{50\times1.6\times10^{-3}}\log_{10}\left(\frac{40}{20}\right) = 208 \text{ sec} = 3 \text{ minutes } 28 \text{ sec.}$$

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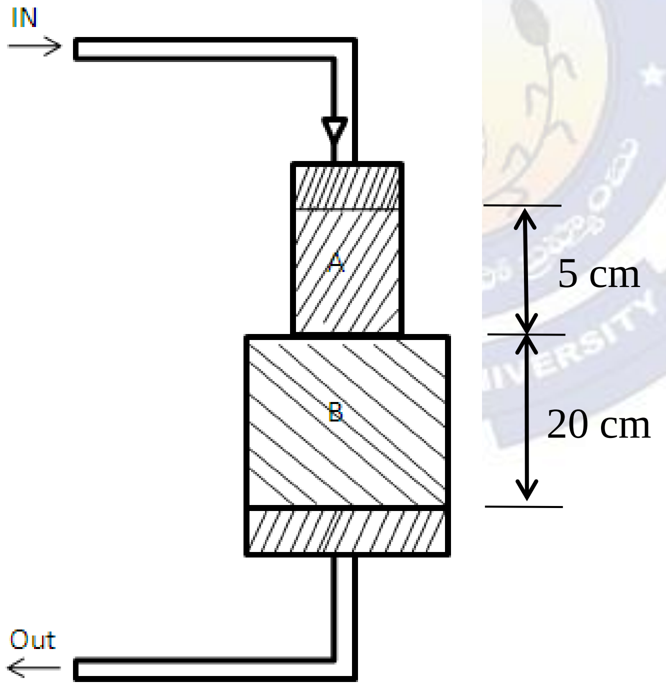
07. The soil sample consists of two soils A and B arranged in a permeability test as shown in fig. The length and cross sectional area of soil A are 5 cm, 50 cm^2 and that of soil B are 20 cm and 100 cm^2. The head loss across sample B is 4 times that of sample A. The ratio of permeabilities of soil A to that of soil B is

a. 1 **b.** 2 c. 3 d. 4



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07 Ans. b

Sample A

$L_1 = 5$ cm

$H_B = 50$ cm^2

Sample B

$L_2 = 20$ cm

$A_2 = 100$ cm^2

h_1 : Head loss across sample A

h_2 : Head loss across sample B

$h_2 = 4h_1$

According to Darcy's law, $Q = k_1 i_1 A_1 = k_2 i_2 A_2$

$$Q = k_1 \frac{h_1}{L_1} A_1 = k_2 \frac{h_2}{L_2} A_2 \quad , \quad \frac{k_1}{k_2} = \frac{h_2}{h_1} . \frac{L_1}{L_2} . \frac{A_2}{A_1} = 4 \times \frac{5}{20} \times \frac{100}{50} = 2$$

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08. The coefficient of permeability of a soil sample is found to be 4×10^{-5} m/sec at a void ratio of 0.6. If the void ratio of the same sample is 0.8, then the coefficient of permeability is

a. 3×10^{-5} m/sec b. 4×10^{-6} m/sec c. 5.33×10^{-5} m/sec **d.** 6.32×10^{-6} m/sec

Ans. d

$k_1 = 4 \times 10^{-5}$ m/sec $\quad e_1 = 0.6$

$k_2 = ?$ $\quad e_2 = 0.8$

We know that $k = D^2.\frac{\gamma}{\eta}.\frac{e^3}{1+e}.C$

$$k\alpha \frac{e^3}{1+e} \Rightarrow \frac{k_2}{k_1} = \frac{e_2^3}{e_1^3}.\frac{1+e_1}{1+e_2} \Rightarrow k_2 = \left(\frac{0.8}{0.6}\right)^3 \times \frac{1+0.6}{1+0.8} \times 4\times10^{-5}$$

$k_2 = 6.32\times10^{-5}$ cm/sec

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09. The coefficient of viscosity and unit weight of a percolating fluid reduced by 10% and 25% respectively due to rise in temperature. Keeping all other things remain constant, the percentage change in coefficient of permeability is

a. Increases by 16.7 | **b**. decreases by 16.7

c. increases by 32.5% | d. decreases by 32.5%

Ans. b

We know that $k = D^2 . \frac{\gamma}{\eta} . \frac{e^3}{1+e} .C$ $k \alpha \frac{\gamma}{\mu}$ $k_1 = k$ $k_2 = ?$

$\gamma_1 = \gamma$ $\gamma_2 = 0.75\gamma$

$\mu_1 = \mu$ $\mu_2 = 0.90\mu$

$$\frac{k_2}{k_1} = \frac{\gamma_2}{\mu_2} . \frac{\mu_1}{\gamma_1} = \frac{0.75\gamma}{0.90\mu} . \frac{\mu}{\gamma} = 0.833$$

% change in $k_2 = \frac{k_2 - k_1}{k_1} \times 100 = \frac{0.833k - k}{k} \times 100 = -16.7\%$

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10. In a variable head permeability test on a soil sample, the head drops from 32 cm to 8 cm in 20 minutes. The head corresponding to 10 minutes is

a. 16 cm　　b. 18 cm　　c. 20 cm　　d. 22 cm

Ans. a

For a variable head permeability test

$$k = \frac{aL}{At}\log_e\left(\frac{h_1}{h_2}\right) \Rightarrow \frac{h_1}{h_2} = \frac{h_2}{h_3} \Rightarrow h_2^2 = h_1.h_3 \Rightarrow h_2 = \sqrt{h_1.h_3}$$

$h_1 = 32$ cm　　$t = 0$

$h_2 = ?$　　$t = 10$ minutes

$h_3 = 8$ cm　　$t = 20$ minutes

$$h_2 = \sqrt{32\times 8} = \sqrt{256} = 16\,\text{cm}$$

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11. If the effective size of soil is 0.02 cm, the coefficient of permeability is

a. 4×10^{-2} m/sec **b**. 4×10^{-4} m/sec c. 2×10^{-2} m/sec d. 2×10^{-4} m/sec

Ans. b

The coefficient of permeability from grain size is $k = C.D_{10}^2$

k : coefficient of permeability, cm/sec

C : Constant, taken as 100

D_{10}: Effective size of soil in cm.

$$k = 100 \times (0.02)^2 = 0.04\,\text{cm/sec} = 4 \times 10^{-4}\,\text{m/sec}$$

Permeability

(Previous GATE Questions)

Prof. B. Jayarami Reddy

1. A constant-head permeability test was conducted on a soil specimen under a hydraulic gradient of 2.5. The soil specimen has specific gravity of 2.65 and saturated water content of 20%. If the coefficient of permeability of the soil is 0.1 cm/s, the seepage velocity (in cm/s, round off to two decimal places) through the soil specimen is…….

