GATE – CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

Prof.B.Jayarami Reddy
Professor and Head
Department of Civil Engineering
Y.S.R. Engineering College of
Yogi Vemana University,
Proddatur, Y.S.R.(Dt.), A.P-516360.

8.7 Seepage Analysis

Prof. B. Jayarami Reddy

8.7 Seepage Analysis

Types of Head:

Total head = Pressure head + Velocity head + Datum head

Velocity head is very small in soils and can be neglected.

Total head = pressure head + datum head.

$$h = h_w \pm z$$

- Flow takes place only due to difference in total heads.
- Pressure head difference alone or datum head difference alone cannot cause the flow of water through the soil

Hydraulic Gradient:

- It is the loss of head per unit seepage length. $i = \frac{h}{L}$ or $i = \frac{h}{z}$

Seepage Pressure $\left(P_s\right)$:

- The pressure exerted by water on the soil through which it percolates

Seepage pressure, $p_s = \pm\gamma_w . h$

Prof. B. Jayarami Reddy

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

At Point A:

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

Datum head $= x_1$

Pressure head $x = h_A - x_1$

At point B:

Pressure head, $h_B = h_1$

Datum head $= h_2$

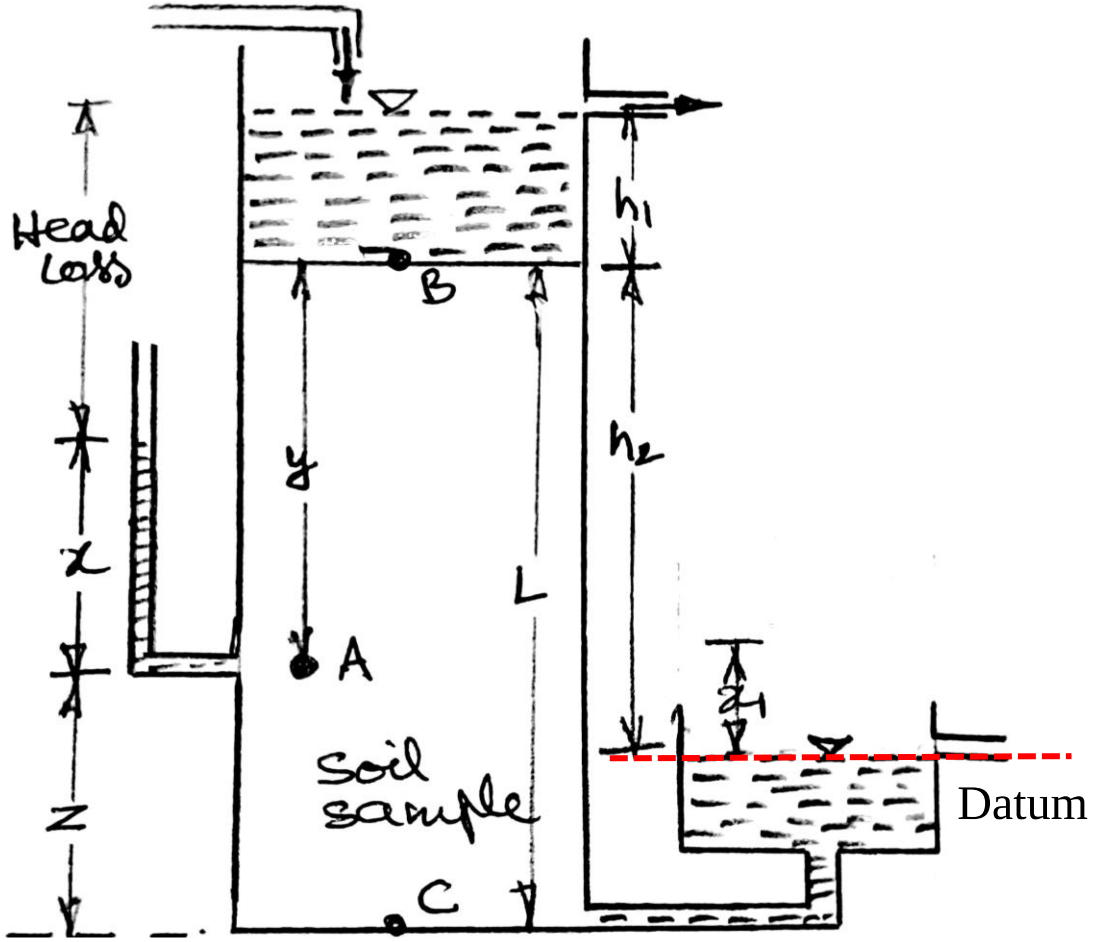
Total head $= h_1 + h_2$

At point C:

Total head, $h_C = 0$

Datum head $= -(z - x_1)$

Pressure head $= 0 - (-(z - x_1)) = +(z - x_1)$



Prof. B. Jayarami Reddy

Upward seepage through soil

At the bottom of the soil A:

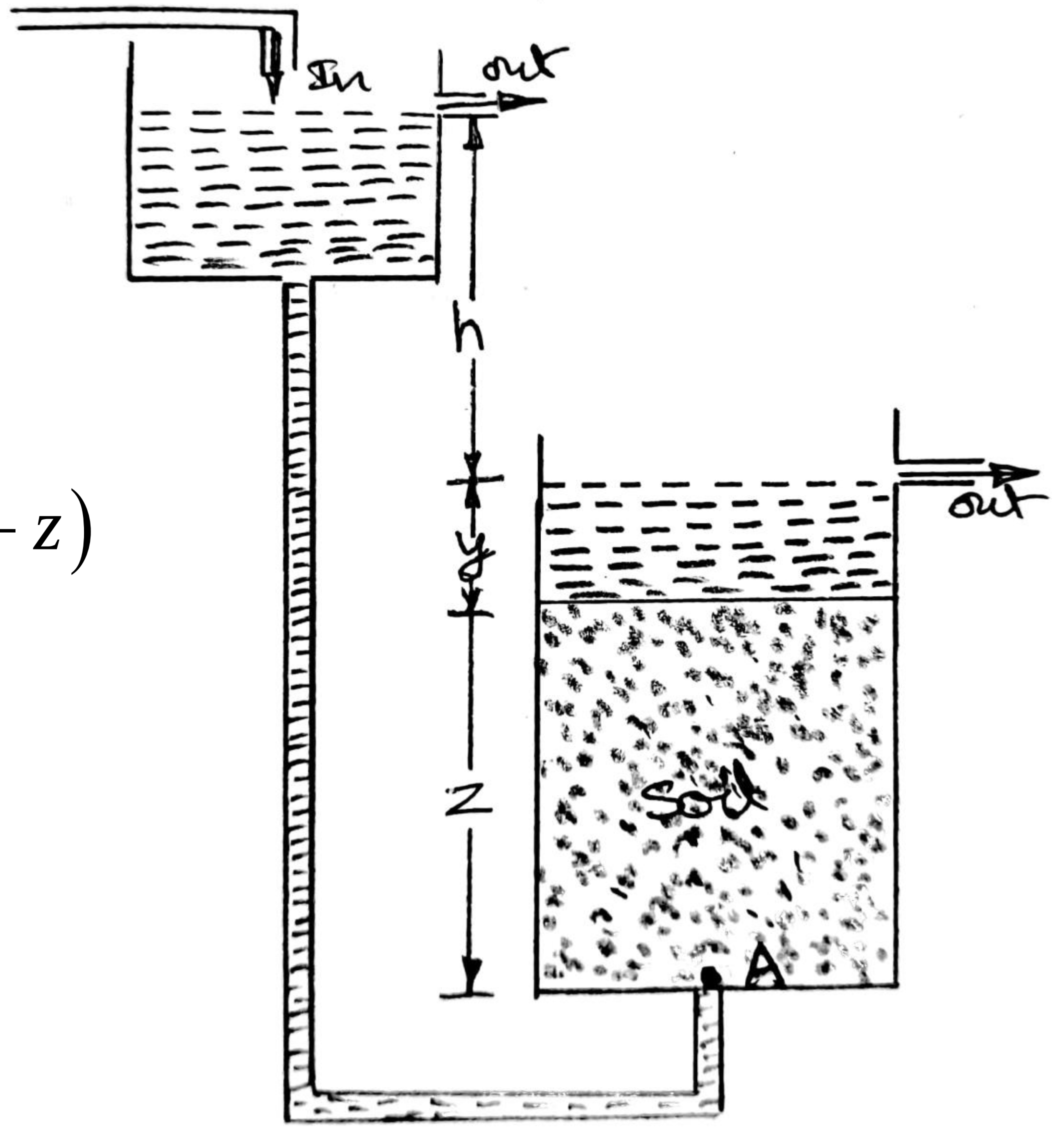
$$\sigma = \gamma_w . y + \gamma_{sat} . z$$

$$u = \gamma_w \left(h + y + z \right)$$

$$\sigma' = \sigma - u = \left(\gamma_w . y + \gamma_{sat} . z \right) - \gamma_w \left(h + y + z \right)$$

$$= \left(\gamma_{sat} - \gamma_w \right) z - \gamma_w . h$$

$$= \gamma' . z - \gamma_w . h$$



Prof. B. Jayarami Reddy

Downward seepage through soil

At the bottom of soil A:

$$\sigma = \gamma_{sat}.z + \gamma_w(y + h)$$

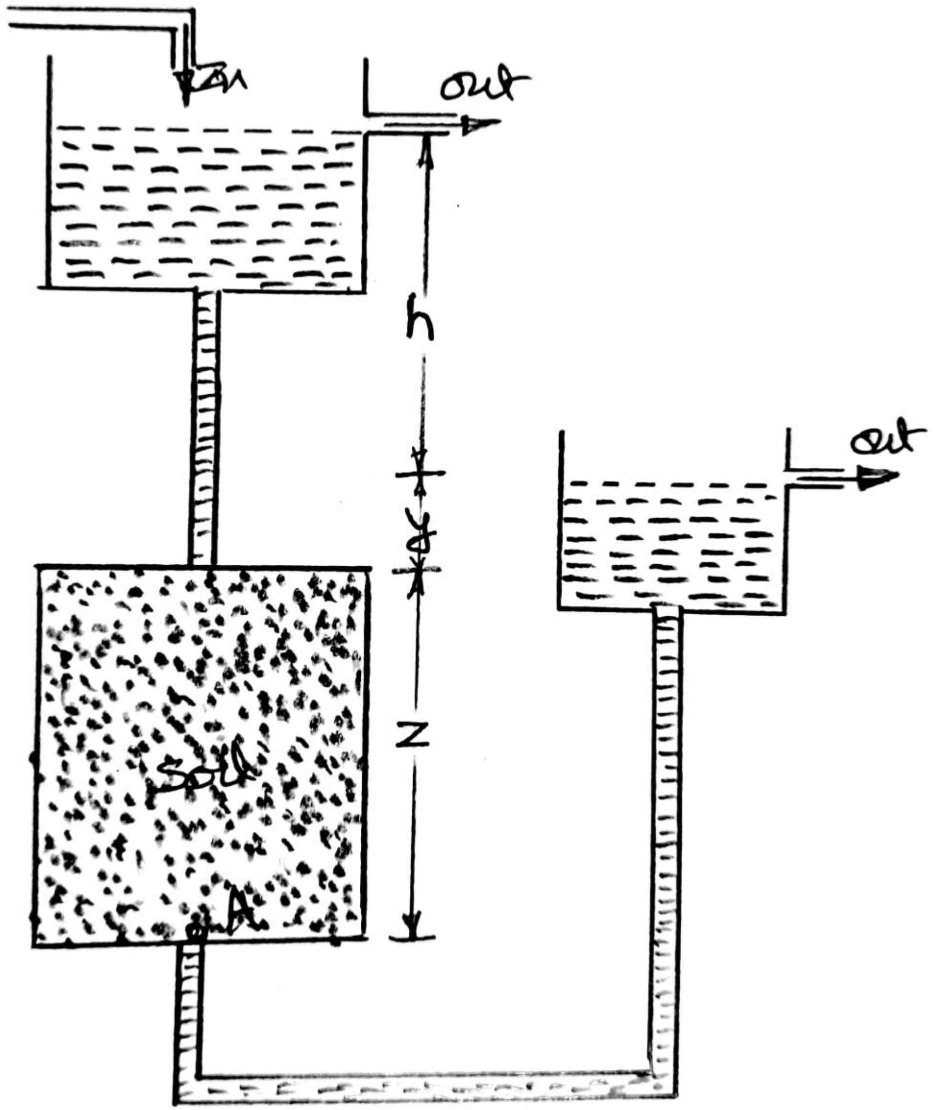
$$u = \gamma_w(y + z)$$

$$\sigma' = \gamma_{sat}.z + \gamma_w(y + h) - \gamma_w(y + z)$$

$$= (\gamma_{sat} - \gamma_w)z + \gamma_w.h = \gamma'.z + \gamma_w.h$$

Hence

$$\sigma' = \gamma'.z \pm \gamma_w.h$$



Prof. B. Jayarami Reddy

$$p_s = \gamma_w . i . z$$

where h : Net head causing flow.

i : Hydraulic gradient.

z : Seepage length

Seepage force = Seepage pressure $\times$ Area

$$= p_s \times A = \gamma_w . i . z . A$$

Seepage force per unit volume = $\dfrac{p_s \times A}{V} = \dfrac{\gamma_w . i . z . A}{z \times A} = \gamma_w . i$

- Seepage pressure always acts in the direction of flow.
- Due to seepage pressure, vertical effective pressure may be increased or decreased based upon direction of flow.
- Effective stress increases if flow is downwards.
- Effective stress decreases if flow is upwards.

Quick Sand Condition:

- Quick sand is a flow condition existing in fine sand or coarse silt.
- When flow takes place in upward direction, the seepage pressure acts in the upward direction and the effective pressure is reduced.
- When the soil pressure and seepage pressure equals, the effective stress reduced to 0.
- Cohesionless soil looses its shear strength and soil particles move in upward direction.
- Quick Condition or Boiling Condition is $\gamma'.z - \gamma_w.h = 0$

Seepage pressure = $i.z.\gamma_w = h.\gamma_w$ Effective pressure = $\gamma' z$

γ' : Submerged weight of soil

γ_w : Unit weight of water

z : Thickness of soil sample

h : Head causing flow.

Prof. B. Jayarami Reddy

$\gamma' z$: Soil pressure

$\gamma_w h$: Seepage pressure at quick condition,

Soil pressure = Seepage pressure

$$\gamma' z = \gamma_w h$$

- Quick Sand is not a type of sand but a flow condition occurring in cohesionless soils.
- In Coarse sand water escapes easily due to high permeability. It requires large heads to make quick condition. But it is not possible in practice.
- The quick condition is most likely to arise in silts and fine sands.
- Quick sand condition does not occur in clay soils as their cohesion holds the grains together even under upward flow at critical hydraulic gradient.

To Prevent quick sand condition:

- Putting some surcharge loads on soil.
- Lowering water table by driving bore holes. Bore holes shall not be completely dewatered.

Critical Hydraulic Gradient line:

- The Hydraulic gradient at the critical condition when the soil particles just begin to move is known as Critical Hydraulic Gradient Line.
- When the exit gradient is equal to or greater than critical hydraulic gradient, the soil is said to be in quick condition.
- Critical hydraulic gradient depends on the specific gravity and void ratio of the soil.
- more common in uniform sands and silts with high void ratios.

$$i_c = \frac{\gamma'}{\gamma_w} = \frac{G-1}{1+e} = (G-1)(1-n)$$

Prof. B. Jayarami Reddy

For value $i_c = 1$, $e = 0.6 - 0.85$ and $G = 2.6 - 2.85$

The critical hydraulic gradient is not affected by depth of water over the soil surface.

