UNIT - III

Permeability

Types of soil water (2) types

- free water
- Held water
  - Structural water
  - Adsorbed water (hygroscopic water)
  - capillary water

Free water :- free water moves in the pores of the soil under the influence of gravity the flow of free water in the soil is just like laminar flow.

Structural water :- It is chemically combined water is crystal structure of the minerals of the soil these water cannot be removed without breaking the structure of minerals

* Temperature of more than 200 C is required for removing structural water.

Problems :-

* Capillary rise in a soil "A" with an effective size of "A" is 0.02 mm was 60 cm effective size of "B" is 0.04 mm then determine capillary rise in soil B.

Sol:- Given data is

Soil A

$D = 0.02\ mm$

$h_{cA} = 60\ cm$

Soil B

$D = 0.04\ mm$

$h_{cB} = ?$

W.K.T $h_c \propto \frac{1}{D} \Rightarrow \frac{h_{cA}}{h_{cB}} = \frac{d_B}{d_A} \Rightarrow h_{cB} = \frac{h_{cA} * d_A}{d_B}$

$$h_{cB} = \frac{0.02 \times 60}{0.04} = 30\ cm.$$

* Capillary rise in silt is 50 cm and fine sand is 30cm what is the difference in diameter of two soils?

Sol:- Given data is

Silt $(h_c) = 50\ cm$

Fine Sand $(h_c) = 30\ cm.$

We know that $(h_c) = \frac{0.3}{d}$

$$d_{silt} = \frac{0.3}{50} = 0.006\ cm$$

$$d_{fine\ Sand} = \frac{0.3}{30} = 0.01\ cm$$

* A soil has void size of 0.01 mm then find the maximum capillary rise present in water and what is the maximum capillary tension present in the soil. if $\gamma_w = 9810\ N/m^3$

Sol:- Given data is

$d = 0.01\ mm = 0.001\ cm$

$\gamma_w = 9810\ N/m^3$

$$h_c = \frac{0.3}{d} = \frac{0.3}{0.001} = 300\ cm = 3m$$

Capillary tension $= -\frac{(Wt\ of\ water)}{Area} = -\frac{Unit\ wt * vol}{A}$

$$= -\frac{\gamma_w * \cancel{A} * h_c}{\cancel{A}} = -\gamma_w h_c$$

Capillary tension $= \gamma_w h_c = 9810 * 3$

$$= 29.4\ KN/m^2$$

DARCY'S LAW :-

* For coase grained soils also flow is generally Laminar how ever in very coarse grained soils such as coarse gravel flow may be turbulent.
* Darcy's law is valid only flow in clay silt and fine sand and in coase sand gravel and boulders darcy's law is not applicable in extremely f.G.s such as collaidal clay in the interstices are very small so velocity also very small in such soils darcy's law is not valid.
* For flow through soils, flow is laminar when reynold's number is less than unity.
* It is difficult to credit exact range of validity of darcy's law. the best method to assertain the range is to conduct experiments and determine actual relationship b/w velocity and hydrolic gradient.
* In darcy's law the relation ship b/w v and i is Linear.

Soil type	K (mm/sec)	Drinage property
Clean Gravel	10^{+4} to 10^{+2}	very good
Coarse & medium Sand	10^{-2} to 10^{+1}	good.
Fine Sand, Loose Silt	10^{-4} to 10^{-2}	fair.
Dense Silt, clayeysilt	10^{-5} to 10^{-4}	poor.
Silty clay, clay	10^{-8} to 10^{-5}	Very poor.

* When eff size of soil grain 0.001 mm the permeability was found to be 1×10^{-3} cm/sec. If grain size is 0.0002 mm what is the change in permeability of soil mass ?

Sol:- Given data is

$K_1 = 1 \times 10^{-3}$ cm/sec. $\quad K_2 = ?$

$D_1 = 0.001$ mm $\quad D_2 = 0.0002$ mm

W.K.T $(K \propto D^2)$ $\quad \frac{K_1}{K_2} = \frac{D_1^2}{D_2^2} \Rightarrow \frac{1 \times 10^{-3}}{K_2} = \frac{0.001^2}{0.0002^2}$

Q) A soil has a co-efficient of permeability of 4.75×10^{-2} mm/sec at 30°c determine its value at 27°c. Take co-efficient of viscosity at 30°c is 8 poise. and at 27°c viscosity = 8.5 poise.

