Syllabus of Road Geotechinque

Course Outline:

week	Topics Covered
1-3	One Dimensional Fluid Flow ,Permeability and seepage
4-6	Two Dimensional Fluid Flow, Flow through Embankments and Dams
7-10	Consolidation Theory for normally and over consolidated Soil
11-13	Shear Strength Tests, Shear Strength of Sand and Clay, The Mohr Coulomb Failure Criterion
14	Problematic Soils and Subgrade Improvement and Strengthening for highway
15	***Exam + Review of Exam***

Textbooks:

1. Lambe, T. W., and Whitman, R. V. (1979) Soil Mechanics. Wiley, New York.

2. Mitchell, J. K. (1993) Fundamentals of soil behavior, 2nd edition. Wiley, New York **Suggested references:**

1. *Soil Mechanics by R.F.Craig*, Inc., 2010.

2. Introduction to Geotechnical Engineering, By Braja M. Das, 2009.

3. Geotechnical Aspects of Pavements. National Highway Institute. Reference Manual. 2006.

Chapter one

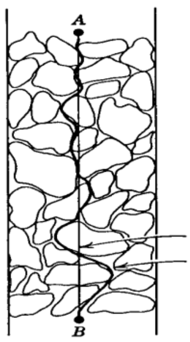
One Dimensional Flow

Soil is a three phase medium (solids, water, and air). Water in soils occurs in various conditions, so permeability can be defined as:

"The property of soils that allows water to pass through them at some rate. This property is a product of the granular nature of the soil"

Different soils have different permabilities, understanding of which is critical to the use of the soil as a foundation or structural element. Soil and rock are porous materials. Fluid flow takes place through interconnected void spaces between particles from a point of high energy to a point of low energy and not through the particles themselves. No soil or rock material is strictly **impermeable**

Why studying flow of water in porous media?



1-To estimate the quantity of underground seepage

2-To determine the quantity of water that can be discharged form a soil

3-To determine the pore water pressure/effective geostatic stresses, and to analyze earth structures subjected to water flow.

4-To determine the volume change in soil layers (soil consolidation) and settlement of foundation.

Flow of Water in Soils depends on:

1. Porosity of the soil
2. Type of the soil - particle size - particle shape - degree of packing
3. Viscosity of the fluid –Temperature – Chemical Components
4. Total head (difference in energy) - Pressure head - Velocity head, Elevation head.
5. The degree of compressibility of a soil is expressed by

Theory

Bernoulli's Law

The total pressure in terms of water head is formed from: pressure head; velocity head; and elevation head. This is known as the Bernoulli's equation:

$$h = P/\gamma_w + v^2/2g + Z$$

h: total head;
u: water pressure;
γw: unit weight of water;
v: velocity of water;
g: gravity acceleration;
Z: elevation head.

The term containing the velocity head can be neglected because the seepage velocity is small, so:

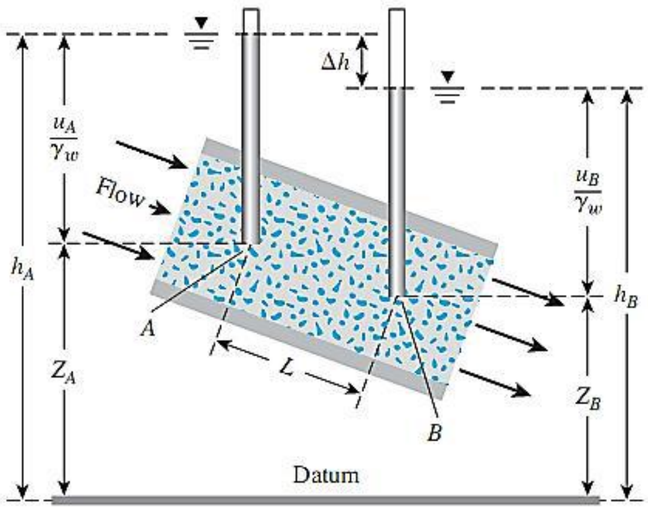
$$h = P/\gamma_w + Z$$

The loss of head between A & B is:

$$\Delta h = hA - hB = (P_A/\gamma_w + ZA) - (P_B/\gamma_w + ZB)$$

$$i = \Delta h / L$$

i: is the hydraulic gradient, L is the distance between A & B and Δh is the head loss between A & B.