GATE CE 2020

Ans. 0.72

Hydraulic gradient, i = 2.5

Specific gravity of soil, G = 2.65

Water content, w = 20%

Coefficient of permeability of soil, k = 0.1 cm/s

Seepage velocity through the specimen, $v_s = ?$

v : discharge velocity

$$v_s = \frac{v}{n}$$

$$v = k.i$$

As per darcy's law, $v = k.i = 0.1 \times 2.5 = 0.25$ cm/s

$$S = \frac{WG}{e} \Rightarrow 1 = \frac{0.2 \times 2.65}{e} \Rightarrow e = 0.53$$

Porosity, $n = \frac{e}{1+e} = \frac{0.53}{1+0.53} = 0.3464$

$$v_s = \frac{v}{n} = \frac{0.25}{0.3464} = 0.7212 \text{ cm/s}$$

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2. Permeability tests were carried out on the samples collected from two different layers as shown in the figure (not drawn to the scale). The relevant horizontal (k_h) and vertical (k_y) coefficients of permeability are indicated for each layer. The ratio of the equivalent horizontal to vertical coefficients of permeability, is GATE CE 2020

a. 37.29 b. 80.20 c. 68.25 d. 0.03

Ans. a

$H_1 = 3m \quad H_2 = 4m$

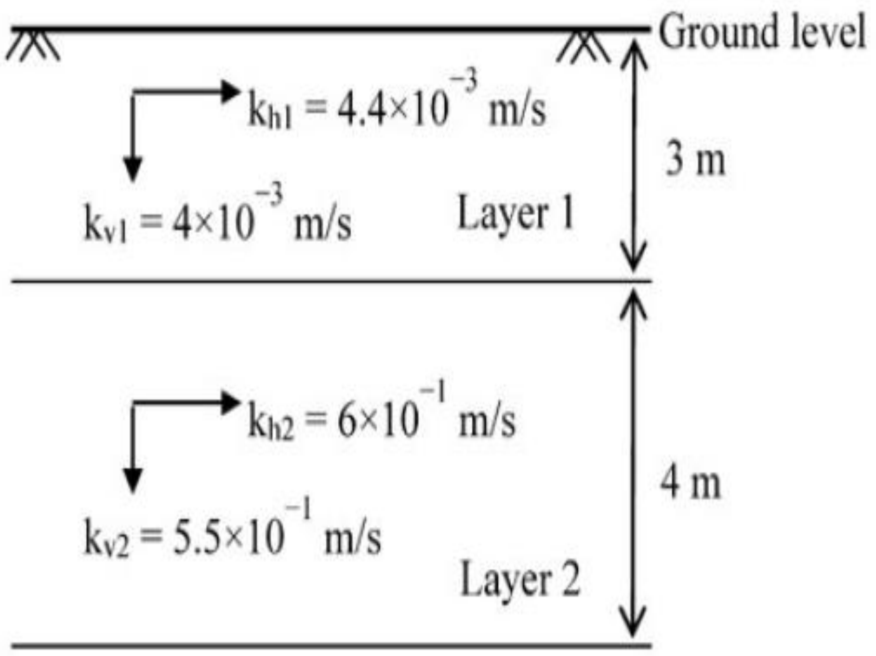
$K_{H_1} = 4.4\times10^{-3}$ m/s $\quad K_{H_2} = 6\times10^{-1}$ m/s

$K_{v_1} = 4\times10^{-3}$ m/s $\quad K_{v_2} = 5.5\times10^{-1}$ m/s

$K_{h\,eq}$: Equivalent horizontal co-efficient of permeability

$$= \frac{K_{h1}.H_1 + K_{h2}.H_2}{H_1 + H_2} = \frac{4.4\times10^{-3}\times3 + 6\times10^{-1}\times4}{3+4} = 0.3447\,\text{m/s}$$

$K_{v\,eq}$: Equivalent horizantal co-efficient of permeability



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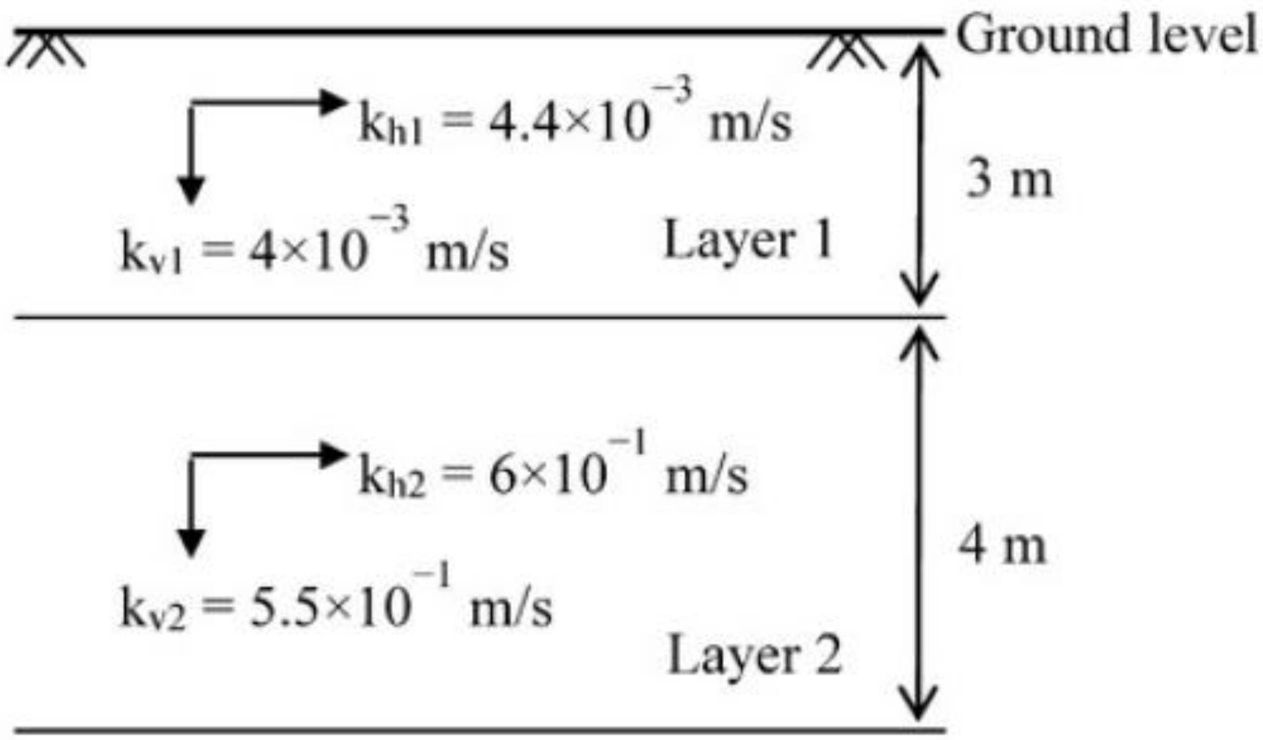
$$K_{v\,eq} = \frac{H_1 + H_2}{\dfrac{H_1}{K_{v1}} + \dfrac{H_2}{K_{v2}}} = \frac{3+4}{\dfrac{3}{4\times10^{-3}} + \dfrac{4}{5.5\times10^{-1}}} = 9.2436\times10^{-3}\ \text{m/s}$$