Sol:- Given data is

$K_{30°c} = 4.75 \times 10^{-2}$ mm/sec. , $\eta_{30°c} = 8$ poise

$K_{27°c} = ?$, $\eta_{27°c} = 8.5$ poise.

from poissules equation $K = C \times \frac{\gamma_w}{\eta} \times Ds^2 \times \frac{e^3}{1+e}$

K inver

$\boxed{K \propto \frac{1}{\eta}}$

$$\frac{K_{30°c}}{K_{27°c}} = \frac{\eta_{27°c}}{\eta_{30°c}}$$

$$\therefore K_{27°c} = \frac{4.75 \times 10^{-2} \times 8}{8.5} = 4.47 \times 10^{-2} \text{mm/sec.}$$

Q) Due to increase in temparature the unit wt of liquid and viscosity decreases to 90 % and 60 % respectevely. what is the change in permeability of soil mass ?

Sol:- Given data is.

Intial $\rightarrow K_1 \quad \gamma_w \quad \eta$

$\rightarrow K_2 \quad 0.9\gamma_w \quad 0.6\eta$

from poiseulli's eqn.

$$\frac{K_1}{K_2} = \frac{(\gamma_{w_1}/\eta_1)}{(\gamma_{w_2}/\eta_2)}$$

$$\frac{K_1}{K_2} = \frac{\gamma_{w_1}}{\gamma_{w_2}} \times \frac{\eta_2}{\eta_1} = \frac{\gamma_w}{0.9\gamma_w} * \frac{0.6\eta}{\eta}$$

$\therefore \boxed{K_1 = 0.66}$, $\boxed{K_2 = 0.99}$

Q) permeability test on a sample gave the following data.

test No	void ratio	temparature	permeabity ($\times 10^{-3}$ m/sec)
1	0.63	20°c	0.36
2	1.02	36°c	1.8

Estimate the co-efficient of permeability at 27°c for a void ratio of 0.9, viscosity at 20°c is 1.009×10^{-9} N.sec/mm², viscosity at 30°c is 0.709×10^{-9} N.sec/mm², viscosity at 27°c is 0.855×10^{-9} N.sec/mm². Unit wt of water 9.81 KN/m³ ?

Sol:- Viscosity $\eta_{20°c} = 1.009 \times 10^{-9}$ N.sec/mm²

$$\eta_{38°c} = 0.709 \times 10^{-9} \text{ N.sec/mm}^2$$

$$\eta_{27°c} = 0.855 \times 10^{-9} \text{ N.sec/mm}^2$$

$$K_{20°c} = CD_s^2 * \frac{r_w}{\eta} * \frac{e^3}{1+e}$$

$$0.36 \times 10^{-3} = CD_s^2 \times \frac{9.81 \times 10^3}{\frac{1.009 \times 10^{-9}}{(10^{-3})^2}} \times \frac{0.68^3}{1+0.68}$$

$$\therefore CD_s^2 = 2.413 \times 10^{-10}$$

$$K_{27°c} = CD_s^2 \times \frac{r_w}{\eta} \times \frac{e^3}{1+e}$$

$$K_{27°c} = 2.418 \times 10^{-10} \times \frac{9.81 \times 10^3}{\frac{0.855 \times 10^{-9}}{(10^{-3})^2}} * \frac{0.9^3}{1+0.9}$$

$$\boxed{K_{27°c} = 1.06 \times 10^{-3} \text{ cm/sec}}$$

Terzaghi & peck relative Eqn:-

Relation b/w h_{cmax} and eff size of particles

$$h_{cmax} = \frac{C}{e D_{10}}$$

D_{10} = Particle diameter

C = Constant

e = Void Ratio.

⊛ Find capillary rise in sandy soils soil with void ratio 0.84 and eff particle size 0.3 mm take $C = 0.36$ cm²

Sol:- Given data is

$C = 0.36$ cm²

$e = 0.89$

$D = 0.3$ mm $= 0.03$ cm

$$h_c = \frac{C}{e D_{10}} = \frac{0.36}{0.89 \times 0.03} = 13.48 \text{ cm}$$

⊛ Capillary rise in soil sample ① with particle size 0.03 mm is 0.9 m. estimate capillary rise in soil sample ② with size 0.39 mm. Assuming same void ratio for both sample