Darcy's Law

In 1856, Darcy published a simple equation for discharge velocity of water through saturated soils, which may expressed as

$$v = ki$$

$$q = vA = kiA$$

Where:

v = discharge velocity = quantity of water flowing in unit time through a unit gross – sectional area of soil at right angles to the direction of flow

q = flow rate

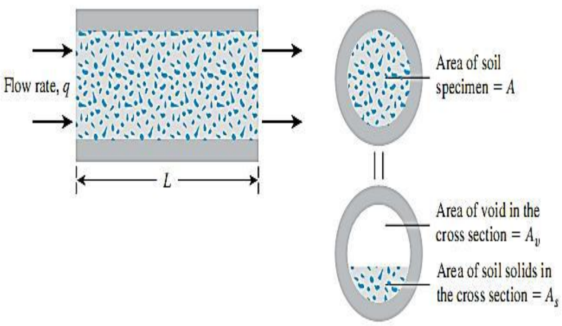
k = coefficient of permeability

A = cross-sectional area

i= hydraulic gradient

(v) is based on the gross sectional area of the soil, however the actual velocity of water (seepage velocity, v_s) through the void spaces is higher than v, this can be derived as following:

$$q = v * A = A_v * v_s$$



Where:

v_s = seepage velocity

A_v = area of void in the cross section of the specimen.

$$A = A_v + A_s$$

Where:

A_s = area of soil solids in the cross section of the specimen.

$$q = v * (A_v + A_s) = A_v * v_s$$

$$v_s = v(A_v + A_s)/Av = v(A_v + A_s) * L / A_v L = v(V_v + V_s)/Vv$$

where

V_v = volume of voids in the specimen

V_s = volume of soil solids in the specimen.

$$v_s = v[(1 + V_v/V_s)/V_v/V_s] = v(1 + e/e) = v/n$$

$$v_s = v/n$$

Coefficient of permeability (Hydraulic conductivity) (K)

- It is defined as the rate of flow per unit area of soil under unit hydraulic gradient, it has the dimensions of velocity (L/T) such (cm/sec or ft/sec).
- The coefficient of permeability is also known as the hydraulic conductivity.
- Hydraulic conductivity of soils depends on several factors such as:
  - fluid viscosity
  - pore-size distribution
  - grain-size distribution
  - void ratio and
  - degree of soil saturation

Typical values of hydraulic conductivity of soil.

Soil Type	k (cm/sec)
Clean gravel	1.0-100
Coarse sand	0.01-1.0
Fine sand	0.001-0.01
Silty clay	0.00001-0.001
Clay	<0.000001

Laboratory determination of hydraulic conductivity

Two standard laboratory tests are used to determine the hydraulic conductivity.

1. **Constant head test**

   The **constant head** test is **used** primarily for **coarse-grained soils**; the test is based on the assumption of laminar flow where k is independent of i; ASTM D 2434.

2. **Falling head test (Variable head test)**

   The **falling head** test is **used** **both** for c**oarse-grained soils as well as fine textured soils**

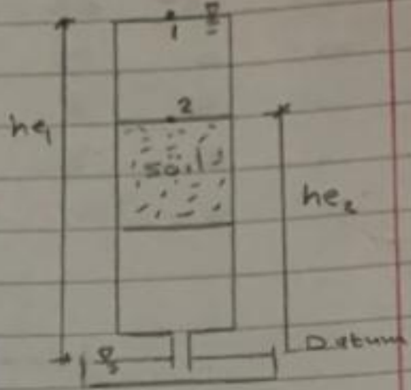
Q/ What causes flow of water through soil?
Answer: ………………….

h_t(at any point inside the soil)=h_t(at begin or end point of the soil) $\mp$ i × (distance)(knowing point to point require

One-Dimension Fluid Flow:

Heads

$h_t = h_p + h_e$ where



h_t = Total head

h_e = elevation head

h_p = pressure head $= P/\gamma_w$

Darcy law

$Q = k\,i\,A$ ← Darcy law

$v = k\,i$ where

Q = volume of fluid

k = coefficient of permeability

i = hydraulic gradient

A = Area of specimen.

v = velocity of fluid in soil (approach velocity)