Effect of Surcharge on quick condition:

$$\gamma_w h = \gamma'.z + q; \; h = \frac{\gamma'.z + q}{\gamma_w}$$

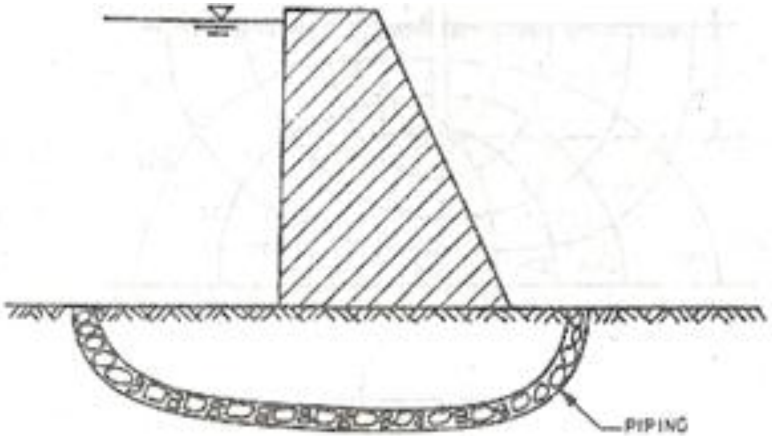
Piping or Undermining:

If seepage takes place through a soil mass below a hydraulic structure, the grains will be lifted by water if effective pressure reduces to 0 and exist gradient is greater than critical hydraulic gradient.

With the removal of the surface soil at the downstream floor there is further concentration of flow into the resulting depression and more soil is removed.

The process of erosion progressively extends backwards towards the upstream side and results in the removal of soil and developing pipe like formation beneath the floor.

The floor may subside in the hollows so formed and fail which is known as failure due to Piping or Undermining.



Backward erosion piping

Prevention:

- Providing sufficient length of the impervious floor so that the path of percolation is increased and exit gradient is reduced.
- Providing piles at the upstream and downstream ends of the impervious floor.
- Providing drainage filter like Graded filter or Inverted filter (Rock toe, Chimney drain etc.)

Factor of safety against piping or quick sand

$$F = \frac{\text{Critical hydraulic gradient}}{\text{Actual or Exit gradient}}$$

Assumptions in Laplace equation for two dimensional flow :

1. Soil mass is homogeneous and isotropic.
2. The soil and water are incompressible.
3. The flow is assumed to be laminar so that Darcy's Law is valid.
4. Quantity of water stored in soil pores is constant so that steady flow conditions established.

Flow of water through soil for a two dimensional flow conditions can be expressed mathematically as

$$k_x.\frac{\partial^2\phi}{\partial x^2}+k_y.\frac{\partial^2\phi}{\partial y^2}=0$$

- For steady flow and isotropic conditions, the above equation reduces to

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$$

- Solutions of this equation gives two sets of curves known as Stream lines and Equipotential lines.

Prof. B. Jayarami Reddy

Seepage Analysis

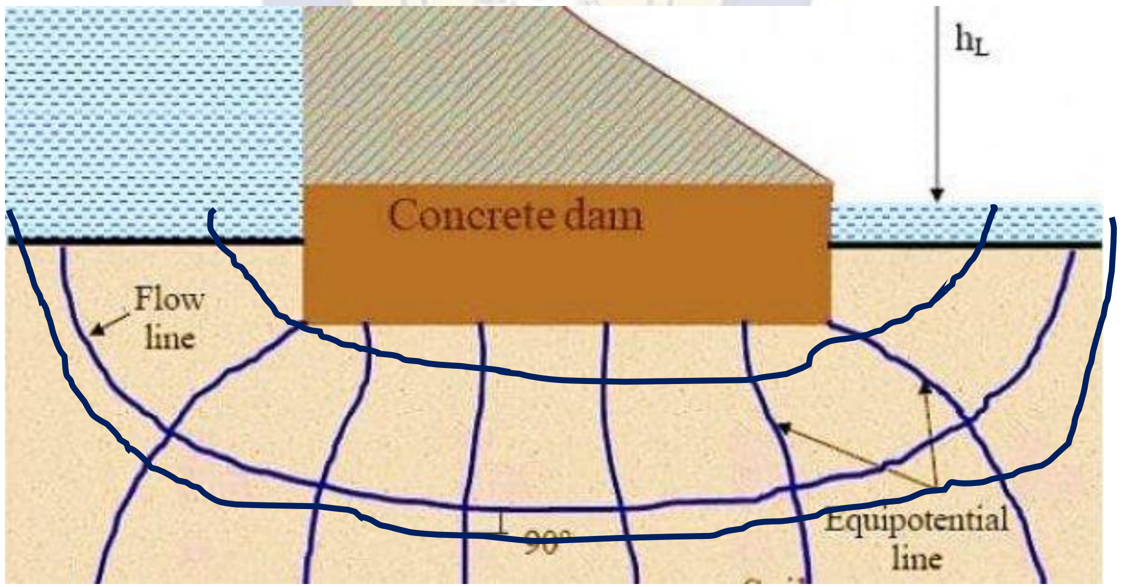
- Percolation of water through the soil pores under an energy gradient is known as seepage.
- The pressure exerted on the soil due to seepage of water is known as seepage force or seepage pressure.
- Seepage problems occur in all earthen dams, retaining walls and foundations on permeable soil.

Flow nets:

- The flow of water through a soil can be represented by a flow net, a form of curvilinear made up of a set of flow lines intersected by a set of equipotential lines.

Flow lines:

- Flow line is the line along which flow takes place.
- Water flows from points of high head to points of low heads and makes smooth curves representing the paths followed by moving particles of water.
- Flow lines are also called as stream lines



Prof. B. Jayarami Reddy

Equipotential line

- Equipotential line is a line joining all the points having equal total heads or potential head
- If piezometers are inserted into the soil at different points along an equipotential line, water would rise to the same elevation in all these piezometers.

Flow path or flow channel

- Flow path or flow channel is the space between two adjacent flow lines
- N_f : Number of flow channels

Field

- Field is the space between any two adjacent flow lines and adjacent equipotential lines

Characteristics of flow net

- Flow lines and equipotential lines are orthogonal (perpendicular) to each other.
- The quantity of seepage in each flow channel is same
- Drop in head between adjacent equipotential lines is same

$$\text{Potential drop} = \frac{\text{Total head loss}}{\text{Number of fields}}$$

- Two flow lines or two equipotential lines can never meet or cross each other.
- Fields are kept approximately squares.
- Smaller the dimension of the field, greater will be the hydraulic gradient and velocity of flow through it.
- In homogeneous soil, every transition in the shape of curves is smooth, being either electrical or parabolic in shape.
- Flow net does not depend on permeability of the soil (k) and head causing flow (h)
- Flow net depends on boundary conditions only.

Uses of flow net:

- To compute seepage quantity or seepage loss
- To compute seepage pressure
- To compute uplift pressure
- To compute exit gradient.

Prof. B. Jayarami Reddy

Seepage Quantity:

$$q = k.h.\frac{N_f}{N_d}$$

k = Permeability of soil

For an isotropic soil $k = \sqrt{k_x.k_y}$

k_x : Permeability in horizontal direction

k_y : Permeability in vertical direction

H : Net head causing flow (difference between u/s and d/s water levels)

N_f : number of flow channels

N_d : the number of potential drops

- The ratio of $\frac{N_f}{N_d}$ is called shape factor of a flow net.

Prof. B. Jayarami Reddy

- For a given boundary conditions, $\frac{N_f}{N_d}$ ratio remains same.
- For a particular set of boundary conditions, the flow net will be unique

Calculation of seepage pressure (p_s) using flow net

The upward Seepage force $= \gamma_w h.A$

Seepage force per unit volume $= \frac{h.\gamma_w.A}{A.L} = i.\gamma_w$

γ_w : Unit weight of water

h_1 : Hydraulic potential or balance hydraulic head after n potential drops

$h_1 = h - n.\Delta h$

h : Head causing flow or difference between u/s and d/s water levels.

Head drop through field, $\Delta h = \frac{h}{N_d}$

Calculation of uplift pressure from flow net:

Uplift pressure at any depth $= \gamma_w . h$

$$h_1 = h - n.\Delta h = h - n.\frac{h}{N_d}$$

n : Number of potential drop up to given point

N_d : Total number of potential drops

h : Head causing flow

γ_w : Unit weight of water

Uplift Pressure:

$$p_w = \gamma_w . h_w$$

h_w : Total head = Elevation head $\pm$ head

Total head, $h = h - n.\Delta h = h - n.\frac{h}{N_d}$

+ sign above datum ; - sign below datum

Prof. B. Jayarami Reddy

Exit Gradient:

$$i_{exit} = \frac{\Delta h}{\Delta L}$$

Head drop per field, $\Delta h = \frac{H}{N_d}$

ΔL : Average length of last field at exit point

- For safety against piping i_{exit} the must always be less than the critical hydraulic gradient (i_c).

Factor of safety against piping, $F = \frac{i_c}{i_{exit}}$

Seepage pressure at a point (p_s)

$$p_s = h.\gamma_w$$

Total head of that point, $h_1 = h - n.\Delta h$

n : Number of potential drops upto the point

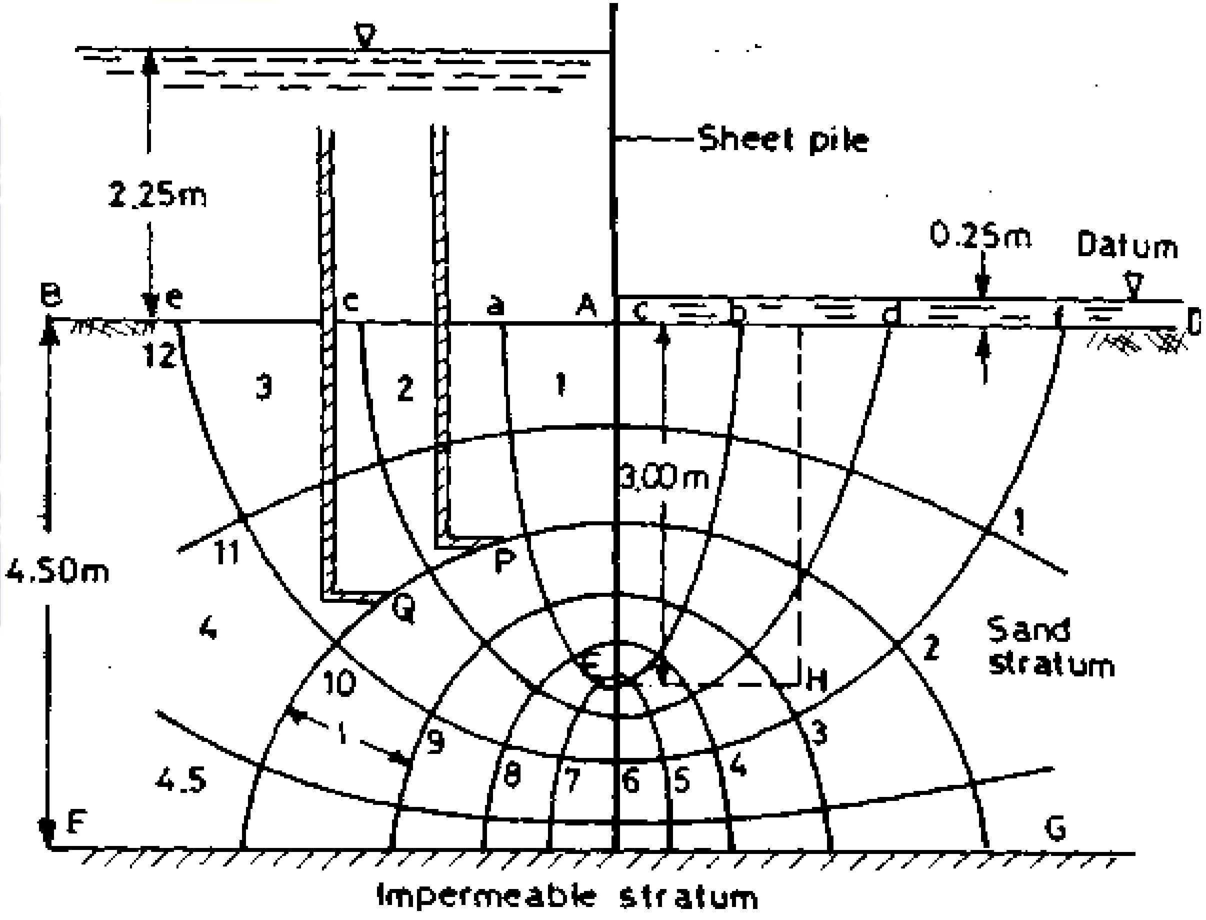
Prof. B. Jayarami Reddy

Potential drop per field, $\Delta h = \dfrac{h}{N_d}$

Hydrostatic pressure a point:

$$h_w = h - z$$
$$h_1 = h - n.\Delta h$$

z : Datum head at that point.



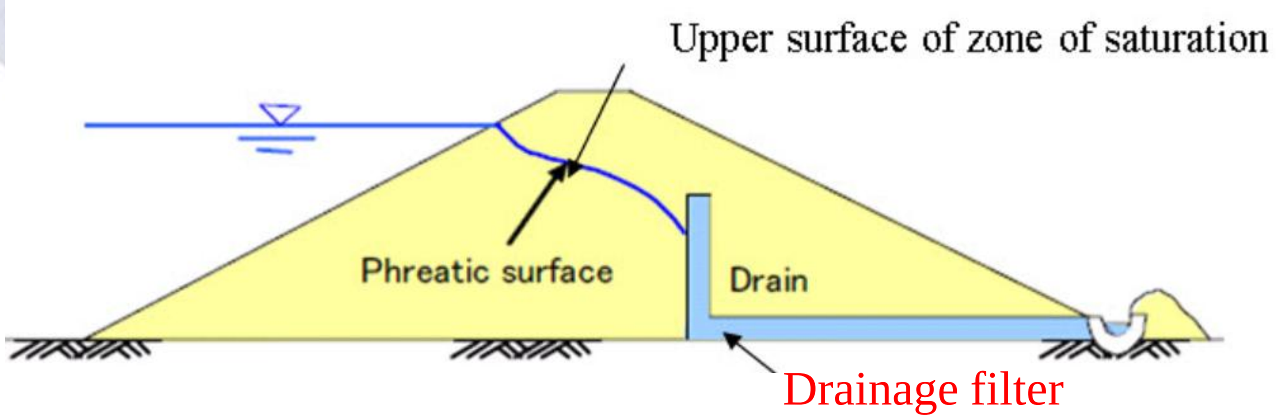
Prof. B. Jayarami Reddy

Phreatic Line:

- Phreatic line is also called as seepage line or top flow line
- Along Phreatic line pressure head is zero. Only atmospheric pressure exists.
- Profile of Phreatic line is in parabolic shape.
- The pressure head at the intersection of the Phreatic line and any equipotential line is 0.
- The head existing on top flow line is Elevation Head (Velocity head neglected, pressure head 0)
- Kozeiny's Solution is used to find seepage through earth dams.