Sol:- Given data is

Sample ① Sample ②

$D_{10} = 0.03\,mm$ $D_{10} = 0.05\,mm$

$h_{c_1} = 0.9\,m$ $h_{c_2} = ?$

$$e = e_1 = e_2$$

W.K.that $h_{c_1} = \frac{C}{e\,D_{10}}$

assume c in b/w $\rightarrow$ 0.1 to 0.5 cm^2

$$0.9 = \frac{0.2}{e \times \frac{0.03}{10}} \Rightarrow 90 = \frac{0.2}{e \times 0.003}$$

$$\therefore \boxed{e = 0.74}$$

$$h_{c_2} = \frac{0.2}{0.74 \times 0.039} = \underline{6.9\,cm}$$

problems on Permeability:-

* A stratum of layer consist of 3 layers equal thickness the permeability of top and bottom soil 1×10^{-4} cm/sec and that of middle layer 10×10^{-4} cm/sec the value of K in horizontal direction is ?

Sol:-

$$K_h = \frac{K_1H_1 + K_2H_2 + K_3H_3}{H_1 + H_2 + H_3}$$

$K_1 = 1 \times 10^{-4}$ cm/sec

$K_2 = 10 \times 10^{-4}$ cm/sec

$K_3 = 1 \times 10^{-4}$ cm/sec

$$K_h = \frac{1 \times 10^{-4}(H) + 10 \times 10^{-4}(H) + 1 \times 10^{-4}(H)}{H + H + H}$$

$$K_h = \frac{H}{3H}\left[1 \times 10^{-4} + 10 \times 10^{-4} + 1 \times 10^{-4}\right]$$

$$\therefore K_h = 4 \times 10^{-4}\ cm/sec$$

* A stratified soil deposit consist of 4 layers of equal thickness co-efficient of permeability of second, third, and fourth layers are 1/5th, 1/4th and twice of co-efficient of permeability of top layer respectively. compute the average co-efficient of permeability ⊥er to bedding planes.?

Sol:- Given

$K_1 = K$

$K_2 = 1/5\,K_1 = \frac{1}{5}K$

$K_3 = \frac{1}{4}K_1 = \frac{1}{4}K$

$K_4 = 2K_1 = 2K$

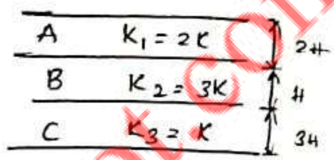
$$K_v = \frac{H_1 + H_2 + H_3 + H_4}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + \frac{H_3}{K_3} + \frac{H_4}{K_4}} = \frac{4H}{\frac{H}{K} + \frac{H}{K/5} + \frac{H}{\frac{K}{4}} + \frac{H}{2K}}$$

$$K_v = \frac{4H}{\frac{1}{K}\left[H+5H+4H+0.5H\right]}$$

$$K_v = K\left[\frac{4\cancel{H}}{10.5\,\cancel{H}}\right] = 0.38\,K.$$

⊛ The permeability of individual layers A, B, C in three layers system is in the ratio of 2, 3, 1 respectively. The ratio of thickness of the layers A, B, C are in the ratio of 2, 1, 3 respectively. Find average co-efficient of permeability $\perp^{er}$ to bedding planes?

Sol:-



W.K.T $K_v = \dfrac{H_1 + H_2 + H_3}{\dfrac{H_1}{K_1} + \dfrac{H_2}{K_2} + \dfrac{H_3}{K_3}}$

$$K_v = \frac{2H + H + 3H}{\frac{H}{2K} + \frac{H}{3K} + \frac{H}{K}}$$

$$K_v = \frac{H}{H}\left[\frac{2+1+3}{\frac{1}{2K} + \frac{1}{3K} + \frac{1}{K}}\right] = \underline{1.38\,K}$$

Seepage velocity:-

$$\text{Seepage velocity} = \frac{\text{Discharge velocity}}{\text{porosity}} = \frac{V}{n}$$