$Q_{in} = Q_{out}$

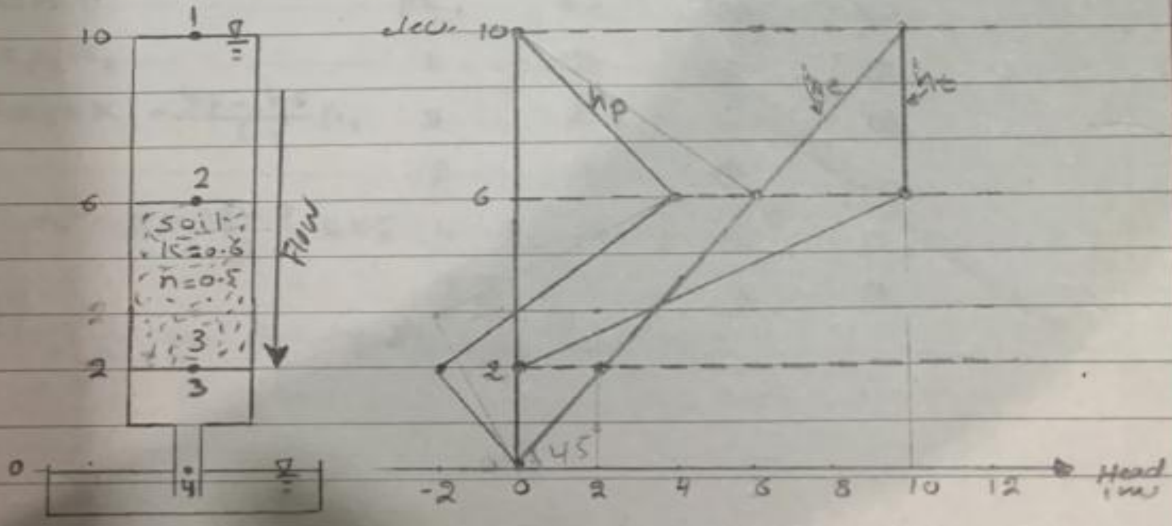
$v_s = \frac{v}{n}$ where v_s = seepage velocity (for soil)

n = porosity.

$i = \frac{\Delta h}{L} = \frac{h_2 - h_1}{L}$

Example No. 1

Find h_e, h_p, h_t, v, v_s at pts.