$$\frac{K_{h\,eq}}{K_{v\,eq}} = \frac{0.3447}{9.2436\times10^{-3}} = 37.29$$



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03.Constant head permeability tests were performed on two soil specimens, S_1 and S_2 . The ratio of height of the two specimens $\left(L_{S1}:L_{S2}\right)$ is 1.5, the ratio of the diameter of specimens $\left(D_{S1}:D_{S2}\right)$ is 0.5, and the ratio of the constant head $\left(h_{S1}:h_{S2}\right)$ applied on the specimens is 2.0. If the discharge from both the specimens is equal, the ratio of the permeability of the soil specimens $\left(k_{S1}:k_{S2}\right)$ is …….. **3** CE2 2019

Ans. 3

Soil specimens: S_1 and S_2

Height ratio of samples, $L_{S1}:L_{S2}$ =1.5

Diameter ratio of samples, $D_{S1}:D_{S2}$ =0.5

Constant head ratio applied, $h_{S1}:h_{S2}$ =2.0

Discharge from specimens is equal, $Q_{S1} = Q_{S2}$

Ratio of permeability's, $k_{S1} : k_{S2} \quad =?$

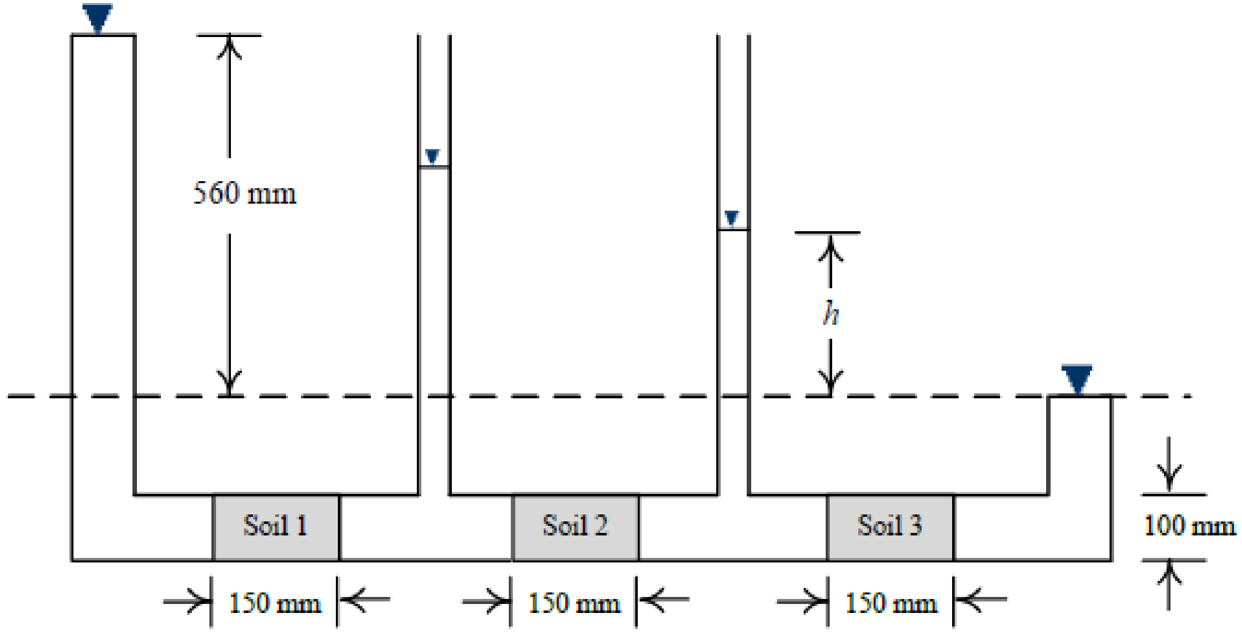
For constant head permeability test, $Q = k.i.A$

$$Q = k.\frac{h}{L}.A = K.\frac{h}{L}.\frac{\pi D^2}{4} \Rightarrow Q \alpha \frac{KhD^2}{L}$$

$$\frac{Q_1}{Q_2} = \left(\frac{K_1}{K_2}\right).\left(\frac{h_1}{h_2}\right).\left(\frac{D_1}{D_2}\right)^2.\left(\frac{L_2}{L_1}\right)$$

$$1 = \frac{k_1}{k_2} \times 2.0 \times (0.5)^2 \times \frac{1}{1.5} \Rightarrow \frac{k_1}{k_2} = 3$$

05. Three soil specimens (Soil 1, Soil 2 and Soil 3), each 150 mm long and 100 mm diameter, are placed in series in a constant head flow set-up as shown in the figure. Suitable screens are provided at the boundaries of the specimens to keep them intact. The values of coefficient of permeability of Soil 1, Soil 2 and Soil 3 are 0.01,0.003 and 0.03 cm/s respectively. CE2 2018



The value of h in the set-up is

a. 0 mm **b.** 40 mm c. 255 mm d. 560 mm

05 Ans. b

The three soil specimen are placed in series in constant head flow. Discharge passing through the specimens is same. Head loss and hydraulic gradient will be different.