$A_1 V_1 = A_2 V_2$

$A\,V = A_v V_s \Rightarrow V_s = \dfrac{AV}{A_v}$

$$V_s = \frac{AV}{A_v} \times \frac{H}{H} = \frac{V \times A \times H}{A_v \times H} = \frac{V \times \text{volume}}{\text{vol of voids}}$$

$$V_s = \frac{V \times \text{volume}}{V_v}$$

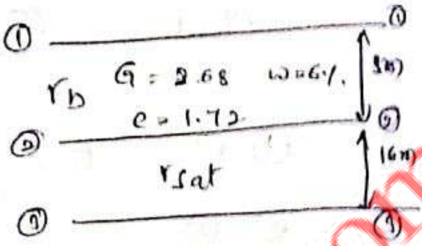
$$\text{Porosity} = \frac{V_v}{V} = V \times \frac{1}{\frac{V_v}{V}} \Rightarrow V_s = \frac{V}{n}$$

$$K_p i = \frac{Ki}{n} \Rightarrow K_p = \frac{K}{n}$$

$\left(\begin{array}{ll} V \propto i & V_s \propto i \\ V = Ki & V_s = K_p i \end{array}\right)$

(8) Determine the total stress and effective stress, neutral stress at a depth of 16m below the ground level, if the following data: the water table is 3m below the ground level, G = 2.68, e = 1.72. The average w.c of the soil above the water table is 6 %.

Sol:- $\sigma, u, \sigma' = ?$



$\sigma = \gamma H$

$$\gamma_b = \frac{G \gamma_w (1+w)}{1+e}$$

$$\gamma_b = \frac{2.68 \times 9.81 \left(1+\frac{6}{100}\right)}{1+1.72}$$

$\gamma_b = 10.24 \ KN/m^3$

and $$\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e}$$

$$= \frac{(2.68+1.72)\,9.81}{1+1.72} = 15.86 \ KN/m^3$$

at ① - ① $\quad \sigma = 0, \quad u = 0, \quad \sigma' = 0$

at ② - ②

$\sigma = \gamma H = \gamma_b * H = 10.24 \times 3 = 30.72 \ KN/m^2$

$u = 0$

$\sigma' = \sigma - u \Rightarrow 30.72 - 0 = 30.72 \ KN/m^2$

at ③ - ③

$\sigma = \gamma_b \times 3 + \gamma_{sat} * (16-3) = 236.25 \ KN/m^2$

$u = \gamma_w * H = 9.81 \times (16-3) = 127.53 \ KN/m^2$

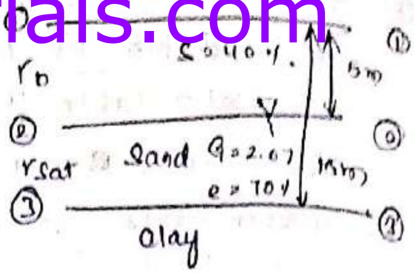
$\sigma' = 236.21 - 127.53 =$

(*) A Sand deposite is 15m thick overlise a bed of soft clay
{ (clay over lies sand) - clay is under laid by sand. ?
{ (clay under lies sand) - Clay is over laid by sand. }
the ground water is 5m below the ground surface ? The sand above the ground water table has degree of saturation 40 % ? draw pressure distribution diagram showing total stress, Neutral stress and effective stress ? The void Ratio of sand deposit is 70 %, G = 2.67

Sol: Given data

$\gamma_b, \ \gamma_{sat} = ?$

$$\gamma_b = \frac{(G+eS_r)\gamma_w}{1+e}$$



$$= \frac{2.67 + 0.7 * 0.4}{1 + \frac{70}{100}}$$

$$\boxed{\gamma_b = 17.02 \text{ KN/m}^2}$$

$$\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e} = \frac{(2.67 + 0.7) * 9.81}{1+0.7} =$$

①-① $\sigma = \gamma H = 0$, $u = 0$, $\sigma' = 0$.

②-②

$\sigma = \gamma_b H = 17.02(5) = 85 \text{ KN/m}^2$

$u = \gamma_w H = 0$.

$\sigma' = \sigma - u = 85 \text{ KN/m}^2$

③-③

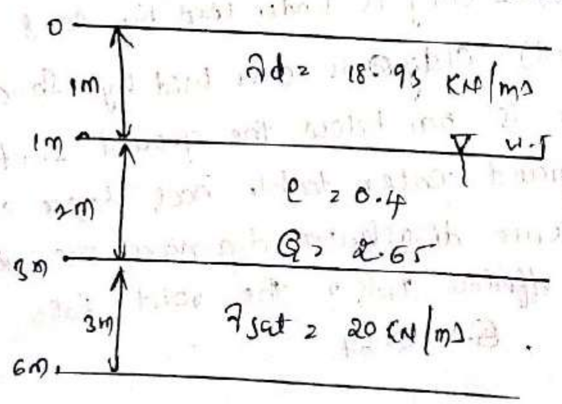
$\sigma = \gamma_b[5] + \gamma_{sat}[10] = 279.1 \text{ KN/m}^2$