$Q = k i A$

$i = \frac{h_2 - h_3}{L} = \frac{10-0}{4} = 2.5$

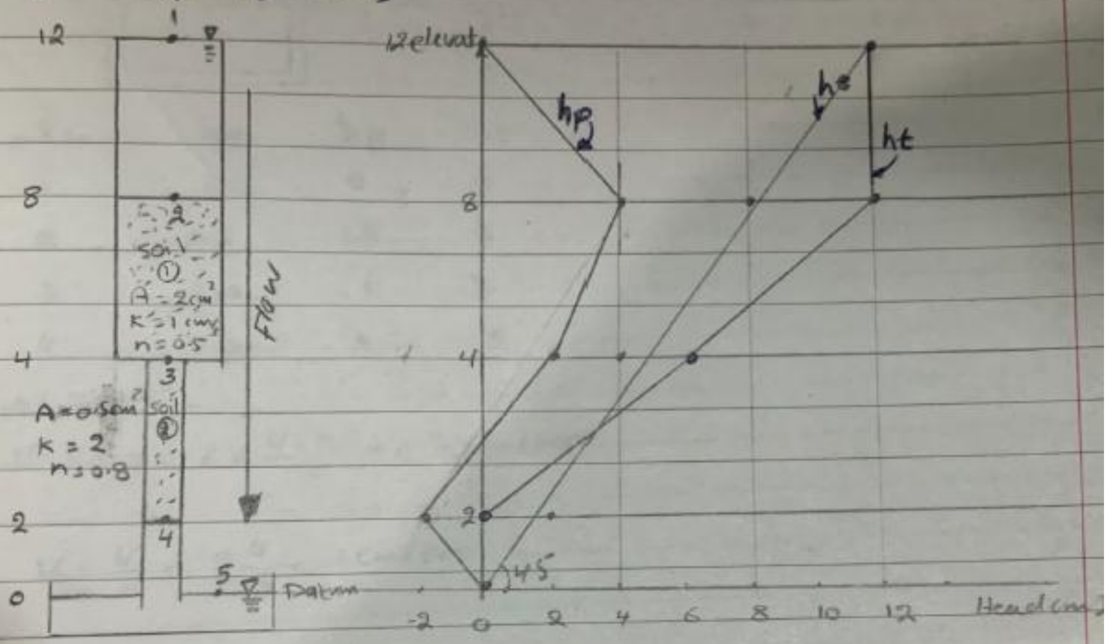
$V = ki = 0.6 * 2.5 = 1.25$ cm/sec

$V_s = \frac{V}{n} = \frac{1.25}{0.5} = 2.5$ cm/sec

pts.	he	hp	ht
1	10	0	10
2	6	4	10
3	2	-2	0
4	0	0	0

Example No. 2

Find he, hp, ht, V, V_s



$Q_{in} = Q_{out}$

$k_1 i_1 A_1 = k_2 i_2 A_2$

$k_1 * \frac{h_1 - h_3}{L_1} * A_1 = k_2 * \frac{h_3 - h_5}{L_2} A_2$

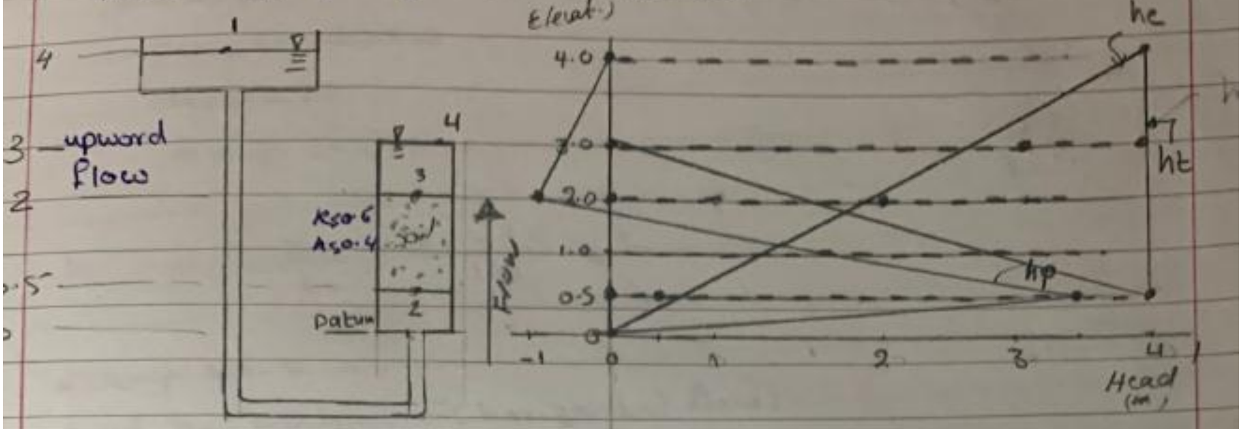
$1 * \frac{12 - h_3}{4} * 2 = 2 * \frac{h_3 - 0}{2} * 0.5$

$\frac{12 - h_3}{4} = \frac{h_3}{4} \rightarrow 12 - h_3 = h_3 \rightarrow h_3 = 6$ m

pt.	he	hp	ht
1	12	0	12
2	8	4	12
3	4	2	6
4	2	-2	0
5	0	0	0

Example No.3

Find h_e, h_p, h_t, velocities, stress



pts.	he	hp	he
1	4	0	4
2	0.5	3.5	4
3	2.0	1	3
4	3.0	0	3

velocities :-

$V = Ki = 0.6 \times \frac{4-3}{1.5} = 0.4$ cm/sec.

$V_s = \frac{V}{n} = \frac{0.4}{0.4} = 1$ cm/sec.

stress :-

$$\gamma_t = \frac{G + Se}{1+e} \gamma_w$$

assume $S = 1$

$$e = \frac{n}{1-n} = \frac{0.4}{1-0.4} = 0.67$$

$$\gamma_t = \gamma_{sat.} = \frac{2.65+0.67}{1+0.67} \times 10 = 20 kN/m^3$$

pts.	$\sigma_t = h_p \cdot \gamma_w$	$u = h_p \gamma_w$	$\sigma' = \sigma_t - u$
3	$1 \times 10 = 10$	$1 \times 10 = 10$	0
2	$1 \times 10 + 1.5 \times 20 = 40$	$3.5 \times 10 = 35$	5