$$q = k_1.i_1.A = k_2.i_2.A = k_3.i_3.A = k_{avg}.i.A$$

$$k_{avg} = \frac{z_1 + z_2 + z_3}{\frac{z_1}{k_1} + \frac{z_2}{k_2} + \frac{z_3}{k_3}} = \frac{150+150+150}{\frac{150}{0.01} + \frac{150}{0.003} + \frac{150}{0.03}} = \frac{450}{70,000} = 6.429 \times 10^{-3}$$

Total head loss, H = 560 mm, L = 450 mm

$$k_3.i_3.A = k_{avg}.i.A$$

$$0.03 \times \frac{h}{150} \times A = 6.429 \times 10^{-3} \times \frac{560}{450} \times A$$

h = 40 mm

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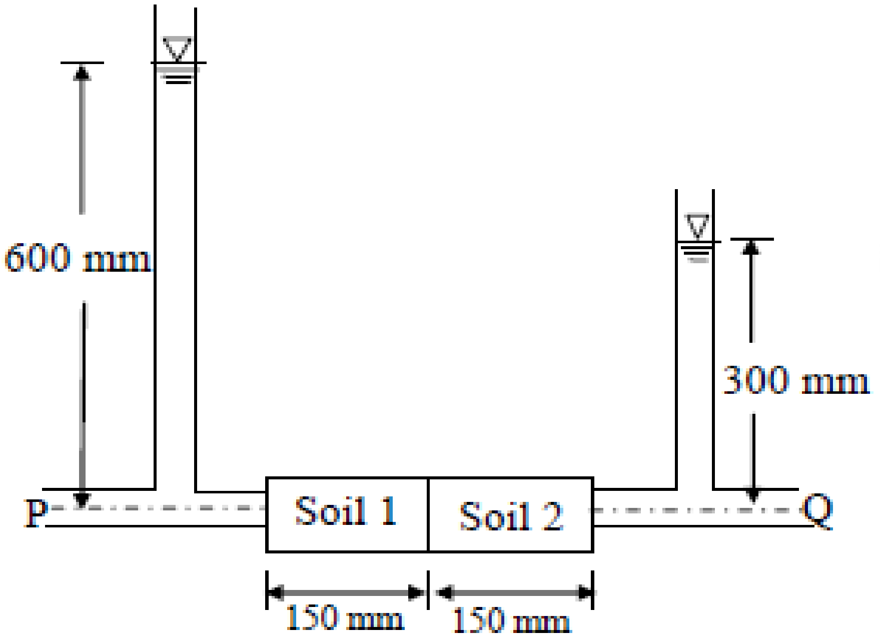
06. Water flows from P to Q through two soil samples, Soil 1 and 2, having cross sectional area of 80 cm^2 as shown in the figure. Over a period of 15 minutes, 200 ml of water was observed to pass through any cross section. The flow conditions can be assumed to be steady state. If the coefficient of permeability of Soil 1 is 0.02 mm/s, the coefficient of permeability of Soil 2 (expressed in mm/s) would be ………. CE2 2016



06 Ans. 0.0445

Coefficient of permeability of soil 1, k_1=0.02 mm/s

Discharge, Q = 200 ml in 15 minutes $= \frac{200}{15 \times 60} cm^3/s$

Cross sectional area, A = 80 cm^2

Head loss, h = 600 – 300 = 300 mm=30 cm

Length of sample, L =150 + 150 = 300 mm = 30 cm

$$Q = k.i.A = k.\frac{h}{L}.A \qquad \frac{200}{15 \times 60} = k \times \frac{30}{30} \times 80 \qquad k = 2.778 \times 10^{-3} cm/s$$

Flow through soil l and 2 is perpendicular to the bedding planes

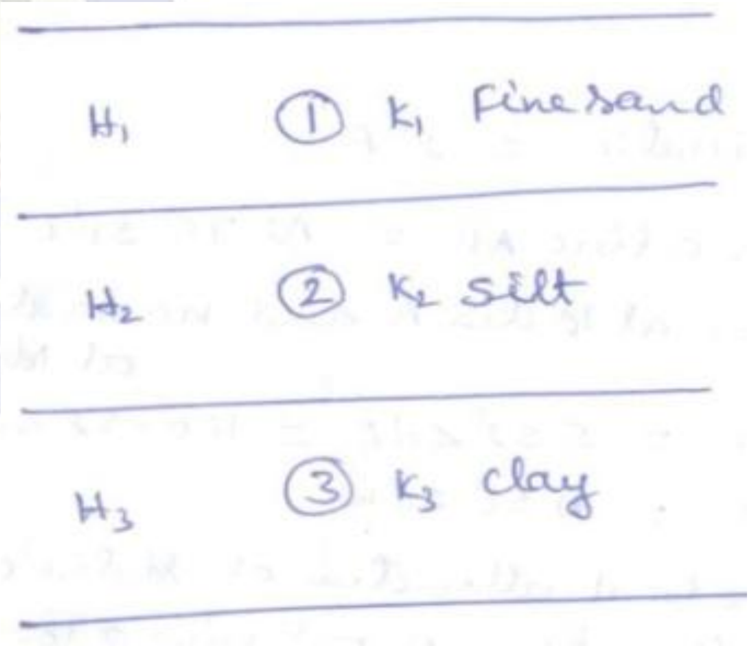
k : Equivalent or average permeability

= 2.778×10^{-2} mm/Sec

$$k = \frac{Z_1 + Z_2}{\frac{Z_1}{k_1} + \frac{Z_2}{k_2}} \Rightarrow 2.778 \times 10^{-2} = \frac{150 + 150}{\frac{150}{0.02} + \frac{150}{k_2}} \Rightarrow k_2 = 0.0455 mm/s$$

07. A non-homogeneous soil deposit consists of a silt layer sandwiched between a fine sand layer at top and a clay layer below, Permeability of the silt is 10 times the permeability of the clay layer and one-tenth of the permeability of the fine sand layer. The thickness of the silt layer is 2 times the thickness of the sand layer and two-third of the thickness of the clay layer. The ratio of equivalent horizontal and equivalent vertical permeability of the deposit is…………… CE1 2015