$u = \gamma_w H = 9.81 * 10 = 98.1 \text{ KN/m}^2$

$\sigma' = \sigma - u = 279.1 - 98.1 = 181 \text{ KN/m}^2$

Pressure distribution diagram:-

⊛ For the subsoil condition shown in the figure calculate total Neutral and eff Stresses at 1m, 3m, 6m below the ground and also draw pressure distribution diagram.



Sol:- $\gamma_{sat} = \frac{(G+e)\gamma_w}{(1+e)} = \frac{(2.65+0.41)*9.81}{1+0.41} = 21.37\ kN/m^3$

at 0m ; $\sigma = 0,\ u = 0,\ \sigma' = 0$

at 1m :

$\sigma = \gamma_d * H = 18.93\,(1) = 18.93\ KN/m^2$

$u = \gamma_w\,(H) = \gamma_w\,(0) = 0.$

$\sigma' = \sigma - u = 18.93\ KN/m^2$

@ 3m ;

$\sigma = \gamma_d\,(1) + \gamma_{sat}\,(2)$

$\sigma = 18.93(1) + 21.37\ (2) = 61.67\ KN/m^2$

Pour water pressure/ Neutral stress $u = \gamma_w\,(2) = 9.81 * 2 = 19.62\ KN/m^2$

effective stress $\sigma' =$ ~~9.81 * 2 = 19.62 KN/m~~ $\sigma - u$

$= 61.67 - 19.62 = 42.05\ KN/m^2$

@ 6m ;

$\sigma = \gamma_d\,(1) + \gamma_{sat}\,(2) + \gamma_{sat}\,(3)$

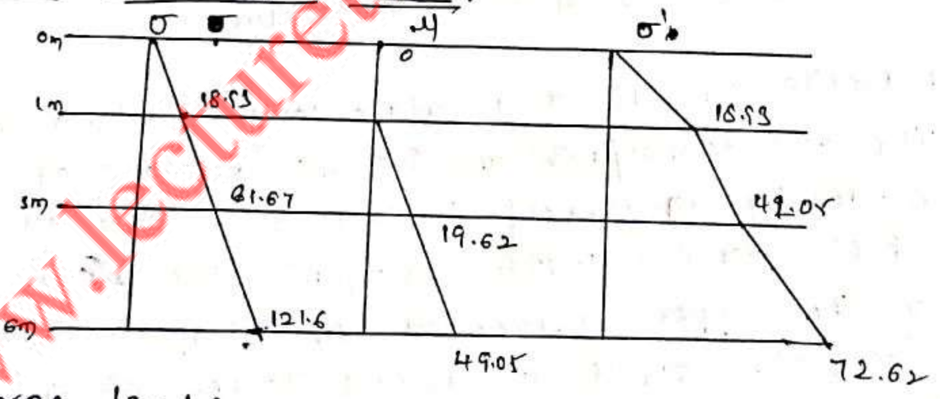
$\sigma = 18.93(1) + 21.37(2) + 20(3)$

$\therefore \boxed{\sigma = 121.67\ KN/m^2}$

$\therefore u = \gamma_w\,(5) = 9.81 * 5 = 49.05\ KN/m^2$

$\therefore \sigma' = \sigma - u = 72.62\ KN/m^2.$

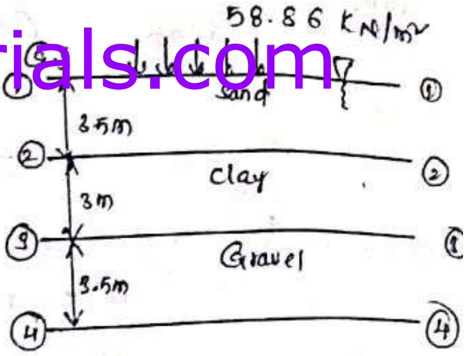
pressure distribution diagram :-



Surcharge load :-

* A soil profile consist of a surface layer of sand 3.5m deep cos thick, density 1.65 g/cc. an intermediate layer of clay is 3m thick, density 1.95 g/c.c and bottom layer of gravel 3.5 m thick, density 1.925 g/c.c . Water table is at the ground surface determine effective pressure at various layers below the ground surface. The soil profile bearing a surcharge of 58.86 KN/m² at the ground surface.