$\sigma_v = \gamma_t b - h \gamma_w$

$0 = 20 * 5 - (h+2) * 10$

$100 = (h+2) * 10$

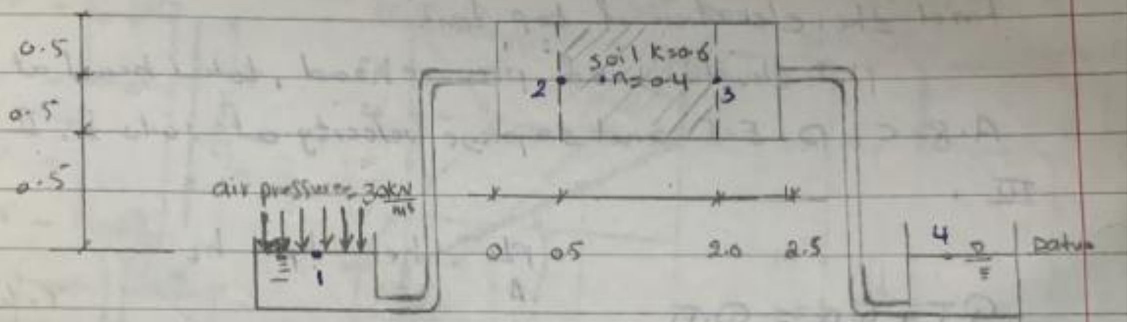
$h + 2 = 10$

$h = 8$ m

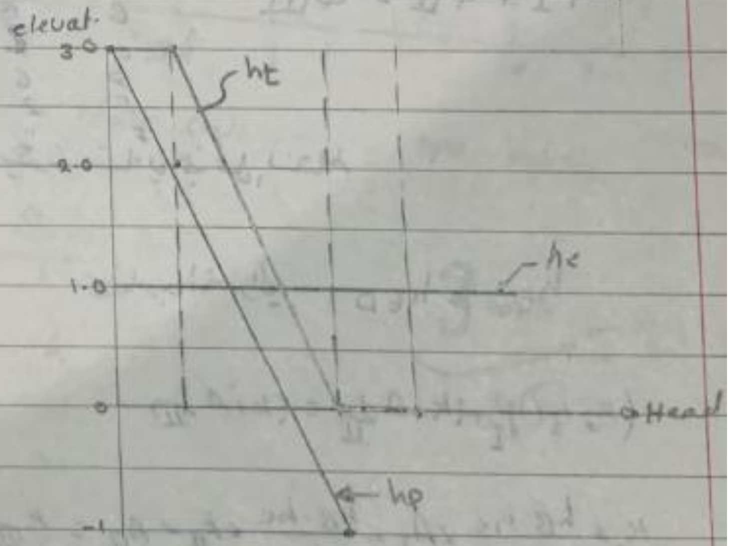
b. $i_c = \frac{\gamma'}{\gamma_w} = \frac{20-10}{10} = 1$

Exampl No. 4 :-

Find h_e, h_p, h_t. (horizontal flow)



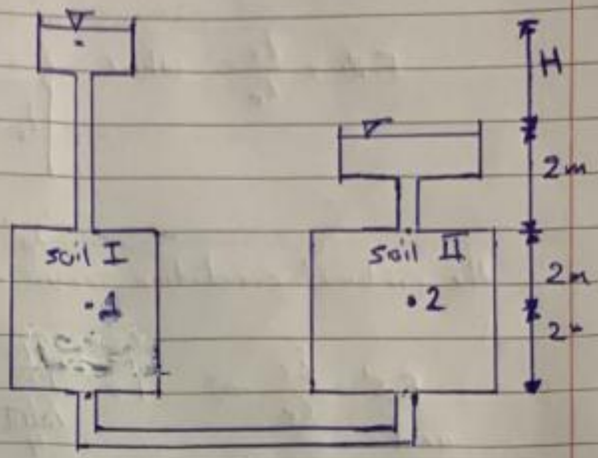
Pts.	he	hp	ht
1	0	3	3
2	1	2	3
3	1	-1	0
4	0	0	0



Ex. 5

For the set up shown the total head at pts. 1 & 2 are 10m and 9.5m respectively. Find:

1. value of H
2. seepage force per unit volume in soil I and II
3. Max. hydraulic head
4. when piping occure in soil I or II first



soil type	K	n	γ	A
soil I	2×10^{-2} cm/se	0.5	18 kN/m³	A
soil II	4×10^{-2} cm/sec	0.333	18 kN/m³	A