Ans. 10.97



Given

$$k_2 = 10\,k_3 = \frac{k_1}{10} \Rightarrow k_2 = \frac{k_1}{10}, k_3 = \frac{k_1}{100}$$

$$H_2 = 2H_1 = \frac{2}{3}H_3 \Rightarrow H_2 = 2H_1, H_3 = 3H_1$$

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Horizontal permeability of soil,

$$k_x = \frac{k_1H_1 + k_2H_2 + k_3H_3}{H_1 + H_2 + H_3} = \frac{k_1H_1 + \frac{k_1}{10}.2H_1 + \frac{k_1}{100}.3H_1}{H_1 + 2H_1 + 3H_1} = 0.205k_1$$

Vertical permeability of soil,

$$k_y = \frac{H_1 + H_2 + H_3}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}} = \frac{H_1 + 2H_1 + 3H_1}{\frac{H_1}{k_1} + \frac{2H_1}{\frac{k_1}{10}} + \frac{3H_1}{\frac{k_1}{100}}} = 0.01869k_1 \Rightarrow \frac{k_x}{k_y} = \frac{0.205k_1}{0.01869k_1} = 10.97$$

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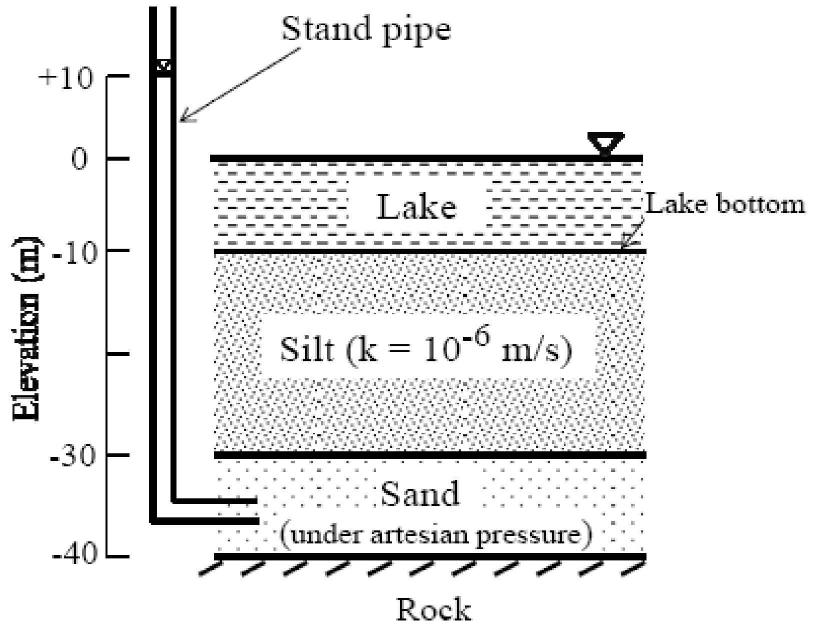
08. The soil profile below a lake with water level at elevation = 0 m and lake bottom at elevation -10 m is shown in the figure, where k is the permeability coefficient. A piezometer (stand pipe) installed in the sand layer shows a reading of +10 m elevation. Assume that the piezometric head is uniform in the sand layer. The quantity of water (in m^3/s) flowing into the lake from the sand layer through the slit layer per unit area of the lake bed is 2013



a. 1.5×10^{-6} b. 2.0×10^{-6} c. 1.0×10^{-6} **d.** 0.5×10^{-6}

8 Ans. d

Coefficient of permeability of silt, $k = 10^{-6} m/s$

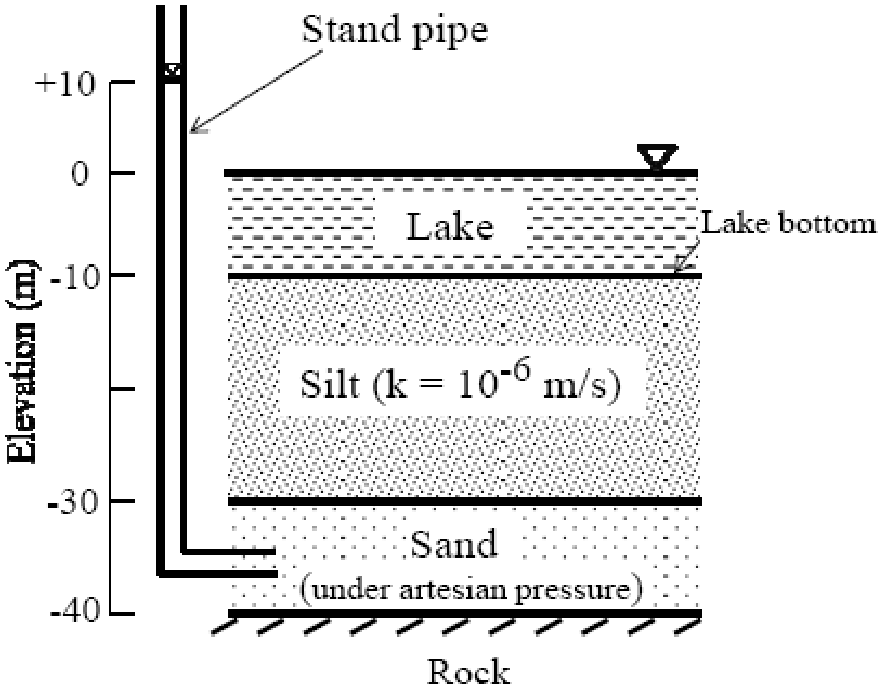
Total head, $H = 10m$

Length of silt layer, $L = 20m$

Hydraulic gradient, $i = \frac{H}{L} = \frac{10}{20} = 0.5$

Area of sand layer $= 1$ unit

Quantity of water flowing into lake through silt layer,



$$q = k.i.A = 10^{-6} \times 0.5 \times 1 = 0.5 \times 10^{-6} m^3/s$$

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09. Two soil specimens with identical geometric dimensions were subjected to falling head permeability tests in the laboratory under identical conditions. The fall of water head was measured after an identical time interval. The ratio of initial to final water heads for the test involving the first specimen was 1.25. If the coefficient of permeability of the test second specimen is 5-times that of the first, the ratio of initial to final water heads in the test involving the second specimen is

a. 3.05 b. 3.80 c. 4.00 d. 6.25 2012

Ans. a

Using the falling head permeability test, the coefficient of permeability is given by

