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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-3

Geo-technical & Foundation Engineering [All Topics]

Highway Engineering-1 + Surveying and Geology-1 + Strength of Materials-2 + Environmental Engineering-2 [Part Syllabus]

Name : .....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Kolkata ☐ Bhubaneswar ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	45
Q.2	—
Q.3	58
Q.4	43
Section-B	
Q.5	21
Q.6	40
Q.7	—
Q.8	—
Total Marks Obtained	203

Signature of Evaluator ..... Cross Checked by .....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Remarks :-

- Excellent work in Cruotech.
- Question Selection is good.
- Keep practicing.
- Keep it up.
- presentation may be improved.

Section A : Geo-technical & Foundation Engineering

Q.1 (a) A partially saturated soil from an earth fill has a natural water content of 19% and a bulk unit weight of 19.33 kN/m^3. Assuming the specific gravity of soil solids as 2.7, compute the degree of saturation and Void ratio. If subsequently the soil gets saturated, then determine the dry density, buoyant unit weight and saturated unit weight of soil.

[12 marks]

$W_n = 19.1$

Bulk unit wt $\gamma_b = 19.33$ kN/m3

$G = 2.7$

12

$\therefore \quad \gamma_d = \dfrac{\gamma_b}{1+w}$

Dry unit wt.

$$\gamma_d = \frac{19.33}{1+0.19} = 16.24 \text{ kN/m}^3$$

$$\gamma_d = 16.24 = \frac{G\gamma_w}{1+e}$$

$$e = \frac{2.7 \times 9.81}{16.24} - 1$$

void ratio $e = 0.6309$

$$\therefore \quad S = \frac{wG}{e} = \frac{0.19 \times 2.7}{0.6309} = 0.8131$$

Degree of saturn $S = 81.31\%$

Saturated unit weight

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

$$\gamma_{sat} = \left(\frac{2.7+0.6309}{1+0.6309}\right) \times 9.81$$

$= 20.03$

$\gamma_{sat} = 20.03 \text{ kN/m}^3$

Submerged or Boyant unit weight

$\gamma_{sub} = \gamma_{sat} - \gamma_w$

$= 20.03 - 9.81$

$\gamma_{sub} = 10.22 \text{ kN/m}^3$

Q.1 (b) The following data were recorded in a falling head permeability test.
Sample thickness = 2.75 cm
Diameter of soil sample = 8.2 cm
Diameter of stand pipe = 9.5 mm
Initial head of water in stand pipe = 100 cm
Water level in the stand pipe after 3 hours 35 minutes = 75 cm
Determine the coefficient of permeability if void ratio of sample = 0.73. What will be its value if void ratio of sample is increased to 0.91?

[12 marks]

$L = 2.75\ cm$

$D = 82\ mm \Rightarrow A = \frac{\pi}{4}(82)^2$

$d = 9.5\ mm \Rightarrow a = \frac{\pi}{4}(9.5)^2$

$h_1 = 100\ cm$
$h_2 = 75\ cm$
} $t = 3\ hr\ 35\ minutes$

K = Permeability

For falling head permeability test

$$K = \frac{2.303\, a L \log\left(\frac{h_1}{h_2}\right)}{A t}$$

$$= \frac{2.303 \times \frac{\pi}{4}(9.5)^2 \times 2.75 \log\left(\frac{100}{75}\right)}{\frac{\pi}{4}(82)^2 \times (3 \times 60 + 35)}$$

$$K = 4.939 \times 10^{-5}\ cm/min$$

at void ratio of $e_1 = 0.73$

$K_1 = 4.939 \times 10^{-5}$ cm/s $K_2 = ?$

$e_1 = 0.73$ $e_2 = 0.91$

By Allen Hazen

$$\frac{K_1}{K_2} = \frac{\left(\frac{e_1^3}{1+e_1}\right)}{\left(\frac{e_2^3}{1+e_2}\right)}$$

(12)

$$\frac{K_1}{K_2} = \left(\frac{e_1}{e_2}\right)^3 \left(\frac{1+e_2}{1+e_1}\right)$$

$$\frac{K_1}{K_2} = \left(\frac{0.73}{0.91}\right)^3 \left(\frac{1+0.91}{1+0.73}\right)$$

$$\frac{4.939 \times 10^{-5}}{K_2} = 0.56994$$

$$K_2 = 8.665 \times 10^{-5} \text{ cm/s}$$

Q.1 (c) (i) Write short notes for the following:

1. Effect of water content on compaction of soil.
2. Effect of compaction over permeability of soil.
3. Stabilization of soil using calcium chloride.