Solution

1- the set up is connected series

so $q_I = q_{II}$

$(KiA)_I = (KiA)_{II}$

$K_I \times (\frac{\Delta h}{l})_I \times A_I = K_{II} \times (\frac{\Delta h}{l})_{II} \times A_{II}$

$2\times10^{-2} \times \frac{\Delta h_I}{4} \times A = 4\times10^{-2} \times \frac{\Delta h_{II}}{4} \times A$

$\therefore$ $\boxed{\Delta h_I = 2\,\Delta h_{II}}$ $\Rightarrow$

i from $(1\to2) = \frac{\Delta h}{l} = \frac{10-9.5}{2} \Rightarrow i = 0.25 = i_{II} = \frac{\Delta h_{II}}{l}$

$\therefore$ $0.25 = \frac{\Delta h_{II}}{4} \Rightarrow \Delta h_{II} = 1\,m$

$\therefore$

$\Delta h_I = 2\,m$ and $\underline{\underline{H}} = \Delta h_I + \Delta h_{II} = 1+2 = 3\,m$

2. $J_I = i_I \gamma_w = \frac{\Delta h_I}{l_I}\gamma_w = \frac{2}{4}\times10 = 5\,kN/m^3$

$J_{II} = i_{II}\gamma_w = \frac{\Delta h_{II}}{l_{II}} = \frac{1}{4}\times10 = 2.5\,kN/m^3$

3. Max. head accoure at critical condition ⇒ F.S. = 1

$F.S. = \frac{i_c}{i_e}$ where i_c = critical hydraulic gradient

$$i_c = \frac{\gamma_{sat} - \gamma_w}{\gamma_w}$$ ← مهم

$$i_e = \frac{\Delta h}{\ell}$$

the critical condition occure at soil II

∴

$$F.S. = \frac{i_c}{i_e} \Rightarrow 1 = \frac{\frac{18-10}{10}}{\frac{\Delta h_{II}}{4}} \Rightarrow \Delta h_{II} = 3.2$$

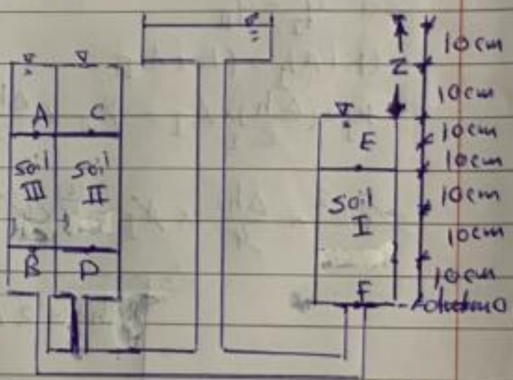
and

$$\%\ \text{loss of soil}_{II} = \frac{\Delta h_{II}}{H} = \frac{1}{3} = 0.333$$

$$\therefore\ H_{max.} = \frac{\Delta h_{II}}{\%\ \text{losss}} = \frac{3.2}{0.333} = 9.6\,m$$

EX. 6

For the set up shown find:
1. h_e, h_p, h_t for pts. A, B, C, D, E & F & V & V_s for soil II ($n = 0.66$)
2. the value of Z that may cause boiling.



	soil I	soil II	soil III	
K	0.02	0.05	0.08	cm/sec
γ	21	20	19	

system is a connect parallel and upward flow

solution:

1.

pt.	he	hp	$h_t = h_p + h_e$
A	40	20	60
B	10	60	70
C	40	20	60
D	10	60	70
E	30	20	50
F	0	70	70

for soil II

$v_s = \frac{v}{n}$ and $v = ki = k \times \frac{h_{tD} - h_{tC}}{\ell_{D \to C}}$

$\therefore v = 0.05 \times \frac{70 - 60}{30} = 0.0167$ cm/sec

$\therefore v_s = \frac{v}{n} = \frac{0.0167}{0.66} = 0.025$ cm/sec > 0.0167 o.k.