Sol:- $\gamma_{d} = 1.1\ t/m^3 = 10\ kN/m^3$



@ ① - ①

$\sigma = 58.86\ KN/m^2$

$u = 0.$

$\sigma' = 58.86\ KN/m^2$

@ ② - ②

$\sigma = 58.86 + \gamma_{sat}\,(H)$

$\therefore \sigma = 58.86 + 1.65 \times 10\,(3.5) = 116.6\ KN/m^2$

$\therefore u = \gamma_w H = 9.81 \times 3.5 = 34.33\ KN/m^2$

$\therefore \sigma' = \sigma - u = 82.27\ KN/m^2$

@ ③ - ③

$\sigma = 58.86 + \gamma_{sat}\,(3.5) + \gamma_{sat}\,(3)$

$\sigma = 58.86 + 16.5\,(3.5) + 19.5\,(3) = 175.12\ KN/m^2$

$u = \gamma_w H = 9.81\,(6.5) = 63.7\ KN/m^2$

$\sigma' = \sigma - u = 111.86\ KN/m^2$

@ ④ - ④

$\sigma = 58.86 + 16.5\,(3.5) + 19.5\,(3) + 19.25\,(3.5)$

$\sigma = 243.36\ KN/m^2$

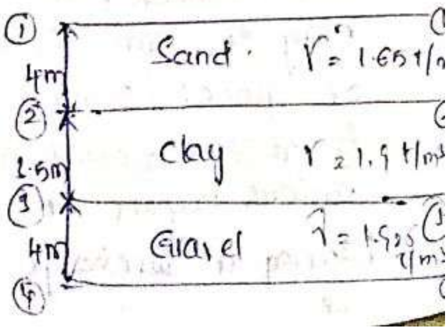
$u = \gamma_w H = 9.81 \times 10 = 98.1\ KN/m^2$

$\sigma' = \sigma - u = 145.26\ KN/m^2$

(*) A soil profile consists of a surface layer of sand 4m and density 1.65 tonnes/m3 an intermediate layer of clay 3.5m density 1.9 tonnes/m3 and bottom layer of gravel 4m thick, density 1.925 tonnes/m3. The water table is at the upper surface of the clay layer. compute the effective stress at various layers of the ground surface. A surcharge of 50 KN/m2 is applied at the ground surface

Sol:-

@ ① - ①



total stress σ = Surcharge + γH (0)

$= 50 + 0$

$= 50\ KN/m^2$

$u = 0$

@ (2) - (2)

total stress

$\sigma = 50\ kN/m^2 + 1.6 \times 10 \times 4$ m kN/m

$\sigma = 116\ kN/m^2$

$u = \gamma_w h = \gamma_w(0) = 0$

$\sigma' = \sigma - u = 116\ kN/m^2$

@ (3) - (3) total stress $(\sigma) = 50 + 16.5 \times 4 + 19 \times 3.5$

$\sigma = 182.5\ kN/m^2$

Pour water pressure $(u) = \gamma_w h = 9.81 \times 3.5$

$u = 34.33\ kN/m^2$

effective stress $\sigma' = \sigma - u = 182.5 - 34.33$

$= 148.17\ kN/m^2$

@ (4) - (4)

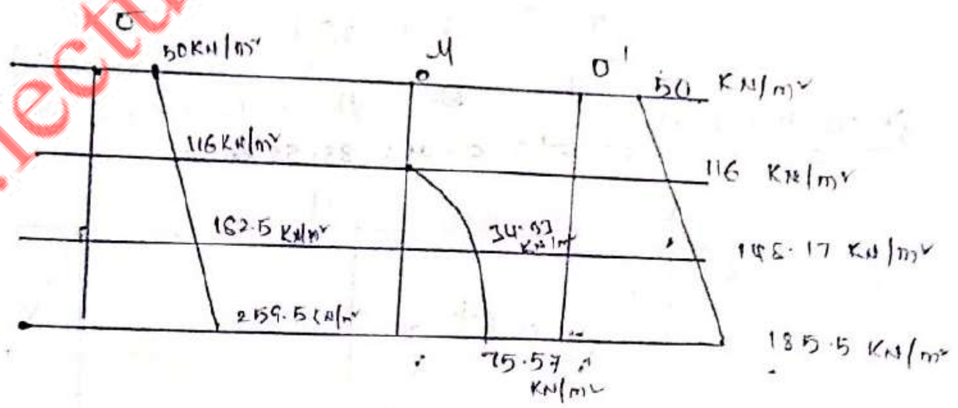
$\sigma = 50 + 16.5(4) + 19(3.5) + 19.25(4)$