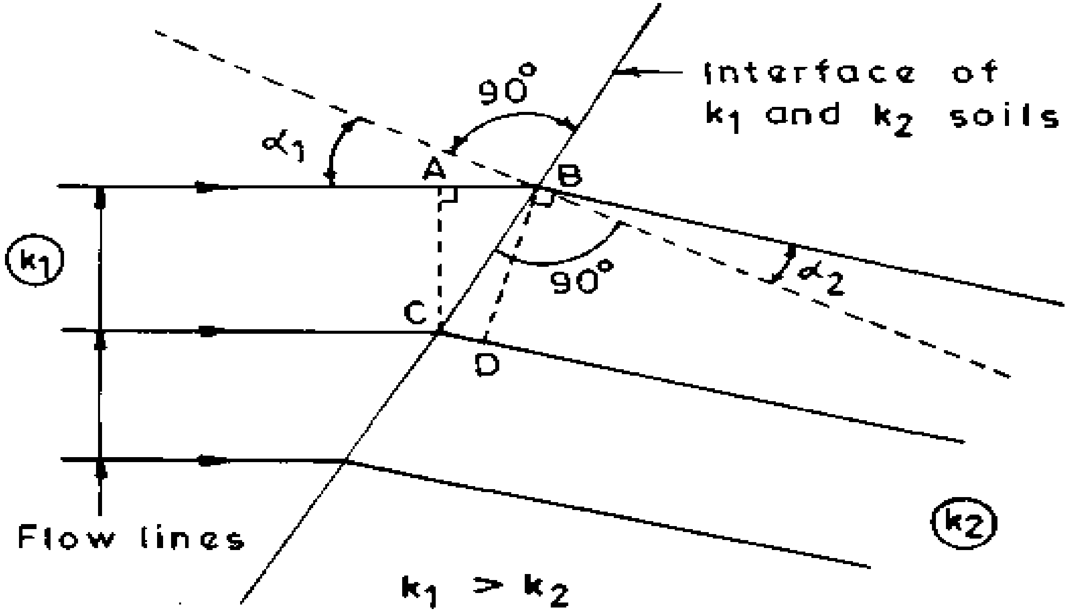
$$q = k.S \qquad S : \text{Focal distance}$$

(i.e. distance between focus and directrix of the parabolic shape phreatic line)



Prof. B. Jayarami Reddy

Seepage in Anisotropic Soils:



Change in direction of flow lines at the interface of two soil layers

$$q = k.h.\frac{N_f}{N_d}$$

k : Equivalent permeability $= \sqrt{k_x . k_y}$

k_x: Permeability in horizontal direction

k_y : Permeability in vertical direction

Prof. B. Jayarami Reddy

- Flow lines and equipotential lines get deflected at the interface between two dissimilar soils, when they pass from one soil to other.

$$\frac{\tan \alpha_1}{\tan \alpha_2} = \frac{k_1}{k_2}$$

Prof. B. Jayarami Reddy

Seepage Analysis

Numerical Questions

Prof. B. Jayarami Reddy

SEEPAGE ANALYSIS

01. If the specific gravity and void ratio of the coarse grained soil deposit are 2.67 and 0.7 respectively, then the critical hydraulic gradient is

a. 0.64 b. 0.96 **c.** 0.98 d. 1.0

Ans. c

Specific gravity of soil, $G = 2.67$

Void ratio, $e = 0.7$

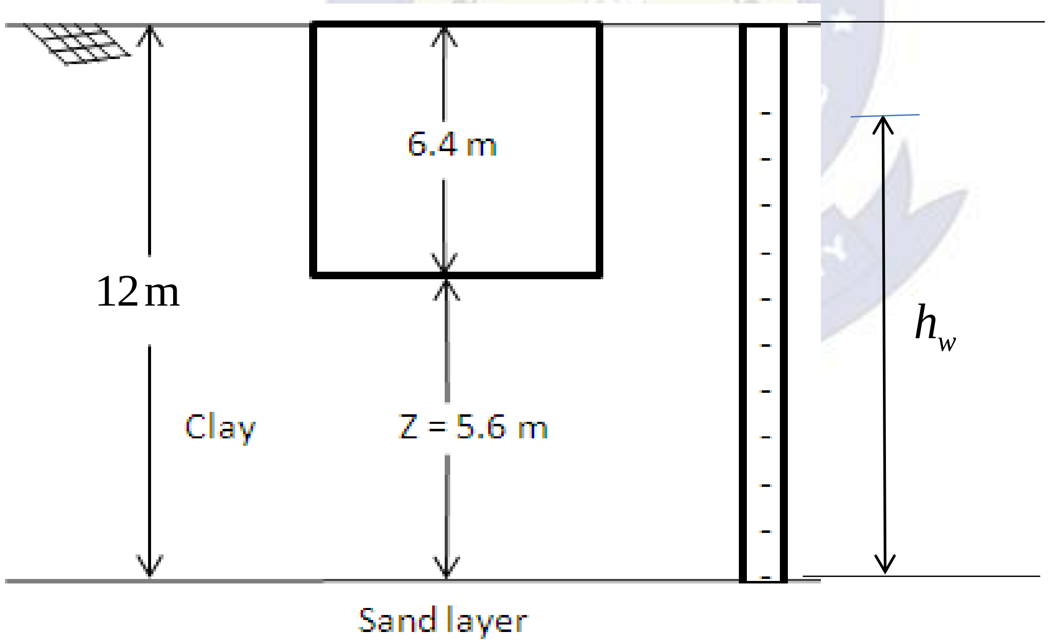
Critical hydraulic gradient, $i_c = \frac{G-1}{1+e} = \frac{2.67-0.7}{1+0.7} = 0.98$

Prof. B. Jayarami Reddy

02. A stiff clay stratum extended upto a depth of 12m below ground level with a saturated unit weight of 17.6 kN/m^3 and was underlain by a sand stratum. An excavation is carried out in a clay and when the depth of excavation reached 6.4 m, the bottom of the pit started rising, cracked and a mixture of soil and water was flowing out of the cracks. If the bore hole is made prior to excavation, the height to which the water would have rised above the surface of the sand stratum is

a. 5.6 m b. 6.4 m c. 7.2 m **d.** 9.86 m

Ans. d

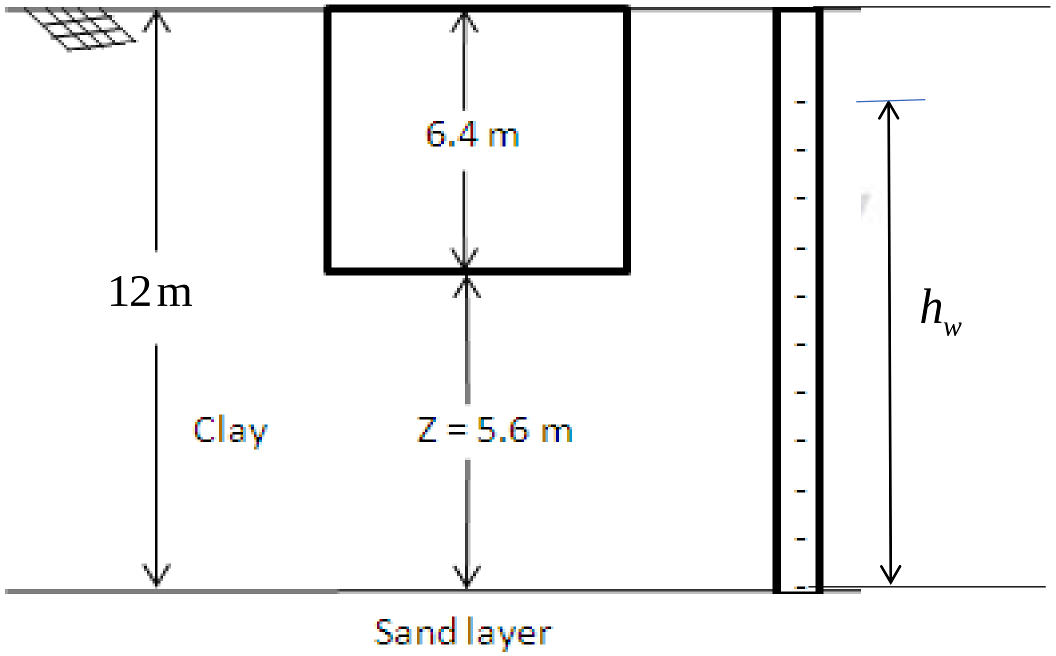


Prof. B. Jayarami Reddy

Let h_w: height to which water will have risen in bore hole, above surface of sand stratum, prior to excavation.

Quick sand condition occurs at the surface of the clay stratum when effective stress becomes zero at that level.

$$\sigma' = \gamma_{sat}.z - \gamma_w.h_w = 0 \Rightarrow h_w = \frac{\gamma_{sat}.z}{\gamma_w} = \frac{17.6 \times 5.6}{10} = 9.86 \text{ m}$$



Prof. B. Jayarami Reddy

03. A cylindrical mould of diameter 10 cm contains 15 cm long soil sample having coefficient of permeability 1×10^{-3} cm/sec with void ratio of 0.7 and specific gravity of 2.70. If water is made to flow through soil sample in upward direction and the rate of discharge is 0.05 ml/sec, the effective stress at the middle of sample is

a. 0 **b.** 0.27 kN/m^2 c. 0.54 kN/m^2 d. 0.75 kN/m^2

Ans. b

Diameter of the soil sample, d = 10 cm

Length of the soil sample, L = 15 cm

Coefficient of permeability, k = 1×10^{-3} cm/sec.

Void ratio, e = 0.7

Specific gravity of soil, G = 2.70

Discharge, q = 0.05 ml/sec = 0.05 cm^3/sec

$$\text{Cross sectional area} = \frac{\pi}{4}(10)^2 = 78.54\,\text{cm}^2$$

Prof. B. Jayarami Reddy

$$q = k.i.A \Rightarrow i = \frac{q}{k.A} = \frac{0.05}{1\times10^{-3}\times78.54} = 0.64$$

When the flow of water is in upward direction, the effective stress at a point is given by $\sigma' = \gamma' z - p_s = \gamma' z - iz\gamma_w$

$$\gamma' = \left(\frac{G-1}{1+e}\right)\gamma_w = \left(\frac{2.70-1}{1+0.7}\right)\times10 = 10\ \text{kN/m}^3$$

Effective stress at the middle of sample

$$\sigma' = 10\times0.075 - 0.64\times0.075\times10 = 0.27\,\text{kN/m}^2$$

Prof. B. Jayarami Reddy

04. A soil sample is placed in a permeameter and water is allowed to flow under a constant head as shown in fig. If 50% of the total head causing flow is lost as water flows through lower layer of soil, the pressure head, datum head and total head respectively at point C are

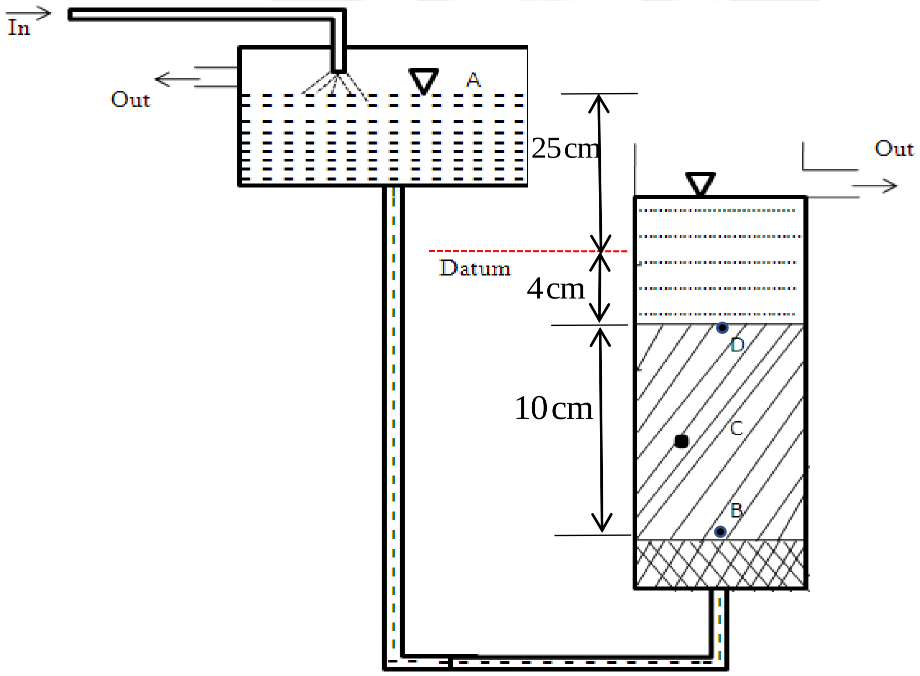
a. 34 cm, 9 cm, 25 cm

b. 25 cm, 0, 25 cm

c. 21.5 cm,-9 cm, 12.5 cm

d. 12.5 cm, 9 cm, 21.5 cm.

Ans. c



Prof. B. Jayarami Reddy

04. Ans. c

At A, $h_w = 0$

$z = 25cm$

$h = h_w + z = 25cm$

At B, h_w = 10 + 4 + 25 = 39 cm

z = -14 cm

h = 39 – 14 = 25 cm.

At C, h = 25 – 0.5 × 25 = 12.5 cm

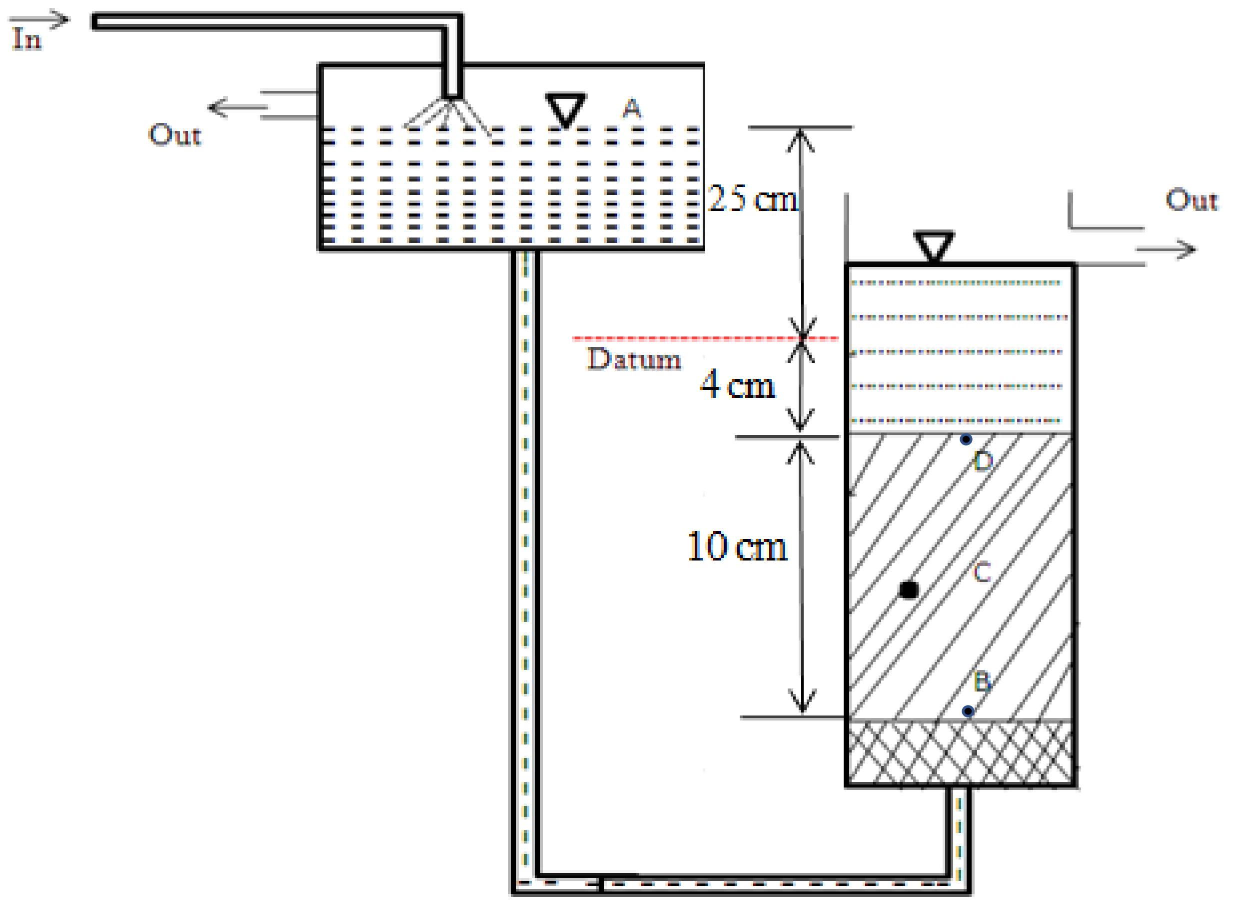
z = -(4+5) = -9 cm

h_w = 12.5 – (-9) = 21.5 cm.

At D, $h = 0$

z = - 4 cm

$h_w = h - z$ = 0 – (- 4) = 4 cm.