$$k = 2.303\frac{aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

$$\frac{k_1}{k_2} = \frac{\log_{10}\left(\frac{h_1}{h_2}\right)_1}{\log_{10}\left(\frac{h_1}{h_2}\right)_2}$$

$$\left(\frac{h_1}{h_2}\right)_1 = 1.25 \quad ; \quad k_2 = 5k_1 \quad ; \quad \left(\frac{h_1}{h_2}\right)_2 = ?$$

$$\frac{k_1}{k_2} = \frac{\log_{10}\left(\frac{h_1}{h_2}\right)_1}{\log_{10}\left(\frac{h_1}{h_2}\right)_2} \quad ; \quad \log_{10}\left(\frac{h_1}{h_2}\right)_2 = 5\times\log_{10}\left(\frac{h_1}{h_2}\right)_1 = 5\times\log_{10}(1.25) = 0.4846$$

$$\left(\frac{h_1}{h_2}\right)_2 = 3.05$$

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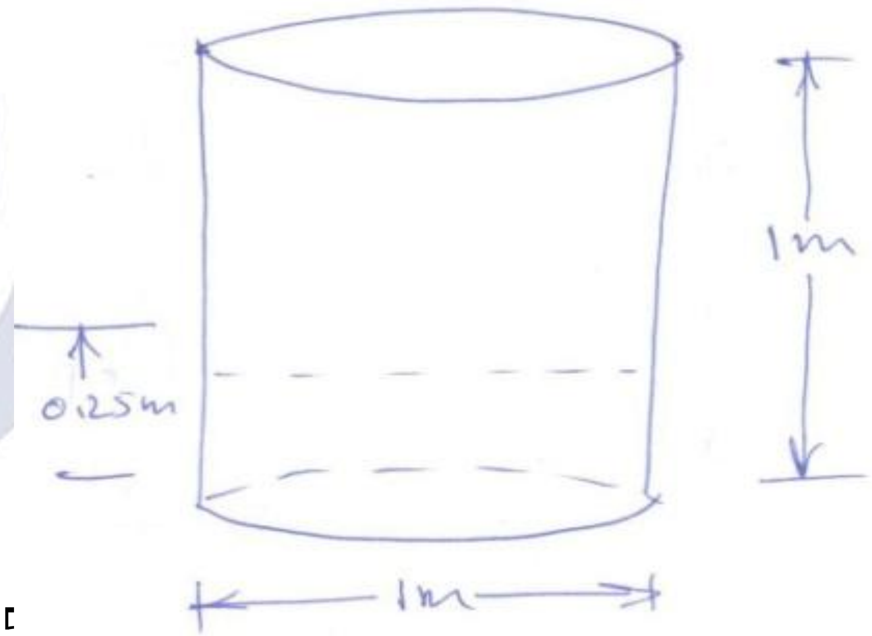
10. An open ended steel barrel of 1m height and 1m diameter is filled with saturated fine sand having coefficient of permeability of 10^{-2} m/s. The barrel stands on a saturated bed of gravel. The time required for the water level in the barrel to drop by 0.75 m is 2010

a. 58.9 s **b.** 75 s c . 100 s d. 150 s

Ans. b

Coefficient of permeability of soil, = 10^{-2} m/s

Since the barrel stands on a saturated bed of gravel, the flow of water through soil is at a velocity equal to the coefficient of permeability of soil.



$$\text{Time required} = \frac{\text{Drop in water level}}{\text{Coefficient of permeability}} = \frac{h}{k} = \frac{0.75}{10^{-2}} = 75\,\text{sec}$$

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Common Data for Questions 11 and 12:

Water is flowing through the permeability apparatus as shown in the figure. The coefficient of permeability of the soil is k m/s and the porosity of the soil sample is 0.50.

11. What are discharge velocity and seepage velocity through the soil sample ? 2007

a. $k, 2k$ b. $\frac{2}{3}k, \frac{4}{3}k$ c. $2k, k$ d. $\frac{4}{3}k, \frac{2}{3}k$

Ans. a

Discharge velocity, $v = k.i$

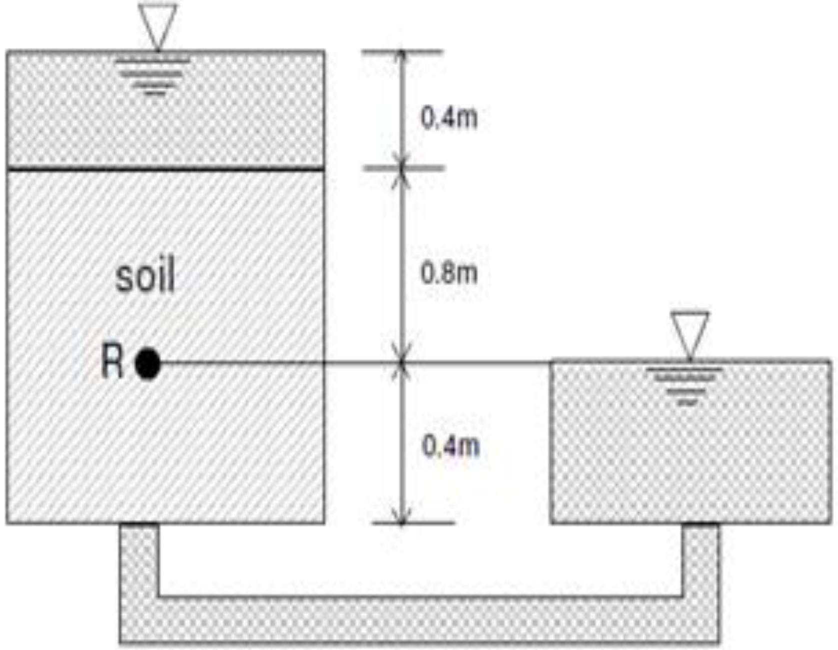
Hydraulic gradient, $i = \frac{\text{head loss}}{\text{length of soil mass}}$

$$= \frac{0.4+0.8}{0.8+0.4} = 1.0$$

$$v = k.i = k \times 1 = k$$

Seepage velocity through soil sample,

$$v_s = \frac{v}{n} = \frac{k}{0.5} = 2k$$



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12. The total head, elevation head and pressure head in metres of water at the point R shown in the figure are 2007