$\sigma = 259.5\ kN/m^2$

$u = \gamma_w h = 9.81(3.5 + 4) = 73.57\ kN/m^2$

$\sigma' = \sigma - u = 185.9\ kN/m^2$

pressure distribution diagram :-

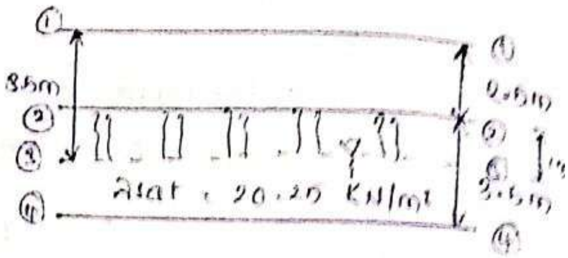


Model 2 :- capillary Rise.

* A sand deposit consists of two layers the top layer is 2.5 m thick density 16.77 kN/m³. and the bottom layer is 3.5 thick. Saturated unit wt is 20.25 kN/m³. The water table is at a depth of 3.5 m from the ground surface. The zone of capillary saturation is 1 m

above the water table draw the Neutral stress effective stress and the water table?

Sol:-



@ ① - ①

$\sigma = \gamma H = 0$

$u = 0$

$\sigma' = \sigma - u = 0$

@ 2.5 m depth (above)

$\sigma = \gamma H = 16.77(2.5) = 41.92$ KN/m²

$u = 0$

$\sigma' = \sigma - u = 41.92$ KN/m²

@ 2.5 m depth (just below)

$u = -\gamma_w H = -9.81(1) = -9.81$ KN/m²

$\sigma = 16.77 \times 2.5 = 41.92$ KN/m²

$\sigma' = \sigma - u$

$= 41.92 - (-9.81) = 51.7$ KN/m²

@ ③ - ③

$\sigma = 16.77(2.5) + 20.25(1)$

$\sigma = 62.17$ KN/m²

$u = \gamma H = 0$ KN/m²

$\sigma' = 62.17$ KN/m²

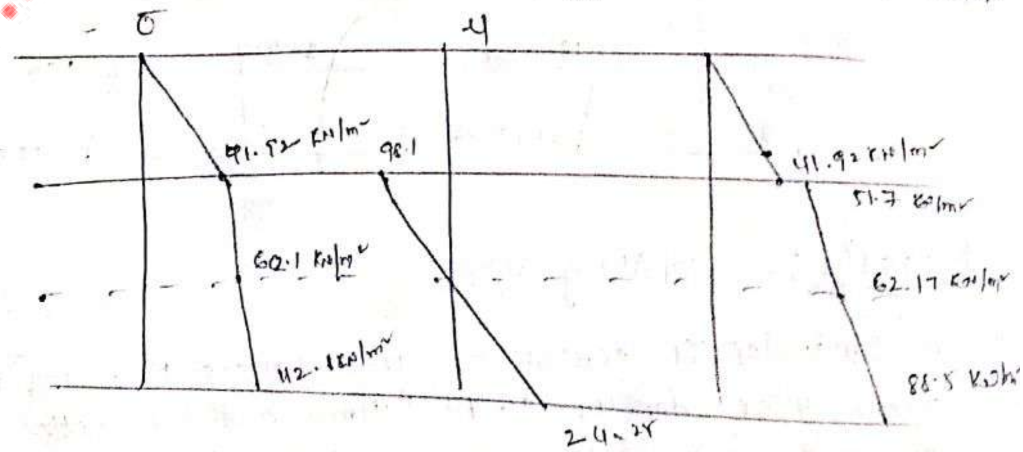
@ ④ - ④

$\sigma = 16.77(2.5) + 20.25(3.5) = 112.8$ KN/m²

$u = \gamma_w H = 9.81(2.5) = 24.25$ KN/m²

$\sigma' = \sigma - u = 88.55$ KN/m²

Stress distribution :-



Q) In a poly head permeameter equal time intervals are not for the drop of head h_1 to h_2 and again h_2 to h_3. Then find h_2