Prof. B. Jayarami Reddy

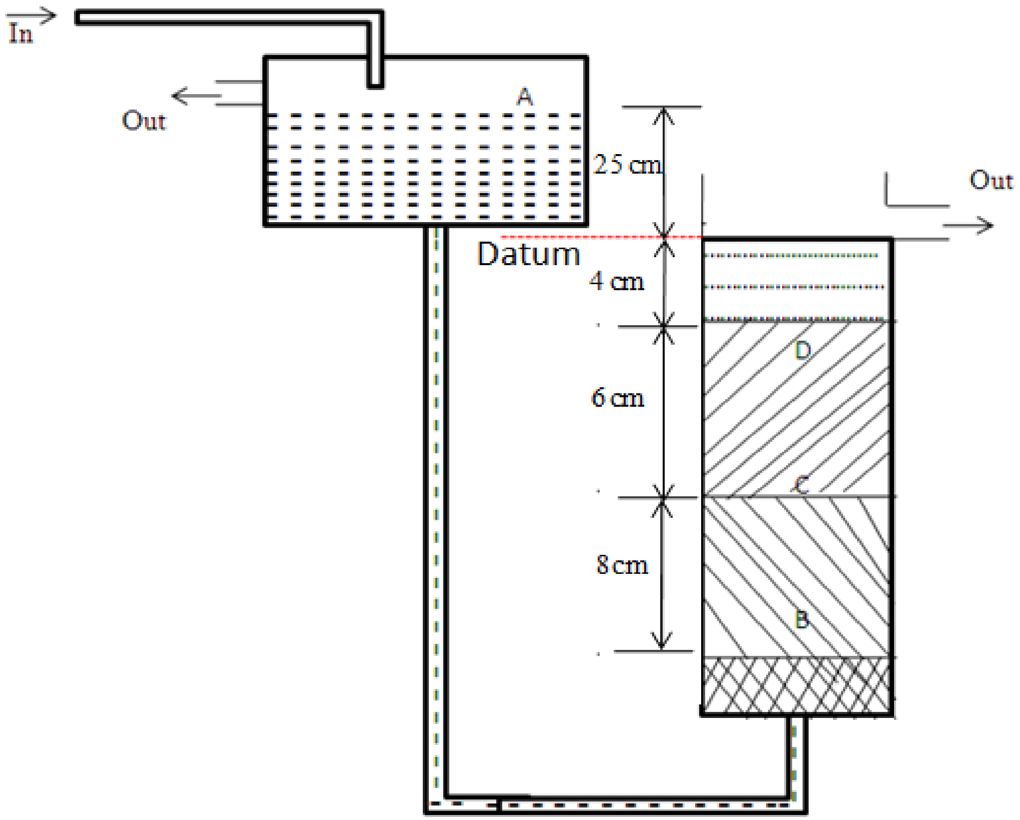
05. Two different types of soil are placed in a permeameter and water is allowed to flow under a constant head as shown in fig. If 60% of the total head causing flow is lost as water flows through lower layer of soil, the pressure head, datum head and total head respectively at point C are

a. 20 cm, -10 cm, 10 cm

b. 10 cm, -10 cm, 20 cm

c. 20 cm, 10 cm, 10 cm

d. 10 cm, 10 cm, 20 cm.



Ans. a

Prof. B. Jayarami Reddy

05 Ans. a

At A, $h_w = 0$

$z = 25cm$

$h = h_w + z = 25cm$

At B, h_w = 8 + 6 + 4 + 25 = 43 cm

z = -18 cm

h = 43 – 18 = 25 cm.

At C, h = 25 – 0.6 × 25 = 10 cm

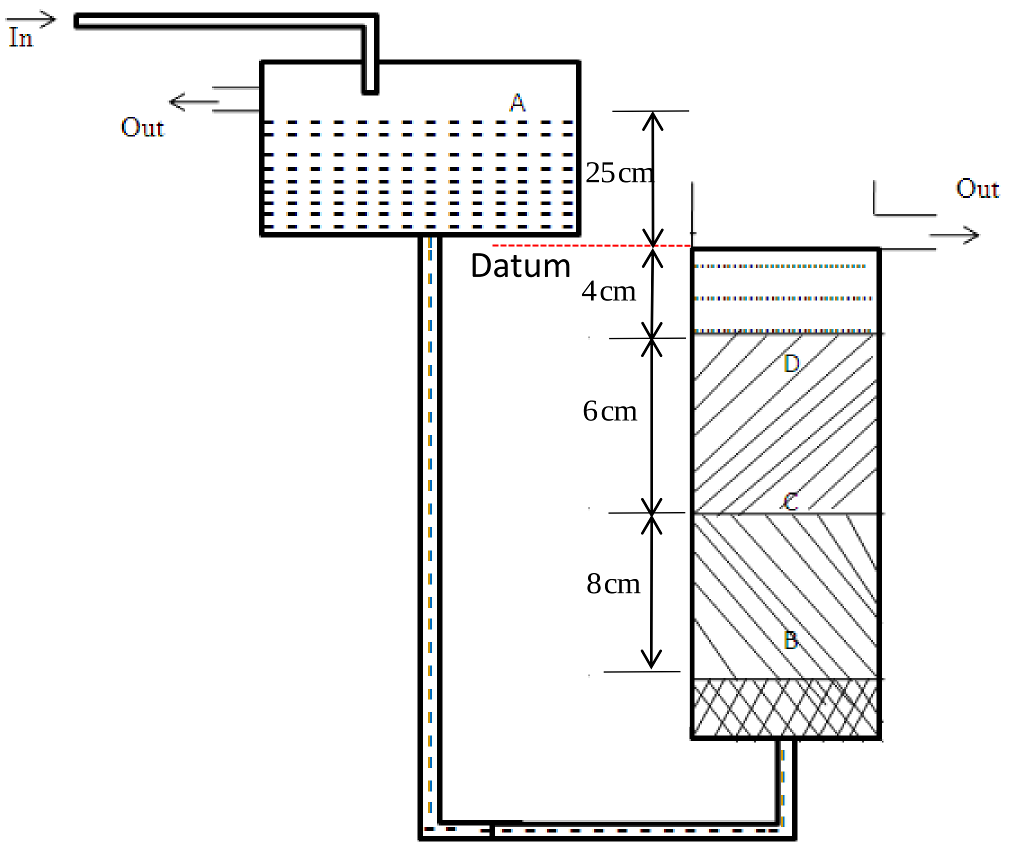
z = -(4+6) = -10 cm

h_w = 10 – (-10) = 20 cm.

At D, $h = 0$

z = - 4 cm

$h_w = h - z$ = 0 – (- 4) = 4 cm.



Prof. B. Jayarami Reddy

06. A soil sample is placed in a permeameter mould having cross sectional area $50\ cm^2$ and water is allowed to flow under a constant head as shown in fig. If the coefficient of permeability of soil is 2×10^{-3} cm/sec, the rate of discharge is

a. $2.5\ cm^3/sec$. **b.** $0.25\ cm^3/sec$ c. $3.9\ cm^3/sec$ d. $0.39\ cm^3/sec$

Ans. b

Total head at B = 25 cm

Total head at C = 0

Head lost during flow through soil

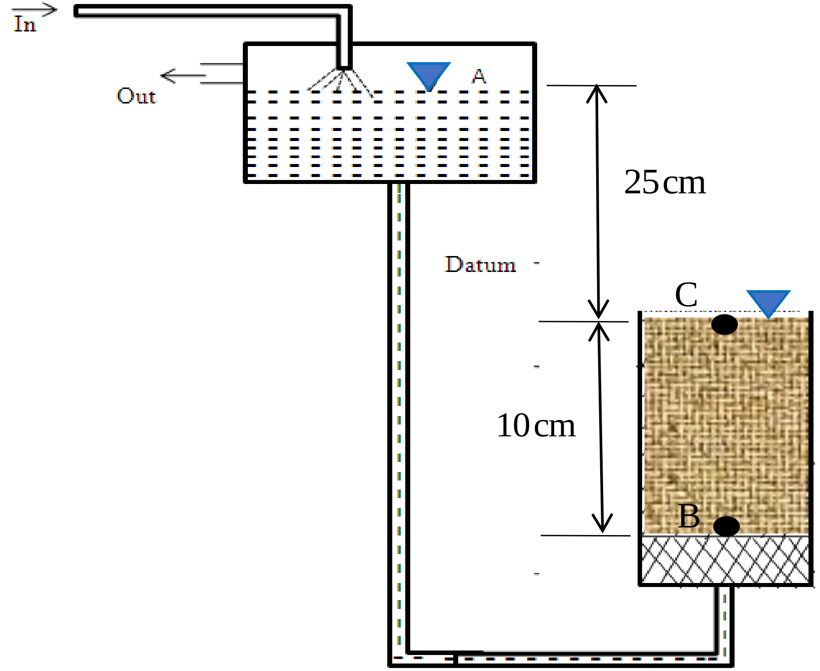
$$h = 25 - 0 = 25 \text{ cm.}$$

Length of sample, $L = 10$ cm

Hydraulic gradient, $i = \frac{h}{L} = \frac{25}{10} = 2.5$

Rate of discharge, $q = kiA = 2\times10^{-3}\times2.5\times50$

$= 0.25\ cm^3/sec.$



Prof. B. Jayarami Reddy

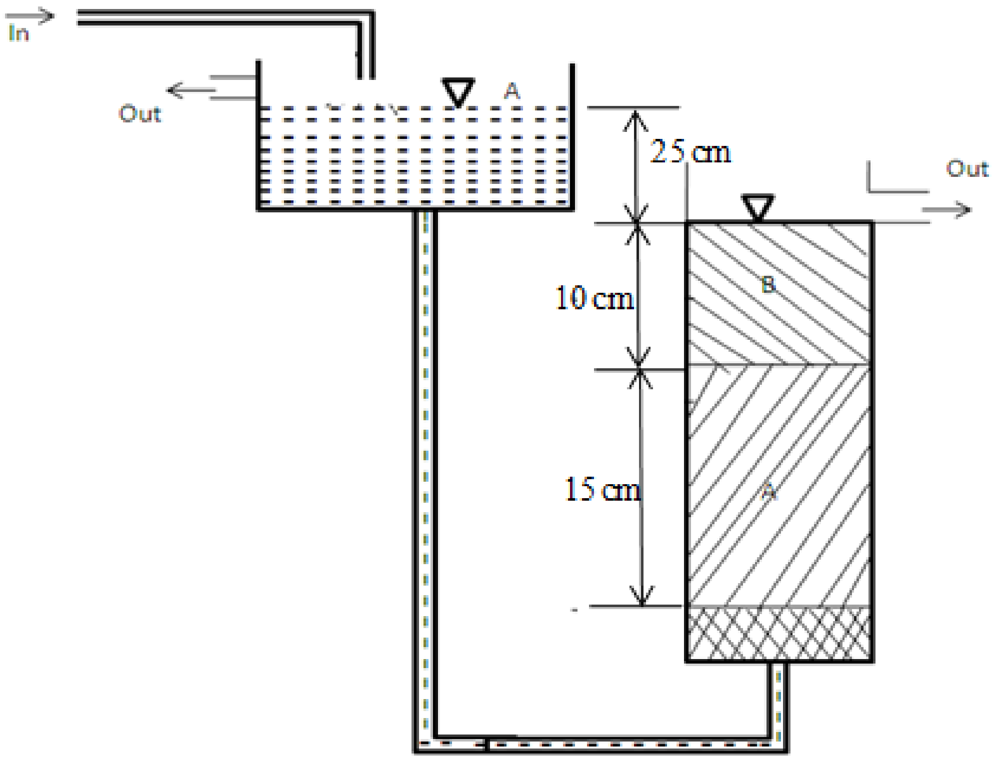
07. Two different types of soil A and B are placed in a permeameter mould having cross sectional area 50 cm^2 and water is allowed to flow through them under a head of 25 cm as shown in fig. If the permeability of soil A is 2×10^{-3} cm/sec and 40% of total head causing flow is lost during flow through the layer of soil A, then the coefficient of permeability of soil B is

a. 8.93×10^{-3} cm/sec

b. 3.0×10^{-3} cm/sec.

c. 2.86×10^{-3} cm/sec.

d. 1.33×10^{-3} cm/sec.



Prof. B. Jayarami Reddy

07 Ans. a

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

Coefficient of permeability of soil A, $k_A = 2\times10^{-3}$ cm/sec.

Total head at bottom of soil A = 25 cm.

Head lost during flow through soil A = 0.4×25 = 10 cm.

Hydraulic gradient, $i = \frac{h}{L} = \frac{10}{15} = 0.67$

Rate of discharge though soil A, $q = kiA$

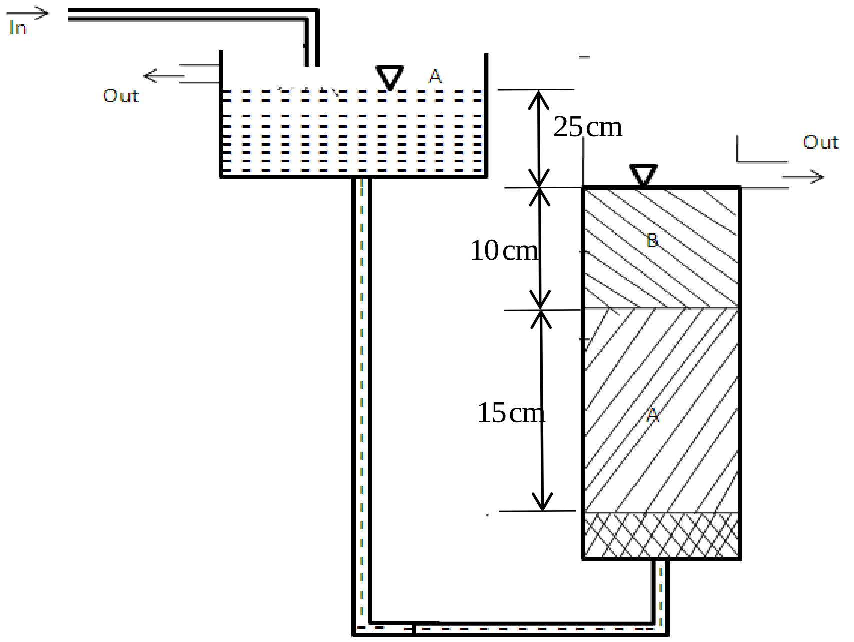
$= 2 \times 10^{-3} \times 0.67 \times 50 = 0.67\ cm^3/sec.$

Head lost during flow through soil B = 0.6 × 25 = 15 cm

Hydraulic gradient, $i = \frac{h}{L} = \frac{15}{10} = 1.5$ $k_B = \frac{q}{i.A}$

Coefficient of permeability of soil B,

$$k_B = \frac{0.67}{1.5\times50} = 8.93\times10^{-3} \text{cm/sec}$$



Prof. B. Jayarami Reddy

08. Two different types of soil A and B are placed in a permeameter mould having cross sectional area 100 cm^2 and water is allowed to flow through them under a constant head of 30 cm. The thickness of soil A and soil B are 20 cm and 15 cm respectively. The void ratio and specific gravity of soil A are 0.6 and 2.76 and that of soil B are 0.8 and 2.62 respectively. It is found that 60% of the total head causing flow is lost during flow through the soil A. The total head either of the soil will be under quick condition is .

a. 30 cm **b.** 33.75 cm c. 36.67 cm d. 45 cm

Ans. b

Critical hydraulic gradient, $i_c = \frac{G-1}{1+e}$

For soil A, G = 2.76 e = 0.6 z = 10 cm $i_A = \frac{2.76-1}{1+0.6} = 1.1$

For soil B, G = 2.62 e = 0.8 z = 15 cm $i_B = \frac{2.62-1}{1+0.8} = 0.9$

Prof. B. Jayarami Reddy

Head lost in soil A $= i_A . z = 0.6h$

$$1.1 \times 20 = 0.6h$$

$$h = 36.67 \text{ cm}$$

Head lost in soil B $= i_B . z = 0.4h$

$$0.9 \times 15 = 0.4h$$

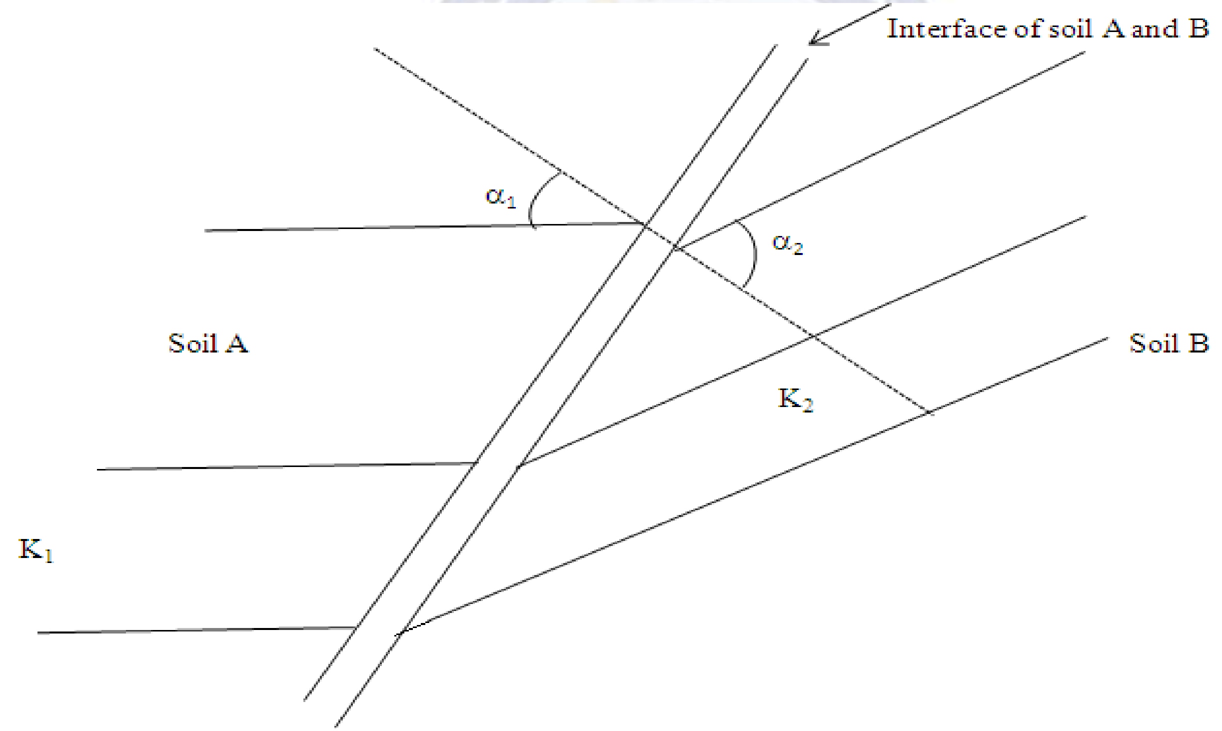
$$h = 33.75 \text{ cm}$$

$\therefore$ Quick sand occurs in soil B when total hydraulic head reaches 33.75 cm.