a. 0.8, 0.4, 0.4 b. 1.2, 0.4, 0.8 c. 0.4, 0, 0.4 **d.** 1.6, 0.4, 1.2

Ans. d

k : Coefficient of permeability of the soil

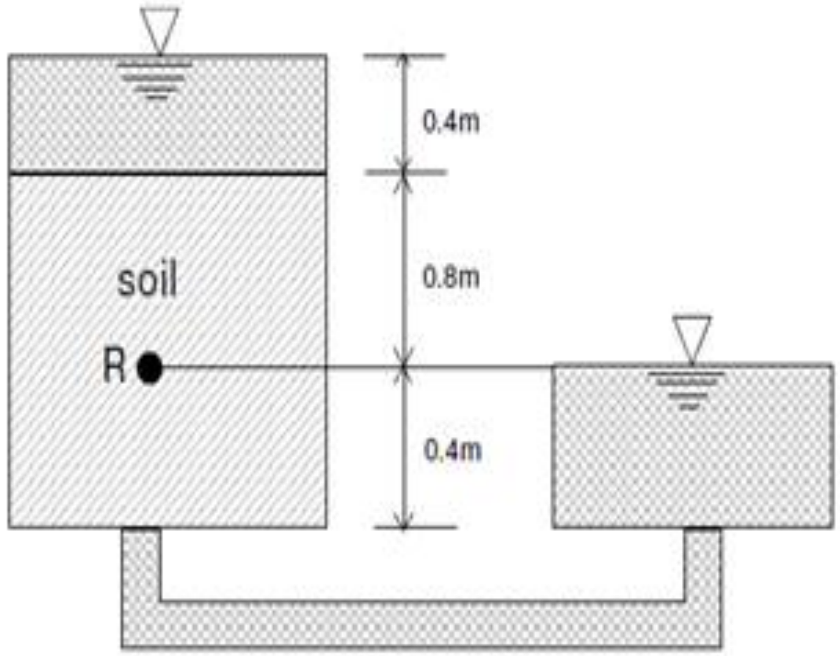
Porosity of the soil, n = 0.50

Pressure head at the point R = 0.4 + 0.8 =1.2 m

Elevation head at the point R = 0.4m

Total head loss at R = Pressure head + Elevation head

= 1.2 + 0.4 = 1.6 m



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13. In a constant head permeameter with cross section area of 10 cm^2, when the flow was taking place under a hydraulic gradient of 0.5, the amount of water collected in 60 seconds is 600 cc. The permeability of the soil is 2005

a. 0.002 cm/s b. 0.02 cm/s c. 0.2 cm/s **d.** 2.0 cm/s

Ans. d

Area of cross section, A = 10 cm^2

Hydraulic gradient, i = 0.5

Time for water collection, t = 60 sec

Volume of water collected, V = 600 ml

Permeability of the soil, k =?

In constant head permeameter, $Q = k.i.A$

$$\frac{V}{t} = k.i.A \qquad \frac{600}{60} = k \times 0.5 \times 10 = 2cm/s$$

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14. In a falling head permeability test the initial head of 1.0 m dropped to 0.35 m in 3 hours, the diameter of the stand pipe being 5 mm. The soil specimen was 200 mm long and of 100 mm diameter. The coefficient of permeability of the soil is 2002

a. 4.86×10^{-5} cm/s **b.** 4.86×10^{-6} cm/s c. 4.86×10^{-7} cm/s d. 4.86×10^{-8} cm/s

Ans. b

Initial head, h_1 = 1 m

Final head, h_2 = 0.35 m

Time taken to drop h_1 to h_2 =3 hours

Diameter of stand pipe, = 5 mm

Cross sectional area of stand pipe, $a = \frac{\pi(5)^2}{4}$ =19.63 mm^2

$$k = 2.303\frac{a.L}{A.t}\log_{10}\left(\frac{h_1}{h_2}\right)$$

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Length of soil sample, L = 200 mm

Diameter of soil sample, d = 100 mm

Cross sectional area of sample, $A = \frac{\pi}{4}(100)^2 = 7854 \text{ mm}^2$

Coefficient of permeability, $k = 2.303 \frac{a.L}{A.t} \log_{10}\left(\frac{h_1}{h_2}\right)$

$$k = 2.303 \frac{19.63 \times 200}{7854 \times 3 \times 60 \times 60} \log_{10}\left(\frac{1}{0.35}\right) = 4.86 \times 10^{-5} \, mm/s$$

$$k = 4.86 \times 10^{-6} \text{ cm/s}$$

15. The two tubes shown in Fig. may be considered to be permeameters. Dimensions of the sample in Fig. (i) and (ii) are alike, and the elevations of head water and tail water are the same for both the figures. $A, B, ...etc.$ indicate points and $AB, AE, ...etc.$ indicated heads. Head loss through these samples are

1999

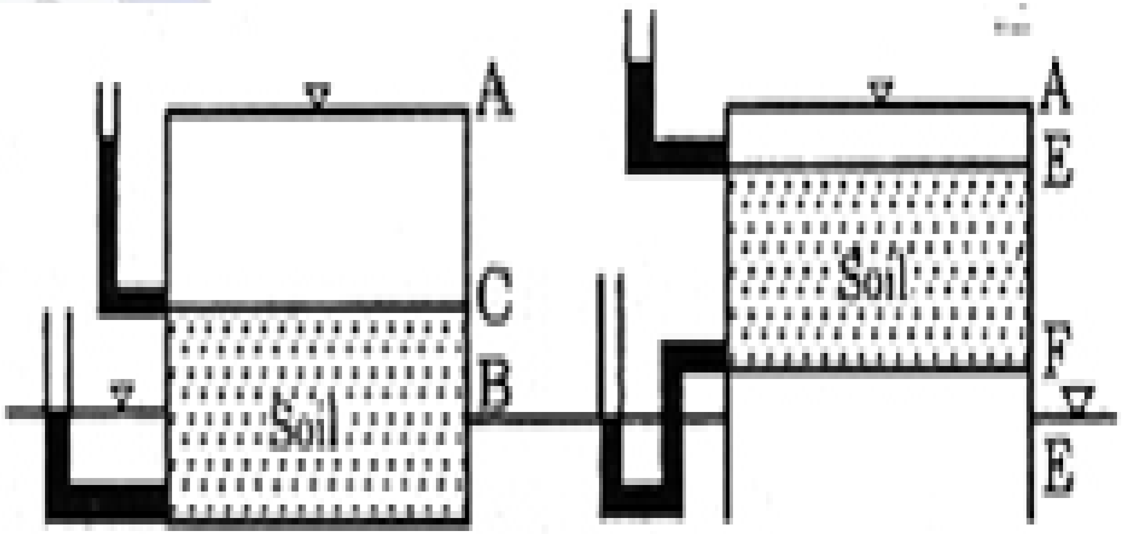
a. $(i)BD, (ii)FB$

b. $(i)AC, (ii)AE$

c. $(i)AD, (ii)AF$

d. $(i)AB, (ii)AB$

Ans. d



The loss of head through the soil sample is equal to the difference between the levels of water in the piezometers provided at top and bottom of soil sample.Therefore, loss of head through the soil sample in each of the permeameters is equal to AB.