Sol:

$t_1 = t_2 = t$

h_1 to h_2 , h_2 to h_3

$K_1 = 2.303 \times \frac{aL}{At_1} \log_{10}\left(\frac{h_1}{h_2}\right)$

$K_2 = 2.303 \times \frac{aL}{At_2} \log_{10}\left[\frac{h_2}{h_3}\right]$

$\log_{10}\left(\frac{h_1}{h_2}\right) = \log_{10}\left(\frac{h_2}{h_3}\right)$

$\frac{h_1}{h_2} = \frac{h_2}{h_3}$

$h_2^2 = h_1 h_3 \Rightarrow \boxed{h_2 = \sqrt{h_1 h_3}}$

Q) In a polyhead permeability test head causing flow was initially 50 cm and it drops 2 cm in 5 min, how much time require for the head to fall 25 cm

Sol:-

$h_1 = 50$ cm

$h_2 = 50 - 2 = 48$ cm

$t_1 = 5\text{min} = 5 \times 60 = 300\text{sec}$

$h_1 = 50$cm

$h_3 = 25$ cm , $t_2 = ?$

We know that $K = 2.303 * \frac{aL}{At} \log_{10}\left(\frac{h_1}{h_2}\right)$

$\cancel{2.303} \times \frac{1}{300} \times \log_{10}\left(\frac{50}{48}\right) = \cancel{2.303} \times \frac{1}{t} \log_{10}\left(\frac{50}{25}\right)$

$\frac{1}{t} = \frac{1}{300} * \log\left(\frac{50}{48}\right) / \log_{10}\left(\frac{50}{25}\right)$

$\boxed{t = 570 \text{ sec}}$

Determination of permeability :-

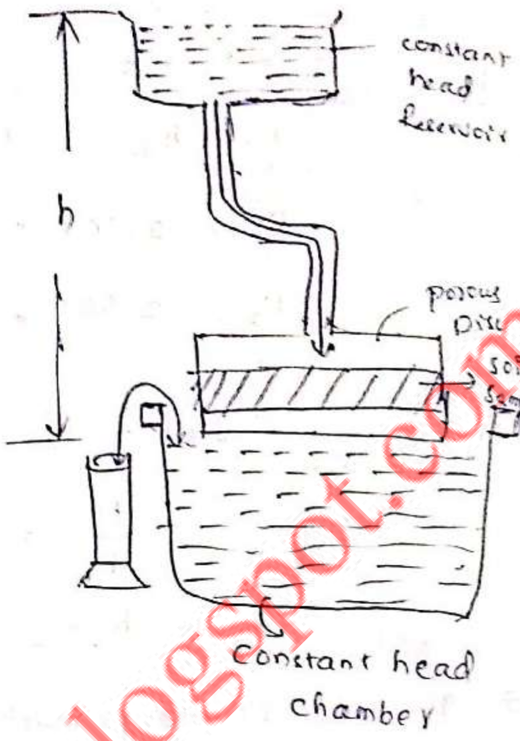
W.K.T $Q = A \times V$

$$Q = A \times Ki$$

$$K = \frac{Q}{A \times i}$$

$$K = \frac{Q}{A \times \frac{h}{L}}$$

$$K = \frac{QL}{Ah}$$



$$Q = \frac{\text{volume of water}}{\text{time}} = \frac{q}{t}$$

$$K = \frac{\frac{q}{t} \times L}{Ah}$$

$$K = \frac{q/t * L}{A \times h \times t}$$

Variable head method :-

$$V = \frac{dh}{dt} \quad , \quad Q = a \times v \quad \text{where } a = \text{standpipe Area}$$

$$Q = a\left(-\frac{dh}{dt}\right)$$

$$\int_{t_1}^{t_2} Q \cdot dt = \int_{h_1}^{h_2} -a\,dh$$

$$AKi \int dt = \int -a\,dh$$

$$AK \cdot \frac{h}{L} \int dt = \int -a\,dh$$

$$K = \frac{a \cdot L \log_e\left(\frac{h_1}{h_2}\right)}{At}$$

$$\therefore \boxed{K = \frac{2.303\, aL \log_{10}\left(\frac{h_1}{h_2}\right)}{At}}$$