13. Flow takes place through a non-homogeneous deposit from zone A to zone B. The coefficient of permeability of zone A is 1×10^{-6} m/sec and that of zone B is 4×10^{-6} m/sec. If the angle of incidence is 30°, then the angle of deflection with respect to normal to interface is

a. $70^0 58'$ b. $19^0 2'$ c. $8^0 4'$ d. $81^0 56'$

Ans. a



Prof. B. Jayarami Reddy

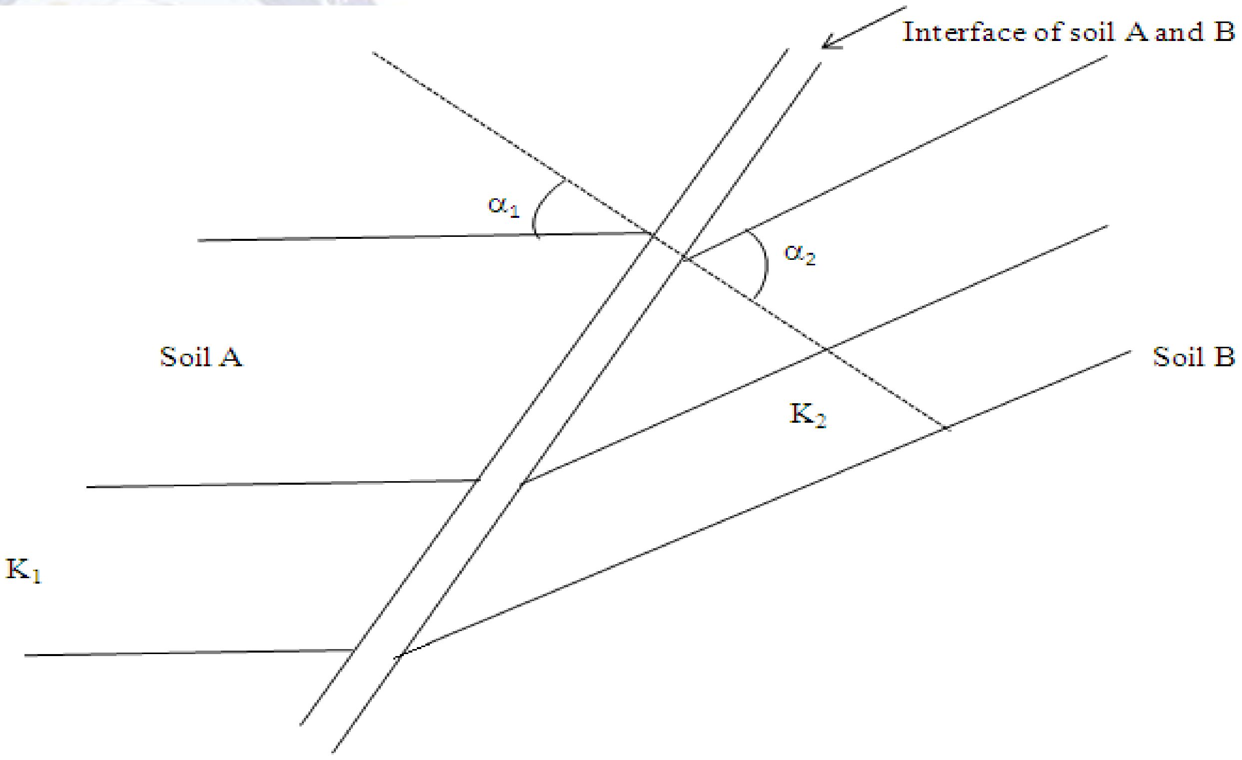
Deflection of flow lines at interface between two soils with different permeabilities.

For soil A, $k_1 = 1\times10^{-6}$ m/sec , $\alpha_1 = 30^0$

For soil B, $k_2 = 4\times10^{-6}$ m/sec , $\alpha_2 = ?$

$$\frac{\mathrm{Tan}\,\alpha_1}{\mathrm{Tan}\,\alpha_2} = \frac{k_1}{k_2} \Rightarrow \frac{\mathrm{Tan}\,30^\circ}{\mathrm{Tan}\,\alpha_2} = \frac{1\times10^{-6}}{4\times10^{-6}}$$

$$\alpha_2 = 70^0 58'$$



Prof. B. Jayarami Reddy

14. A dam is located over anisotropic soil having coefficient of permeability of 8×10^{-6}m/sec in horizontal direction and 2×10^{-6} m/sec in vertical direction. The flow net drawn has 6 numbers of flow channels and 12 numbers of equipotential drops. If the head causing flow is 16 m, the quantity of seepage through the dam in 10^{-6} m^3/sec/m run is

a. 2 b. 8 b. 16 **d.** 32

Ans. d

Horizontal permeability of soil, $k_x = 8\times10^{-6}$ m/sec.

Vertical permeability of soil, $k_y = 2\times10^{-6}$ m/sec.

Number of flow channels, $N_f = 6$

Number of equipotential drops, $N_d = 12$

Prof. B. Jayarami Reddy

Head causing flow, $h = 16$ m

Quantity of seepage through the dam

$$q = \sqrt{k_x k_y}.h.\frac{N_f}{N_d}$$

$$q = \sqrt{8\times10^{-6}\times2\times10^{-6}}\times16\times\frac{6}{12} = 32\times10^{-6}\ \text{m}^3\text{/sec/m run}$$

15. The discharge through a pervious soil under the weir section is 264 cm^3/day. The flow net shows 4 flow channels and 12 equipotential drops. If the head causing flow is 4.0 m, then the coefficient of permeability of soil is

a. 22.9×10^{-4} m/sec.
b. 22.9×10^{-4} cm/sec.
c. 198 m/day
d. 1.98×10^{-2} m/sec.

Ans. b

Quantity of seepage through soil, q = 264 cm^3/day

Number of flow channels, $N_f = 4$

Number of potential drops, $N_d = 12$

Head causing flow, h = 4 m

Coefficient of permeability of soil = k

$$q = k.h.\frac{N_f}{N_d} \Rightarrow 264 = k \times 400 \times \frac{4}{12} \Rightarrow k = 1.98 \text{ cm/day} = 22.9 \times 10^{-4} \text{ cm/sec.}$$

Prof. B. Jayarami Reddy

16. A flow net shows 12 equipotential drops and the approximate size of each field is 0.50 m. If the head causing the flow in a saturated medium is 4 m, then the hydraulic gradient across each field is …………

Prof. B. Jayarami Reddy

Seepage Analysis

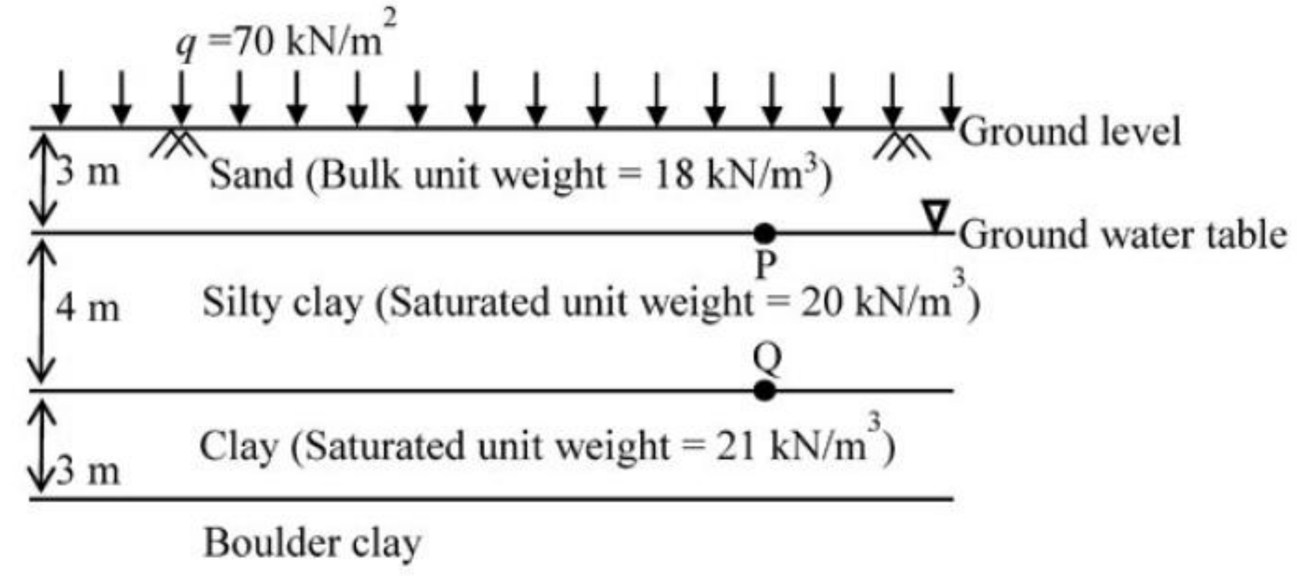
Previous GATE Questions

Prof. B. Jayarami Reddy

1. The soil profile at a site up to a depth of 10 m is shown in the figure (not drawn to the scale). The soil is preloaded with a uniform surcharge (q) of 70 kN/m^2 at the ground level. The water table is at a depth of 3 m below ground level. The soil unit weight of the respective layers is shown in the figure. Consider unit weight of water as 9.81 kN/m^3 and assume that the surcharge (q) is applied instantaneously. Immediately after preloading, the effective stresses (in kPa) at points P and Q, respectively, are GATE CE 2020

a. 124 and 204 b. 36 and 90 c. 36 and 126 d. 54 and 95

Ans.d



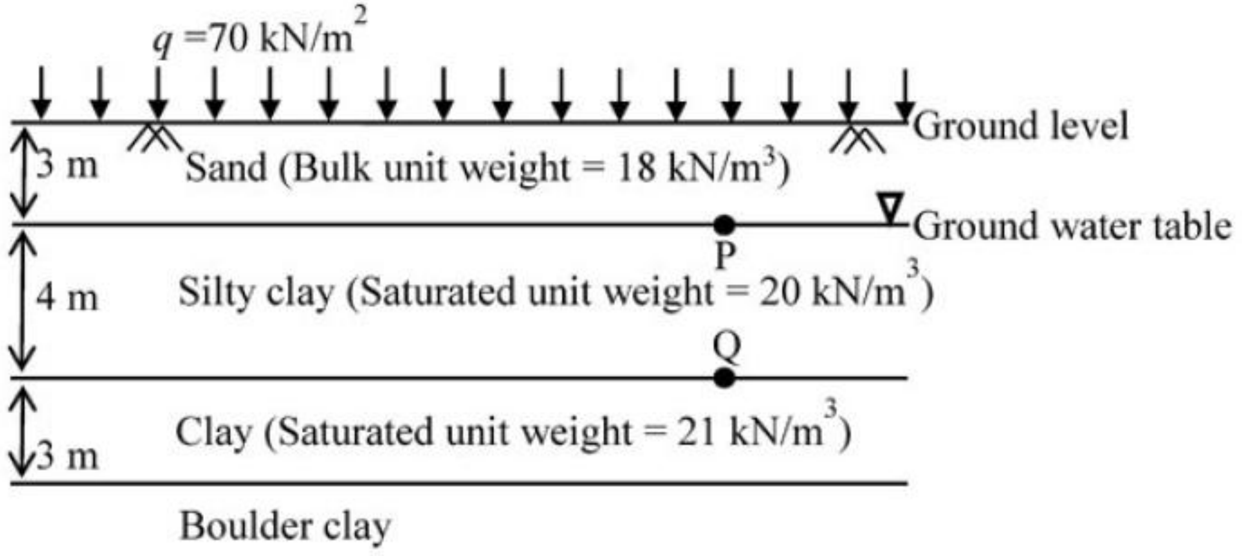
Prof. B. Jayarami Reddy

1 Ans.d

Immediately after the application of surcharge load at the ground level, the effective stress does not change as the load does not get transferred to the soil grains. Hence effective stress at point P and Q immediately after the application of surcharge load remains the same as that before the load application.

Effective stress at P, $= 3 \times 18 = 54$kN/

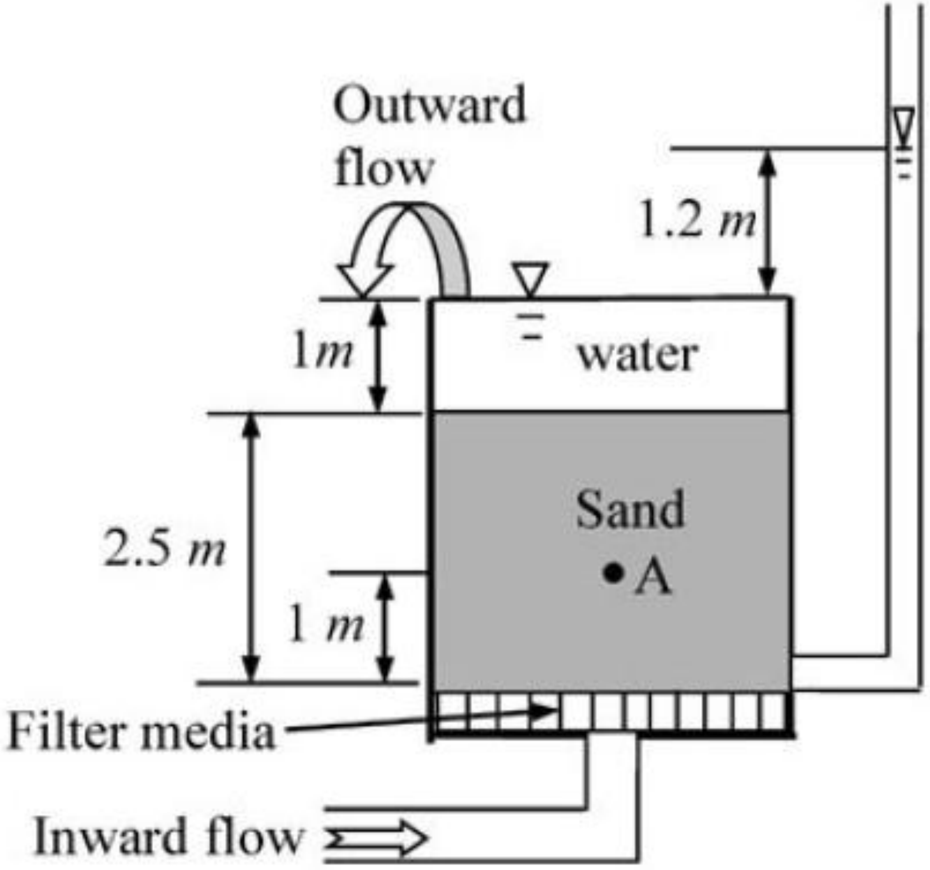
Effective stress at Q, $= 3 \times 18 + 4(20-.81) = 94.76$ kN/



Prof. B. Jayarami Reddy

2.Water flows in the upward direction in a tank through 2.5 m thick sand layer as shown in the figure. The void ratio and specific gravity of sand are 0.58 and 2.7, respectively. The sand is fully saturated. Unit weight of water is 10 kN/m^3.