2. boiling condition $\Rightarrow F.S. = 1$

$F.S. = \frac{i_c}{i_e} = \frac{\frac{\gamma_{sat} - \gamma_w}{\gamma_w}}{\frac{\Delta h}{\ell}} = \frac{\frac{21 - 10}{10}}{\frac{\Delta h}{0.3}} \Rightarrow \Delta h = 0.33 m = 33$ cm

(مهم ٪ فقدان Δh)

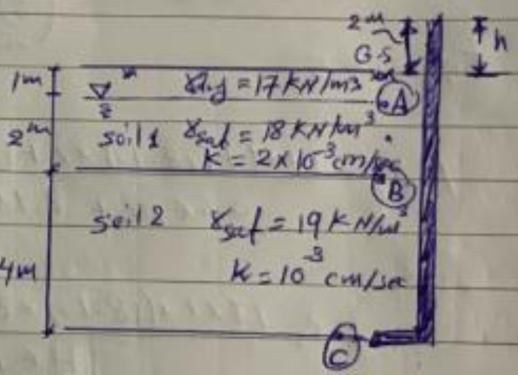
اي الفرق بين الخزانات للوصول ٪ عن نقطة

EX.7.

For soil profile shown in fig.

Find:-

1. The seepage through soil ① in $m^3/day/m^2$
2. effective stress (σ_v') at points A, B, C
3. Max.(h) without cause boiling use F.S. = 1.5



solution:-

$q = kiA = k \times \frac{\Delta h}{\ell} \times A$

first must be found Δh at soil ① $\Rightarrow h_{tA} \to h_{tB}$

but soil profile is in series $\Rightarrow q_1 = q_2$

at pt. A $h_e = 6m$ $h_p = 0 \Rightarrow h_t = 6$

C $h_e = 0$ $h_p = 9 \Rightarrow h_t = 9$

($h_{pA} = 0$ لأنها تقع على سطح الماء)

$\therefore q_1 = q_2 \Rightarrow (kiA)_1 = (kiA)_2$

$2 \times 10^{-3} \times \frac{600 - h_{tB}}{2 \times 100} \times A = 10^{-3} \times \frac{h_{tB} - 9}{4 \times 100} \times A$ (تحويل m إلى SI)

$\therefore h_{tB} = 6.6m$ and $h_e = 4m \Rightarrow h_p = 2.6m$

لكل متر مربع

$$q_{soil_1} = 2 \times 10^{-3}\ \frac{cm}{sec} \times \frac{3600\,sec}{1\,hr} \times \frac{24\,hr}{1\,day} \times \frac{6.6-6}{2} \times (A)$$

$$q = 0.5184\ m^3/day/(m^2)$$

عبارة عن تراكمي من الأعلى الى الأسفل

② pb.

	$\sigma_v = \sum h\gamma$	$u = h_p \times \gamma_w$	$\sigma_v' = \sigma_v - u$
A	$17 \times 1 = 17$	0 (معامل السطح)	17
B	$17 \times 1 + 18 \times 1 + 18 \times 1 = 53$	$2.6 \times 10 = 26$	$53 - 26 = 27$
C	$53 + 2 \times 19 + 19 \times 2 = 129$	$9 \times 10 = 90$	$129 - 90 = 39$

$$3.\quad F.S = \frac{\frac{\gamma_{sat} - \gamma_w}{\gamma_w}}{\frac{\Delta h}{\ell}} \Rightarrow \frac{(\gamma_{sat} - \gamma_w)\,\ell}{\Delta h\,\gamma_w}$$

هنا عمق ارتفاع الماء سطح التربة

لتحديد اي التربة الأضعف يجب حساب (F.S) لكل تربة ومقارنته مع (F.S) المعطى والتربة عليها هي التربة الأضعف

هنا مثل التراكمي

$$F.S_1 = \frac{17 \times 1 + (18-10) \times 2}{0.6 \times 10}$$

التربة الأولى متكونة من الرمل ... الماء الأضعف

$$F.S_1 = 5.5$$

$$F.S_2 = \frac{17 \times 1 + (18-10) \times 2 + (19-10) \times 4}{0.6 \times 10 + 2.4 \times 10} = 2.3 \simeq F.S = 1.5$$

قريب من الحل

$$\therefore F.S = \frac{17 \times 1 + (18-10) \times 2 + (19-10) \times 4}{H \times 10} = 1.5$$

$H = \Delta h_1 + \Delta h_2$

$$\therefore H = 4.6\,m \Rightarrow H_{max} = 4.6 - 1 = 3.6\,m$$

ارتفاع عمود الماء فوق سطح الأرض