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16. For an anisotropic soil, permeability's x in y and directions are k_x and k_y respectively in a two dimensional flow. The effective permeability k_{eff} for the soil is given by 1999

a. $k_x + k_y$ b. $\frac{k_x}{k_y}$ c. $(k_x^2 + k_y^2)^{1/2}$ **d.** $(k_x k_y)^{1/2}$

Ans. d

k_x : Coefficient of permeability in direction

k_y : Coefficient of permeability in direction

Effective coefficient of permeability of soil, $k_{eff} = \sqrt{k_x . k_y}$

17. A soil mass has coefficients of horizontal and vertical permeability as 9×10^{-7} cm/s and 4×10^{-7} cm/s, respectively. The transformed coefficient of permeability of an equivalent isotropic soil mass is 1997

a. 9×10^{-7}cm/s b. 4×10^{-7}cm/s c. 13×10^{-7}cm/s **d.** 6×10^{-7}cm/s

Ans. d

Horizontal coefficient of permeability, $k_h = 9\times10^{-7}$ cm/s

Vertical coefficient of permeability, $k_v = 4\times10^{-7}$ cm/s

Transformed coefficient of permeability, $k_e = \sqrt{k_x . k_z}$

$$k_e = \sqrt{9\times10^{-7}\times4\times10^{-7}} = 6\times10^{-7} \text{ cm/sec}$$

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18. According to Darcy's law for flow through porous media, the velocity is proportional to 1997

a. effective stress **b.** hydraulic gradient c. cohesion d. stability number

Ans. b

Darcy's law is $q = k.i.A$ $v \propto i$

The velocity is proportional to hydraulic gradient.

19. The difference between the free water levels in two wells 48 m apart in an aquifer is 0.6 m, It took an interval of 8 hours between detecting the traces of a tracer material at the two wells in succession. The porosity of the aquifer is 25%. The coefficient of permeability of the aquifer is……… cm/sec. 1991

Ans. 3.33

Distance between two wells , $L = 48$ m

Difference between free water levels in two wells, $h = 0.6$ m

Porosity of the aquifer, $n = 0.25$

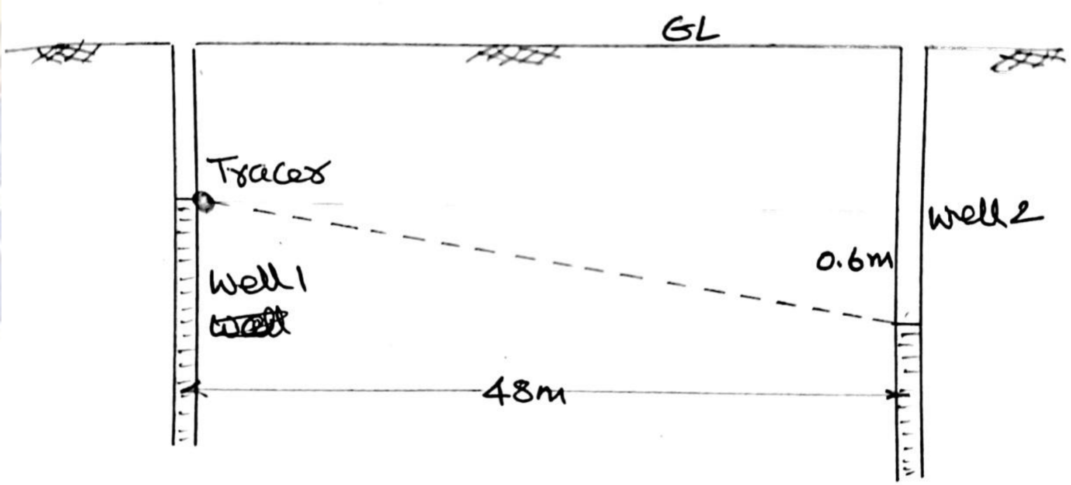
Time taken to detect the traces, $t = 8$ hours

According to Darcy law, $v \propto i \quad v = k.i$

$V:$ Flow velocity

$i:$ Hydraulic gradient = h/L

$k:$ Coefficient of permeability



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$$v = \frac{k.h}{L}$$

Seepage velocity, $v_s = \frac{v}{n}$ $\quad v = v_s.n$

$$\frac{k.h}{L} = v_s.n \qquad \frac{k.h}{L} = \frac{L}{t}.n \qquad k \times \frac{0.6}{48} = \frac{48}{8 \times 60 \times 60} \times 0.25$$

$$k = 0.033 \text{ m/s} = 3.33 \text{ cm/s}$$

20. The coefficient of permeability of a soil is 5 10^{-5} cm/sec for a certain pore fluid. If the viscosity of the pore fluid is reduced to half, the coefficient of permeability will be 1991

a. 5×10^{-5} cm/sec **b.** 10×10^{-5} cm/sec c. 2.5×10^{-5} cm/sec d. 1.25×10^{-5} cm/sec

Ans. b

Coefficient of permeability of soil, $k_1 = 5\times10^{-5}$ cm/s

Viscosity of fluid, $\mu_1 = \mu$

Viscosity of another fluid, $\mu_2 = 0.5\,\mu$

Coefficient of permeability of soil through another fluid, $k_2 = ?$

$$k = D_s^2 . \frac{\gamma}{\mu} . \frac{e^3}{1+e} . C \qquad k \propto \frac{1}{\mu} \; , \quad k_1\mu_1 = k_2\mu_2$$

$$5\times10^{-5} \times \mu = k_2 \times 0.5\,\mu \Rightarrow k_2 = 10\times10^{-5} \text{ cm/s}$$

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