The effective stress (in kPa, round off to two decimal places) at point A, located 1 m above the base of tank, is ….



Ans. 8.94

Void ratio, e = 0.58

Specific gravity, G =2.7

Unit weight of water, $\gamma_w = 10 kN/m^3$

$$\gamma_{sub} = \left(\frac{G-1}{1+e}\right)\gamma_w = \left(\frac{2.7-1}{1+0.58}\right)10 = 10.76 \text{ kN/m}^3$$

Effective stress at A, $\overline{\sigma_A} = r^1 h - i.h.\gamma_w$

$$\overline{\sigma_A} = 10.76 \times 1.5 - \frac{1.2}{2.5} \times 1.5 \times 10 = 8.94 kN/m^2$$

Prof. B. Jayarami Reddy

(OR)

$$\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w = \left(\frac{2.7+0.58}{1+0.58}\right)10 = 20.76\ \text{KN/m}^3$$

Total stress at A, $\sigma_A = \gamma_w h_1 + \gamma_{sat} h_2 = 10\times1+20.76\times1.5 = 41.14\ \text{kN/m}^2$

Total head loss in sand = 1.2 m

Head loss up to point $A = \frac{1.2}{2.5}\times1$

Pore water pressure at A, $\sigma_{uA} = \left(3.7-\frac{1.2}{2.5}\right)\times10 = 32.2\ \text{kN/m}^2$

Effective stress at A, $\overline{\sigma_A} = \sigma_A - \sigma_{uA} = 41.14-32.2 = 8.94\ \text{kN/m}^2$

03. In a soil specimen, the total stress, effective stress, hydraulic gradient and critical hydraulic gradient are σ, σ', i and i_c , respectively. For initiation of quicksand condition, which one of the following statements is true? CE 2019

a. $\sigma' \neq 0$ and $i = i_c$

b. $\sigma' = 0$ and $i = i_c$

c. $\sigma' \neq 0$ and $i \neq i_c$

d. $\sigma = 0$ and $i = i_c$

Ans.b

In the case of upward seepage, quick sand condition occurs when the seepage force becomes equal to the buoyant weight of the soil ie., effective stress in the soil becomes equal to zero.

$$\gamma'.z - \gamma_w.h = 0 \Rightarrow \gamma'.z = i.z.\gamma_w \Rightarrow \gamma' = i\gamma_w$$

$$i = \frac{\gamma'}{\gamma_w} \Rightarrow i = i_c$$

For quick sand condition to occur, $\sigma = 0$ and $i = i_c$

Prof. B. Jayarami Reddy

04. A flownet below a dam consists of 24 equipotential drops and 7 flow channels. The difference between the upstream and downstream water levels is 6 m. The length of the flow line adjacent to the toe of the dam at exit is 1 m. The specific gravity and void ratio of the soil below the dam are 2.70 and 0.70, respectively. The factor of safety against piping is CE2 2018

a. 1.67 b. 2.5 c. 3.4 **d.** 4

Ans. d

Number of equipotential drops, $N_d = 24$

Number of flow channels, $N_f = 7$

Head causing flow, $h = 6\text{m}$

Length of flow line adjacent to the toe of the dam exit, $\Delta L = 1\text{m}$

Specific gravity of soil, $G = 2.70$

Prof. B. Jayarami Reddy

Void ratio of soil, $e = 0.70$

Factor of safety against piping, $F = ?$

Critical hydraulic gradient, $i_c = \frac{G-1}{1+e} = \frac{2.70-1}{1+0.70} = \frac{1.70}{1.70} = 1$

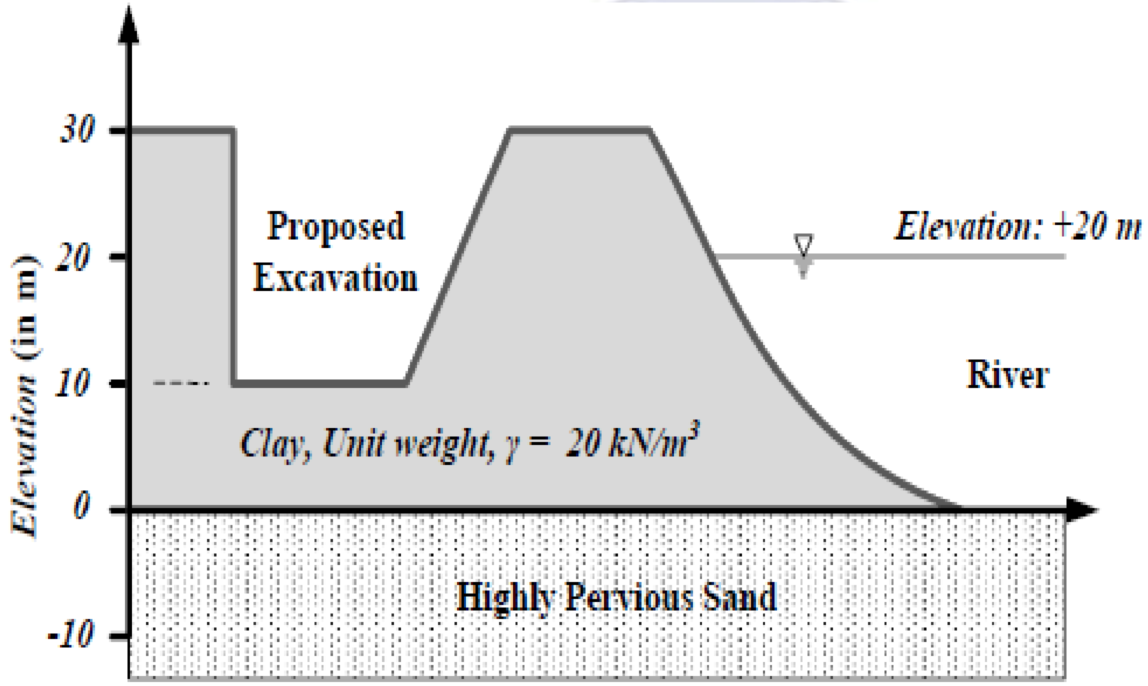
Loss of head per drop, $\Delta h = \frac{h}{N_d} = \frac{6}{24} = \frac{1}{4}$

Exit gradient, $i_e = \frac{\Delta h}{\Delta L} = \frac{1/4}{1} = \frac{1}{4}$

$$F = \frac{i_c}{i_e} = \frac{1}{1/4} = 4$$

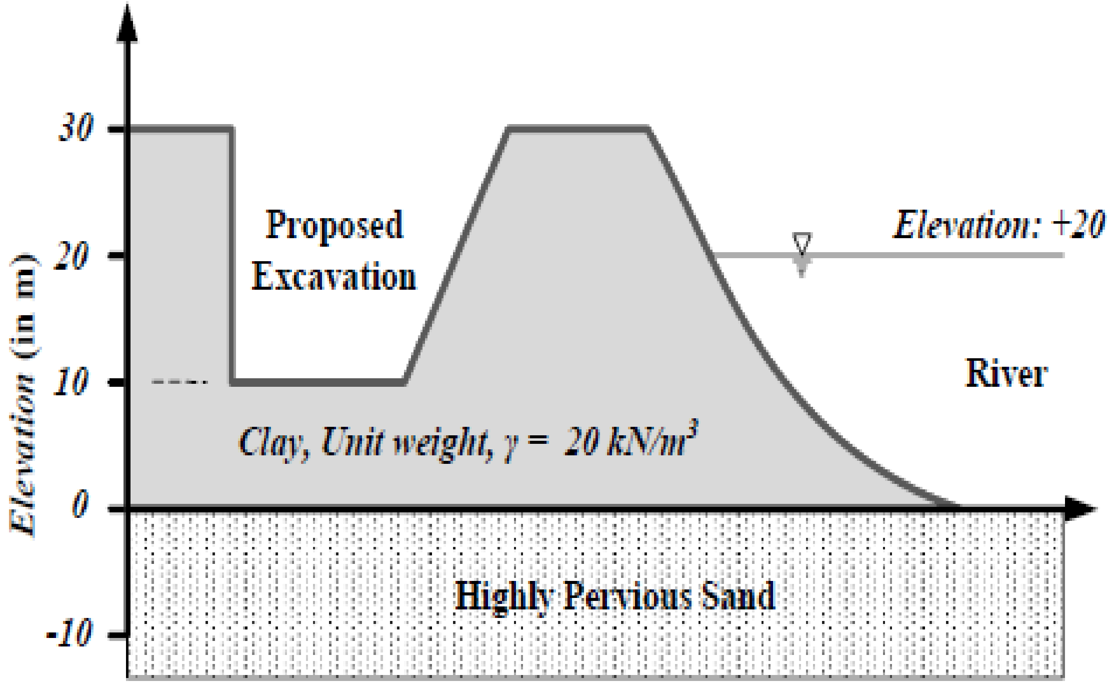
Prof. B. Jayarami Reddy

05. At a construction site, a contractor plans to make an excavation as shown in the figure. The water level in the adjacent river is at an elevation of 20 m . Unit weight of water is 10 kN/m^3. The factor of safety (up to two decimal places) against sand boiling for the proposed excavation is…. CE1 2018



Prof. B. Jayarami Reddy

05. Ans. 1



Uplift pressure due to pore water pressure = $\gamma_w h$ = 10×20 = 200 kN/m^2.

Total downward pressure at the interface of sand and clay after excavation = γh = 20×10 = 200 kN/m^2.

Factor of safety, $F_s = \dfrac{\text{Total downward pressure}}{\text{Uplift pressure}} = \dfrac{200}{200} = 1$

06. A sheet pile has an embedment depth of 12 m in a homogeneous soil stratum. The coefficient of permeability of soil is 10^{-6} m/s. Difference in the water levels between the two sides of the sheet pile is 4 m. The flow net is constructed with five number of flow lines and eleven number of equipotential lines. The quantity of seepage (in cm^3/s per m. up to one decimal place) under the sheet pile is .

Ans. 1.6 CE2 2017

Embedment depth of sheet pile = 12 m

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

Head of water, h = 4m

Number of flow lines = 5

Number of flow channels, N_f = 4

Number of equipotential lines = 11

Number of potential drops, $N_d = 11 - 1 = 10$

Quantity of seepage, $q = k.h.\frac{N_f}{N_d}$

$$q = 10^{-6} \times 4 \times \frac{4}{10} = 1.6 \times 10^{-6} m^3 / s / m = 1.6 \times 10^{-6} \times 10^6 cm^3 / s / m$$

$q = 1.6 cm^3 / s / m$ width.

Prof. B. Jayarami Reddy

07. The seepage occurring through an earthen dam is represented by a flow net comprising of 10 equipotential drops and 20 flow channels. The coefficient of permeability of the soil is 3 mm/min and the head loss is 5 m. The rate of seepage (expressed in cm^3/s per m length of the dam) through the earthen dam is ………

Ans. 500 CE2 2016

Number of equipotential drops, $N_d = 10$

Number of flow channels, $N_f = 20$

Coefficient of permeability of the soil, $k = 3mm/\min$

$$k = \frac{3}{1000 \times 60} = 5 \times 10^{-5} m/s$$

Head loss, $h = 5m$

Rate of seepage, $q = k.h.\frac{N_f}{N_d}$

$$q = 5 \times 10^{-5} \times 5 \times \frac{20}{10} = 5 \times 10^{-4} m^3/s/m = 5 \times 10^{-4} \times 10^6 cm^3/s/m = 500 cm^3/s/m$$

08. The relationship between the specific gravity of sand and the hydraulic gradient to initiate quick condition in the sand layer having porosity of 30% is

CE1 2016

a. $G = 0.7i + 1$ b. $G = 1.43i - 1$ **c.** $G = 1.43i + 1$ d. $G = 0.7i - 1$

Ans. c

G : Specific gravity of sand

i : Hydraulic gradient

Porosity, n =30%

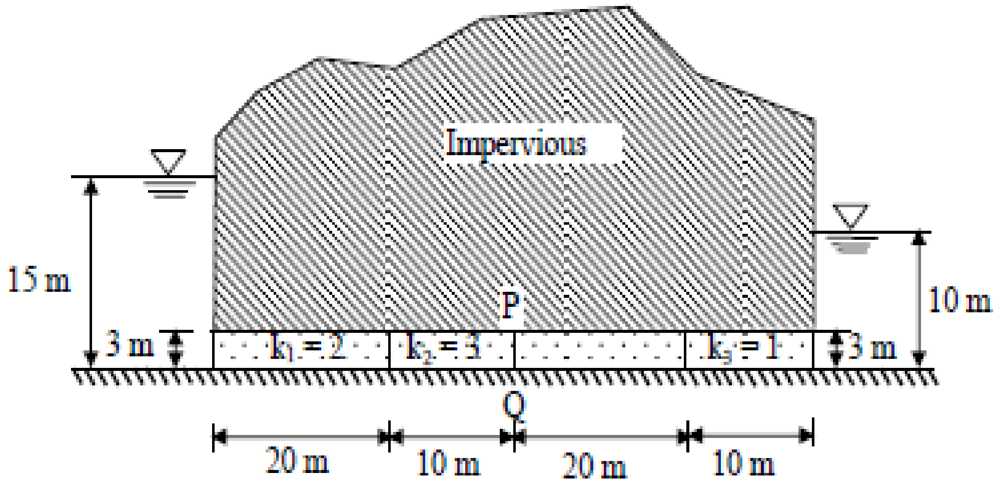
At quick sand condition, $i = i_c$

$$i = \frac{G-e}{1+e} = (G-1)(1-n) = (G-1)(1-0.3) \Rightarrow i = (G-1)0.7$$

$$G = 1.43i + 1$$

Prof. B. Jayarami Reddy

09. Seepage is occurring through a porous media shown in the figure. The hydraulic conductivity values are (k_1, k_2, k_3) in m/day. CE1 2016



The seepage discharge (m^3/day per m) through the porous media at section PQ is

a. $\frac{7}{12}$ b. $\frac{1}{2}$ c. $\frac{9}{16}$ d. $\frac{3}{4}$

Ans. b

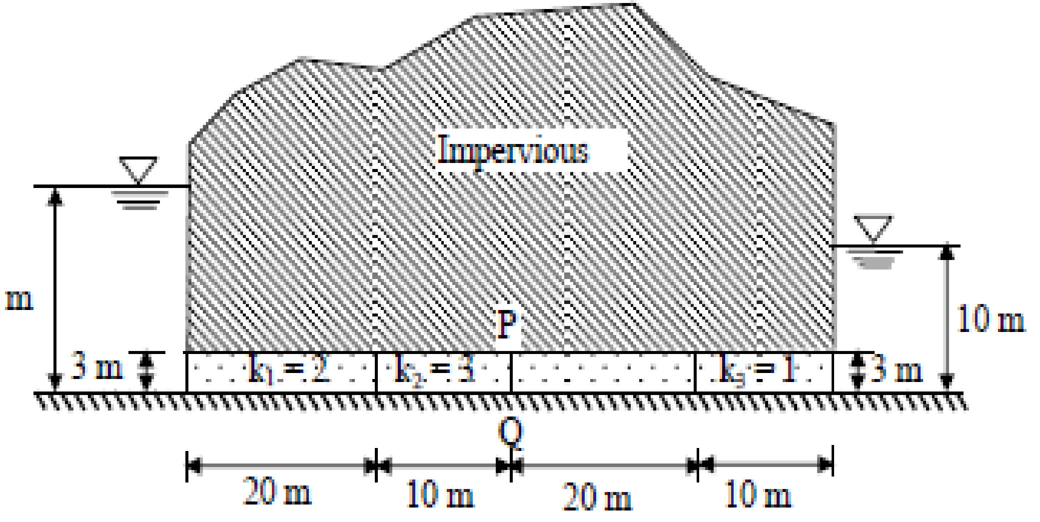
Prof. B. Jayarami Reddy

$$k_1 = 2m/day \qquad Z_1 = 20m$$

$$k_2 = 3m/day \qquad Z_2 = 10 + 20 = 30m$$

$$k_3 = 1m/day \qquad Z_3 = 10m$$

$$h = 15 - 10 = 5m, L = 60m$$



k : Equivalent hydraulic conductivity

$$= \frac{Z_1 + Z_2 + Z_3}{\frac{Z_1}{k_1} + \frac{Z_2}{k_2} + \frac{Z_3}{k_3}} = \frac{20 + 30 + 10}{\frac{20}{2} + \frac{30}{3} + \frac{10}{1}} = 2m/day$$

Seepage discharge $Q = k.i.A = k.\frac{h}{L}.A$

$$Q = 2 \times \frac{5}{60} \times 3 \times 1 = 0.5m^3/day/m$$

Prof. B. Jayarami Reddy

10. Which of the following statements if TRUE for the relation between discharge velocity and seepage velocity? CE1 2015

a. Seepage velocity is always smaller than discharge velocity

b. Seepage velocity can never be smaller than discharge velocity

c. Seepage velocity is equal to the discharge velocity

d. No relation between seepage velocity and discharge velocity can be established.

Ans. b

Discharge velocity (V) is the rate of discharge of water through a porous medium per unit of total area perpendicular to the direction of flow. Seepage velocity (or Actual velocity or true velocity) is the velocity of water through soil obtained by considering the actual pre space available for flow.

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

n : Porosity of soil

n is always less than 1.

Therefore, seepage velocity (V_s) is always greater than the discharge velocity (V).

i.e., $V_s > V$

Prof. B. Jayarami Reddy

11. Water is flowing at a steady rate through a homogeneous and saturated horizontal soil strip at 10 m length. The strip is being subjected to a constant water head (H) of 5 m at the beginning and 1 m at the end. If the governing equation of the flow in the soil strip is $\frac{d^2H}{dx^2} = 0$ (where is the distance along the soil strip), the value of H (in m) at the middle of the strip is __________ CE2 2014

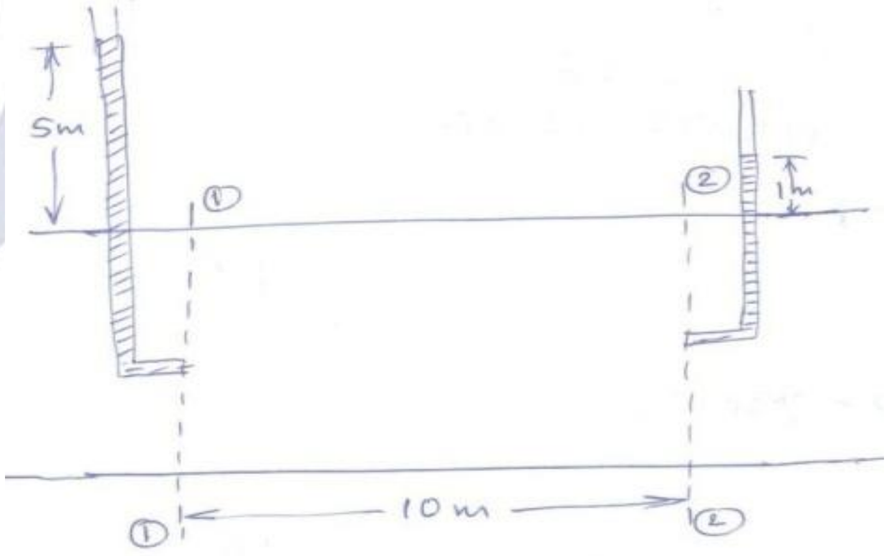
Ans. 3

Length of the soil strip, $L = 10m$

At $x = 0$ Head of water, $H = 5m$

At $x = 10m$ Head of water, $H = 1m$

The equation of flow in the soil strip is $\frac{d^2H}{dx^2} = 0$



Prof. B. Jayarami Reddy

At $x = 5$, Head of water, $H = ?$

Integrating with respect to x, $\frac{dH}{dx} = C_1$

Integrating again with respect to x, $H = C_1 x + C_2$

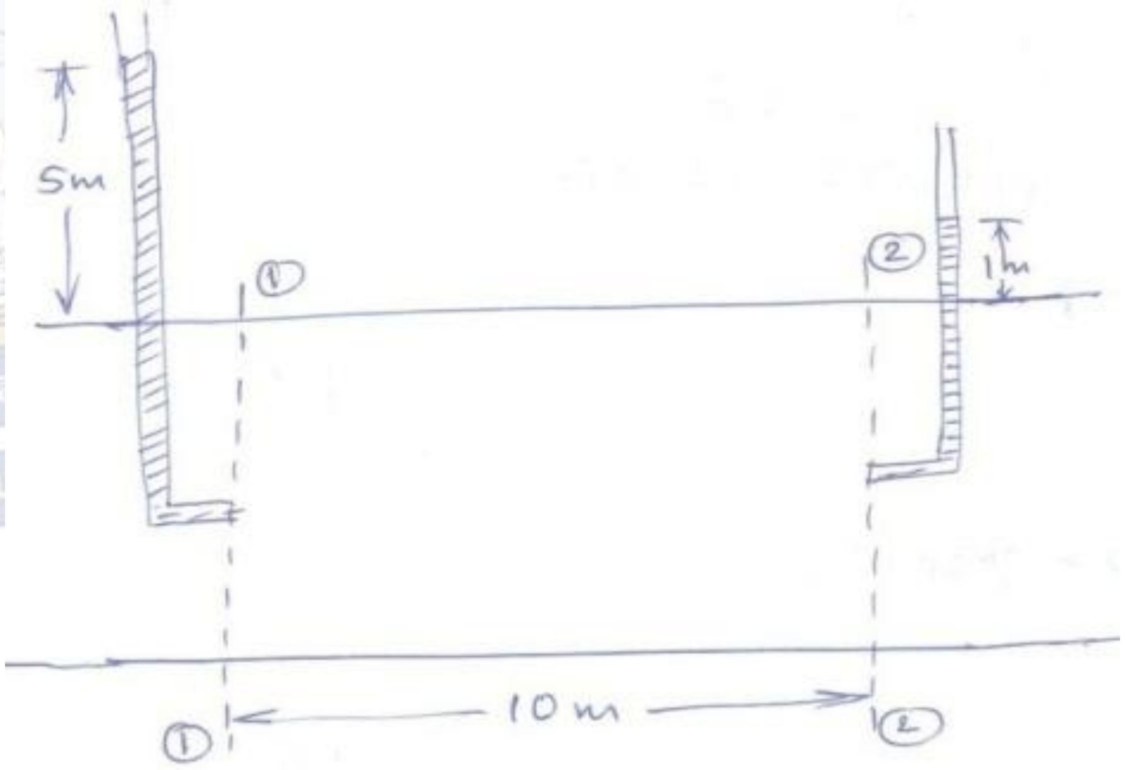
At, $x = 0, H = 5m \Rightarrow 5 = 0 + C_2 \Rightarrow C_2 = 5$

At, $x = 10m, H = 1m \Rightarrow 1 = C_1 \times 10 + 5$

$$10C_1 = -4 \Rightarrow C_1 = -\frac{2}{5}$$

Therefore, $H = -\frac{2}{5}x + 5$

At, $x = 5m, H = -\frac{2}{5} \times 5 + 5 = 3m$



Prof. B. Jayarami Reddy

12. The flow net constructed for the dam is shown in the figure below. Taking coefficient of permeability as 3.8×10^{-6} m/s, the quantity of flow (in cm^3/sec) under the dam per meter of dam is __________ CE1 2014

Ans. 7.182

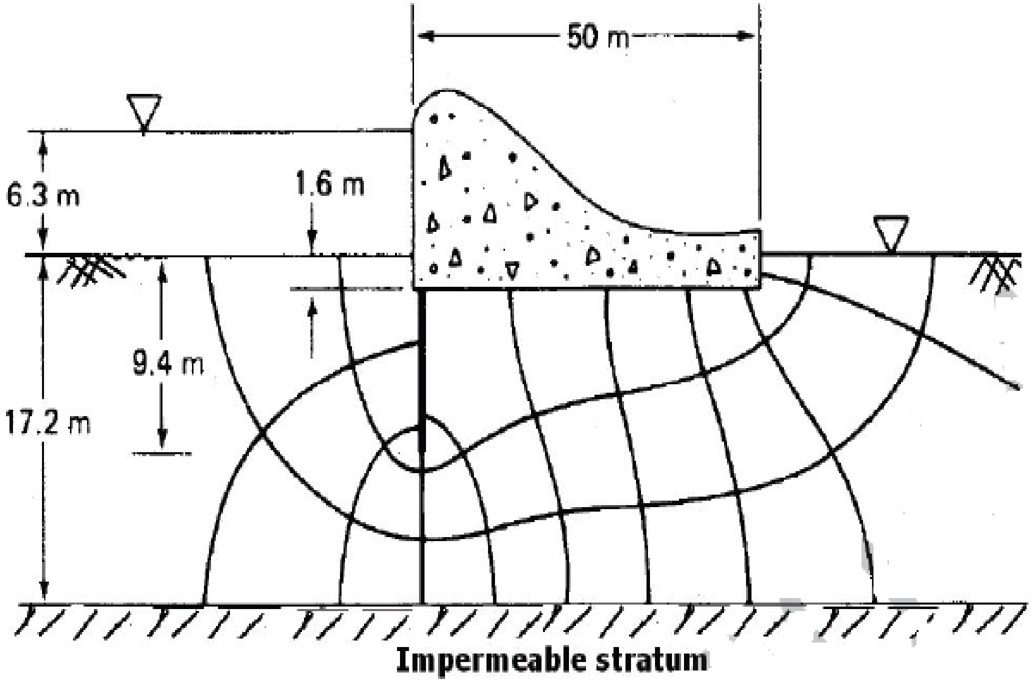
Coefficient of permeability, $k = 3.8\times10^{-6}\, m/\sec$

Head of water causing flow, $h = 6.3m$

Number of flow channels, $N_f = 3$

Number of equi-potential drops, $N_d = 10$

Quantity of flow under the dam, $q = k.H.\frac{N_f}{N_d}$



$$q = 3.8\times10^{-6}\times6.3\times\frac{3}{10} = 7.182\times10^{-6}\, m^3/\sec/m = 7.182\times10^{-6}\times10^{6}\, cm^3/\sec/m$$

Prof. B. Jayarami Reddy

13. The ratio N_f / N_d is known as shape factor, where is N_f the number of flow lines and N_d is the number of equipotential drops. Flow net is always drawn with a constant b/a ratio, where b and a are distances between two consecutive flow lines and equipotential lines, respectively. Assuming that ratio remains the same, the shape factor of a flow net will change if the 2013

a. upstream and downstream heads are interchanged

b. soil in the flow space is changed.

c. dimensions of the flow space are changed

d. head difference causing the flow is changed.

Ans. c

N_f : Number of flow lines

N_d : Number of equipotential drops

Flow net is always drawn with a constant b/a ratio.

Prof. B. Jayarami Reddy

b : Distance between two consecutive flow lines

a : Distance between two consecutive equipotential lines

Shape factor $= N_f / N_d$

Seepage through flownet, $q = k.H.\dfrac{N_f}{N_d}.\dfrac{b}{a}$

Shape factor does not depends on

i. Interchanging the upstream and downstream heads. ie., Head causing flow is same.

ii. Soil in the flow space is changed and varies accordingly.

iii. Head difference causing the flow is changed.

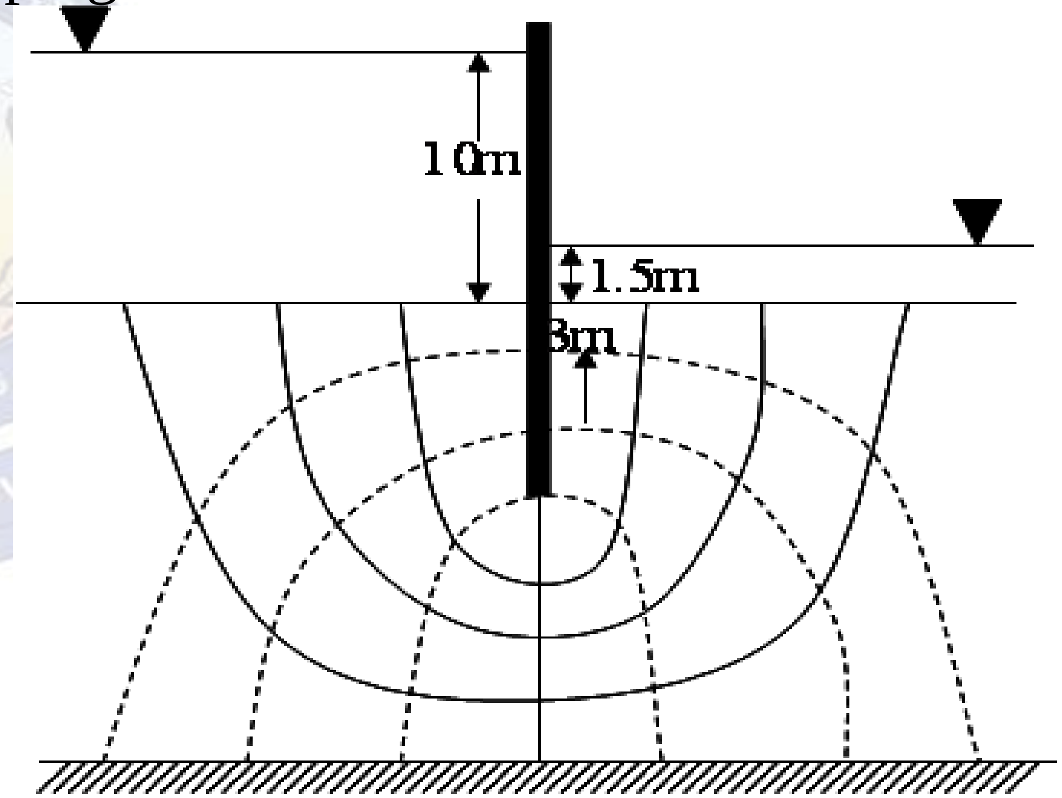
Common Data for Questions: 14 and 15:

The flow net around a sheet pile wall is shown in the sketch. The properties of the soil are: permeability coefficient = 0.09 m/day (isotropic), specific gravity =2.70 and void ratio = 0.85. The sheet pile wall and the bottom of the soil are impermeable.

The factor of safety against the occurrence of piping failure is 2012

a. 3.55 b. 2.93

c. 2.60 d. 0.39



Ans. c

Factor of safety against the occurrence of piping failure

$$F = \frac{\text{Critical hydraulic gradient}}{\text{Actual exit gradient}}$$

$$F.S = \frac{i_c}{i_e} \qquad i_e = \frac{\Delta h}{\Delta l}$$

Prof. B. Jayarami Reddy

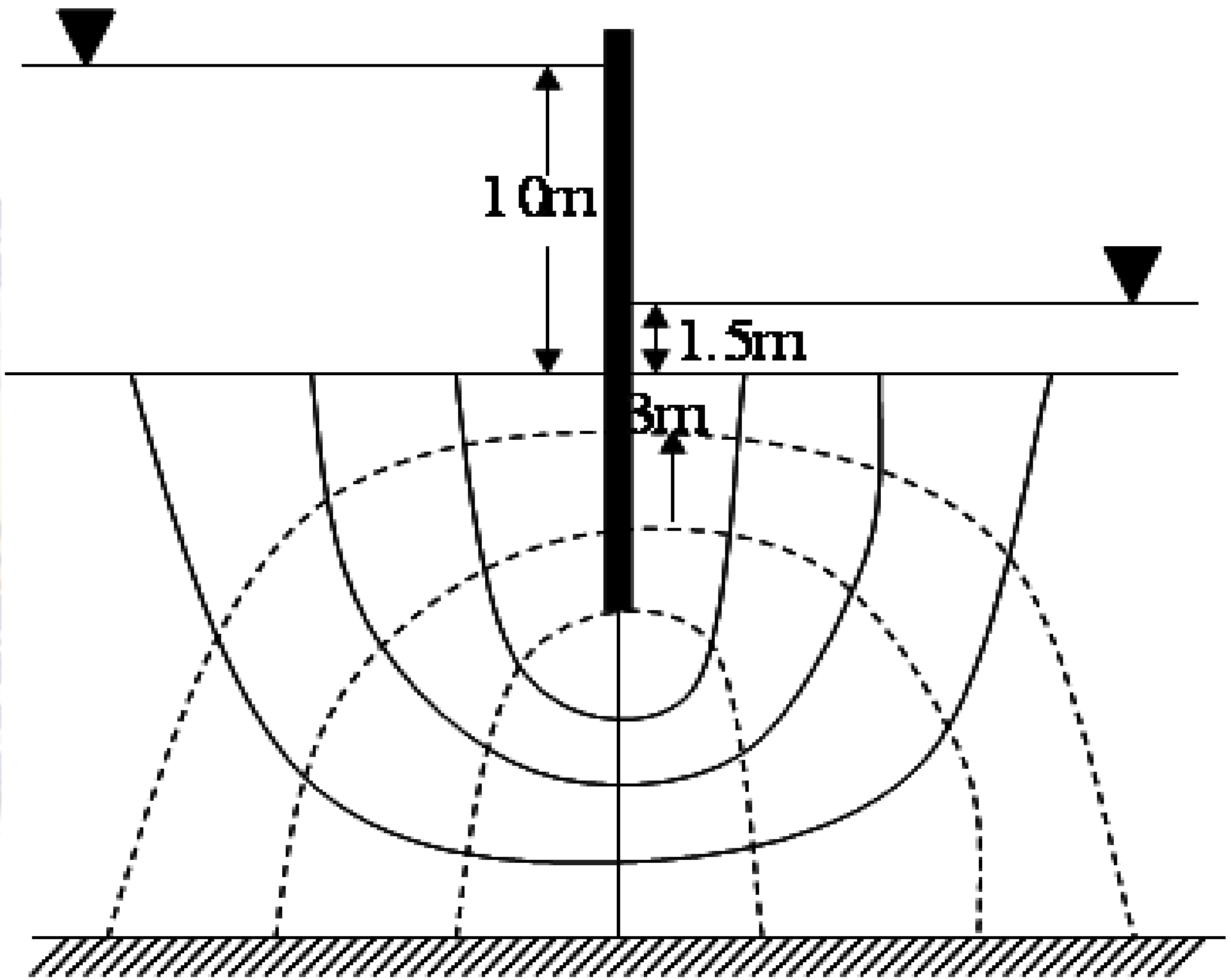
$$\text{Head loss per drop}, \Delta h = \frac{h}{N_d} = \frac{8.5}{8}$$

$$\text{length of flow}, \Delta l = 3$$

$$i_e = \frac{8.5}{8 \times 3} = 0.354$$

$$i_c = \frac{G-1}{1+e} = \frac{2.7-1}{1+0.85} = 0.919$$

$$F.S = \frac{i_c}{i_e} = \frac{0.919}{0.354} = 2.60$$



Prof. B. Jayarami Reddy

15. The seepage loss (in m^3 per day per unit length of the wall) of water is 2012

a. 0.33 **b.** 0.38 c. 0.43 d. 0.54

Ans. b

Coefficient of permeability, k =0.09 m/day

Specific gravity of soil, G =2.70

Void ratio, e = 0.85

Head of water, h =10 -1.5 = 8.5m

Number of flow channels, N_f =4

Number of equipotential drops, N_d =8

Seepage loss per unit length of wall, $q = k.h.\frac{N_f}{N_d}$

$$q = 0.09 \times 8.5 \times \frac{4}{8} = 0.38 \text{ m}^3\text{/day/m run}$$

Prof. B. Jayarami Reddy

16. For a saturated sand deposit, the void ratio and the specific gravity of solids are 0.70 and 2.67, respectively. The critical (upward) hydraulic gradient for the deposit would be 2011

a. 0.54 **b.** 0.98 c. 1.02 d. 1.87

Ans. b

Void ratio, e = 0.70

Specific gravity of solids, G = 2.67

Critical hydraulic gradient, i_c = ?

$$i_c = \frac{G-1}{1+e} = \frac{2.67-1}{1+0.7} = 0.98$$

Prof. B. Jayarami Reddy

17. Quick sand condition occurs when 2010

a. The void ratio of the soil becomes 1.0

b. The upward seepage pressure in soil becomes zero

c. The upward seepage pressure in soil becomes equal to the saturated unit weight of the soil

d. The upward seepage pressure in soil becomes equal to the submerged unit weight of the soil

Ans. d

Quick sand condition occurs when the upward seepage pressure in soil becomes equal to the submerged unit weight of the soil.

18. To provide safety against piping failure, with a factor of safety of 5, what should be the maximum permissible exit gradient for soil with specific gravity of 2.5 and porosity of 0.35? 2006

a. 0.155 b. 0.176 **c.** 0.195 d. 0.213

Ans. c

Factor of safety, $F = 5$

Specific gravity, $G = 2.5$

Porosity, $n = 0.35$

Permissible exit gradient $= i$

Void ratio, $e = \dfrac{n}{1-n} = \dfrac{0.35}{1-0.35} = 0.538$

Critical hydraulic gradient, $i_c = \dfrac{G-1}{1+e} = \dfrac{2.5-1}{1+0.538} = 0.975$

Permissible exit gradient, $i_e = \dfrac{i_c}{F} = \dfrac{0.975}{5} = 0.195$

19. The range of void ratio between which quick sand conditions occurs in cohesionless granular soil deposits is 2006

a. 0.4-0.5 **b.** 0.6-0.7 c. 0.8-0.9 d. 1.0-1.1

Ans. b

Critical hydraulic gradient, $i = \frac{G-1}{1+e}$

The specific gravity of cohesionless granular soil varies from 2.6 to 2.7. Quick sand condition occurs when the critical hydraulic gradient is unity.

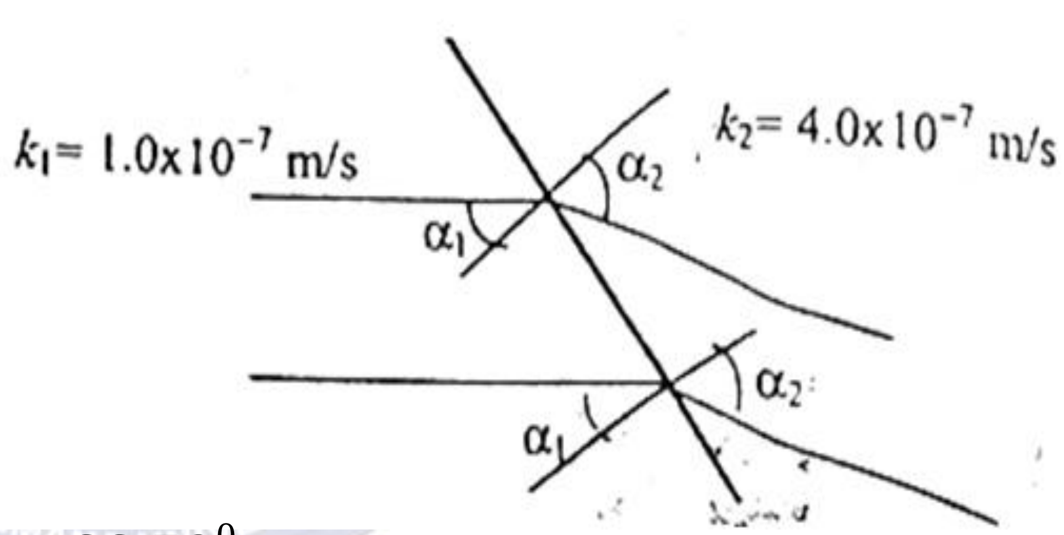
The range of void ratio is 0.6 to 0.7

20. The figure below shows two flow lines for seepage across an interface between two soil media of different co-efficients of permeability. If entrance angle $=30^0$, the exit angle will be 2004

a. 7.50^0 b. 14.03^0

c. 66.59^0 d. 75.96^0

Ans. C



We know that $\dfrac{k_1}{k_2} = \dfrac{\tan\alpha_1}{\tan\alpha_2}$

$$\frac{1.0\times10^{-7}}{4.0\times10^{-7}} = \frac{\tan 30^0}{\tan\alpha_2}; \tan\alpha_2 = 2.309; \alpha_2 = 66.59^0$$

Prof. B. Jayarami Reddy

21. An unit volume of a mass of saturated soil is subjected to horizontal seepage. The saturated unit weight is 22 KN/m^3 and the hydraulic gradient is 0.3. The resultant body force on the soil mass is 2004

a. 1.98 KN b. 6.6 KN c. 11.49 KN d. 22.97 KN

Ans. --

Saturated unit weight of soil, $\gamma_{sat} = 22 kN/m^3$

Hydraulic gradient, $i = 0.3$

Horizontal seepage force per unit volume $= i.\gamma_w$ $F_H = 0.3 \times 10 = 3kN$

Vertical force due to submerged soil mass per unit volume, $F_V = 22 - 10 = 12kN$

Resultant body force on the soil mass, $R = \sqrt{F_H{}^2 + F_V{}^2} = \sqrt{(3)^2 + (12)^2} = 12.37kN$

Prof. B. Jayarami Reddy

22. A masonry dam is founded on pervious sand having porosity equal to 45% and specific gravity of sand particles is 2.65. For a desired factor of safety of 3 against sand boiling, the maximum permissible upward gradient will be 2003

a. 0.225 **b.** 0.302 c. 1.0 d. None of these

Ans. b

Porosity of sand, $n = 45\% = 0.45$

Specific gravity of sand, $G = 2.65$

Factor of safety, $F = 3$

Critical hydraulic gradient, $i_c = \dfrac{G-1}{1+e}$

$$i_c = (G-1)(1-n) = (2.65-1)(1-0.45) = 0.9075$$

$$F = \frac{\text{Critical hydraulic gradient}(i_c)}{\text{Maximum permissible gradient (i)}}$$

$$i = \frac{i_c}{F} = \frac{0.9075}{3} = 0.3025$$

Prof. B. Jayarami Reddy

23. The specific gravity and in-situ void ratio of a soil deposit are 2.71 and 0.85 respectively. The value of the critical hydraulic gradient is 2002

a. 0.82 b. 85 **c.** 0.92 d. 0.95

Ans. c

Specific gravity of soil, $G = 2.71$

Void ratio, $e = 0.85$

Critical hydraulic gradient, $i_c = \frac{G-1}{1+e}$

$$i_c = \frac{2.71-1}{1+0.85} = 0.924$$

Prof. B. Jayarami Reddy

24. The coefficients of permeability of a soil in horizontal and vertical directions are 3.46 m/day and 1.5 m/day respectively. The base length of a concrete dam resting in this soil is 100 m. When the flow net is developed for this soil with 1:25 scale factor in the vertical direction, the reduced base length of the dam will be

a. 2.63 m b. 4.00 m c. 6.08 m d. 5.43 m 2001

Ans. a

Coefficient of permeability in horizontal direction, $k_x = 3.46 m/day$

Coefficient of permeability in vertical direction, $k_y = 1.5 m/day$

Base length of concrete dam, $B = 100m$

Scale factor in vertical direction $1:25$

Let b : Reduced horizontal dimension for the transformed section.

$$\frac{b}{B} = \sqrt{\frac{k_y}{k_x}} \qquad b = \sqrt{\frac{1.5}{3.46}} \times 100 = 65.84m$$

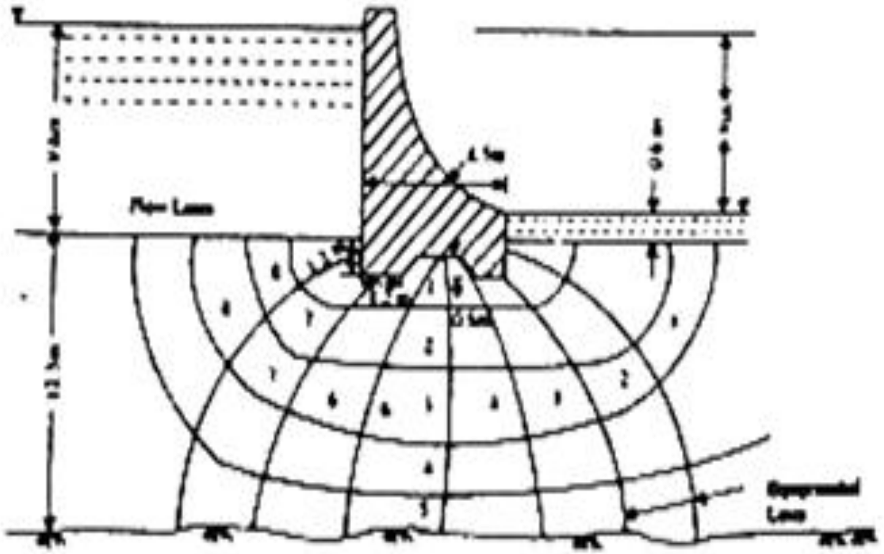
$$\text{Reduced base width of scale} = \frac{65.84}{25} = 2.63m$$

Prof. B. Jayarami Reddy

25. The proposed dam shown in the figure is 90 m long and the coefficient of permeability of the soil is 0.0013 mm/s. The quantity of water (m^3) that will be lost per day be seepage is (rounded to the nearest number): 1998

a. 55 **b.** 57

c. 59 d. 61



Ans. b

Length of the dam, $L = 90m$

Coefficient of permeability of soil, $k = 0.0013 mm/s$

Quantity of seepage through the dam, $Q = ?$

Quantity of water lost through seepage, $q = k.H.\frac{N_f}{N_d}$

Head of water, $h = 9m$

Number of flow lines, $N_f = 5$

Number of equipotential drops, $N_d = 8$

$$q = 0.0013 \times 10^{-3} \times 60 \times 60 \times 24 \times 9 \times \frac{5}{8} = 0.632 m^3 / day / m$$

$$Q = q.L = 0.632 \times 90 = 56.88 m^3 / day$$

Prof. B. Jayarami Reddy

26. Piping in soil occurs when 1996

a. the soil is highly porous

b. sudden change in permeability occurs

c. effective pressure becomes zero

d. the soil is highly stratified

Ans. c

Piping in soil occurs when effective pressure becomes zero.

Prof. B. Jayarami Reddy

27. Seepage force per unit volume (j) can be expressed as 1996

a. $i.\gamma_w.L$ b. $i.L$ c. $\gamma_w.h$ **d.** $i.\gamma_w$

Ans. d

Seepage pressure, $p_s = \gamma_w.h = \gamma_w.i.z$

Seepage force = Seepage pressure × area. $P_s = \gamma_w.i.z.A$

Seepage force per unit volume $\frac{P_s}{V} = \frac{\gamma_w.i.z.A}{z.A} = \gamma_w.i$

γ_w : Unit weight of water

h : Head loss

i : Hydraulic gradient $= h/z$

z : Length of seepage

28. The number of flow channels and head drops is 4 and 12 respectively. If the difference in the upstream and downstream water levels is 3 m, what is the discharge per meter width of a sheet pile wall, if $k = 0.1 m/s$? 1992

Ans. 0.1 m^3/s/m.

Number of flow channels, $N_f = 4$

Number of head drops, $N_d = 12$

Head causing flow, $h = 3m$

Coefficient of permeability, $k = 0.1 m/s$

Discharge per m width of sheet pile, $q = k.h.\frac{N_f}{N_d}$

$$q = 0.1 \times 3 \times \frac{4}{12} = 0.1 m^3/s/m$$

Prof. B. Jayarami Reddy

29. Along a phreatic line in an earth dam 1991

a. the total head is constant but not zero

b. the total head is everywhere zero

c. the pressure head is everywhere zero

d. None of the above

Ans. c

Phreatic line is the top flow line which follows the path of base parabola. It is a stream line. The pressure head on the phreatic line is atmosphere (zero) and the total head is equal to the elevation head. Below this line, the pressure is hydrostatic. Therefore, along the phreatic line in an earth dam, the pressure head is zero, everywhere.