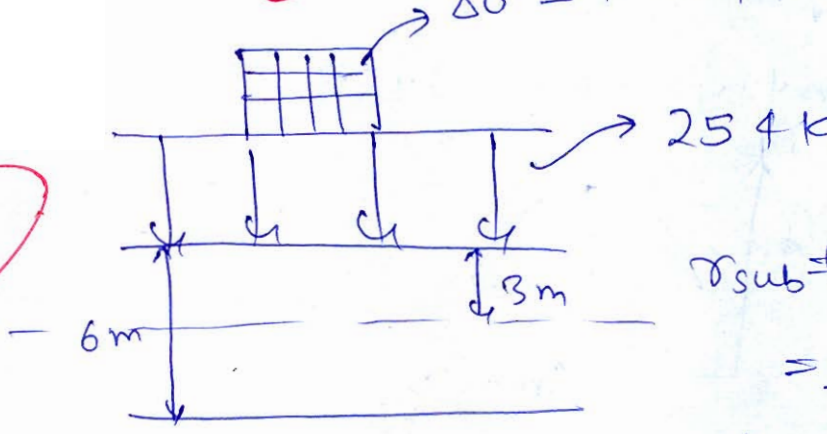
(ii) A layer of saturated clay is 6 m thick and lies under a newly constructed building. The weight of sand overlying the clay layer is 254 kN/m^2 and the new construction increases the overburden pressure by 112 kN/m^2. If the compression index is 0.5, compute the settlement if water content is 45% and specific gravity of solid particles is 2.7.

[6 + 6 marks]

(ii) The layer is saturated $S = 1$

$$e = \frac{wG}{S} = \frac{2.7 \times 0.45}{1}$$

$$e = 1.215$$



$$\gamma_{sub} = \frac{(G-1)}{1+e}\gamma_w = \frac{2.7-1}{1+1.215} \times 9.81$$

$$\gamma_{sub} = 7.529 \text{ kN/m}^3$$

$C_c = 0.5$

Initial Overburden pressure

$$= q + \gamma_{sub} \times 3$$

$$= 254 + 7.529 \times 3$$

$$\bar{\sigma}_o = 276.587 \text{ kN/m}^2$$

$$\Delta\sigma = 112 \text{ kN/m}^2$$

ΔH = Ultimate settlement

$$\Delta H = \frac{C_c H_o}{1+e_o} \log\left(\frac{\bar{\sigma}_o + \Delta\sigma}{\bar{\sigma}_o}\right)$$

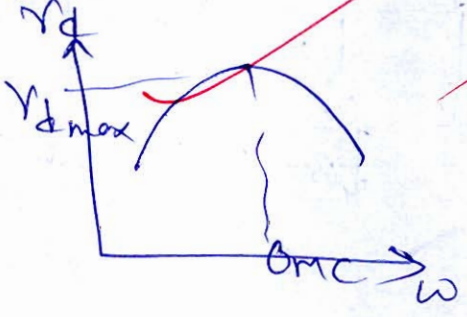
$$\Delta H = \frac{0.5 \times 6\times10^{3}}{1+1.21r}\log\left(\frac{276.587+112}{276.587}\right)$$

$$= 199.98$$

$$\boxed{\Delta H \simeq 200\,mm}$$

(ii) Water content

- By adding water soil can be compacted more
- The fluid particle sorround the soil solid
- lubrication helps to move easily over one another
- Gets into dense state



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→ Permeability:

- Compaction reduces the permeability of soil
- The voids are decreased
- Hence water can not move easily.
- void ratio is decrease by compaction

→ Stablization of soil by CaCl2

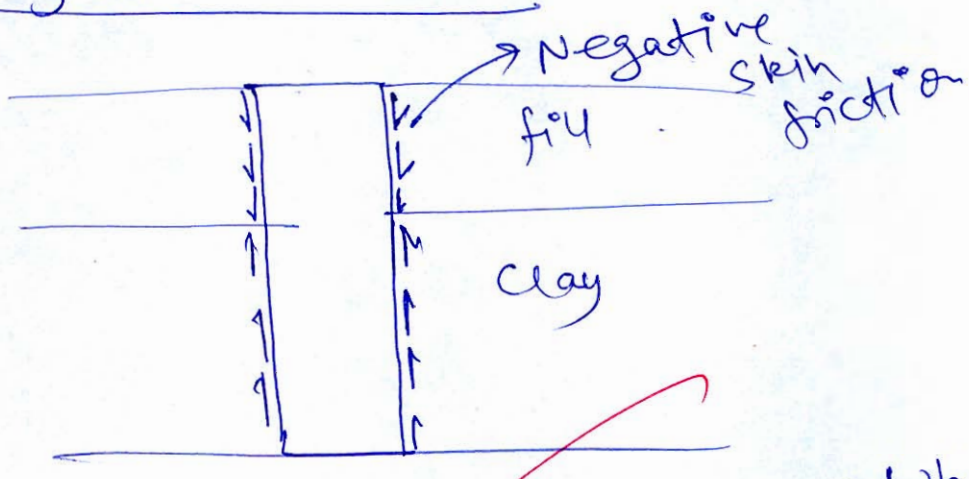
- CaCl2 gets into the void of soil & forms a crystal gel.
- Reduces permeability
- Improves strength.

Q.1 (d) **(i)** Describe methods of foundation design in swelling soil to reduce the swelling effects.

(ii) Explain negative skin friction in case of piles.

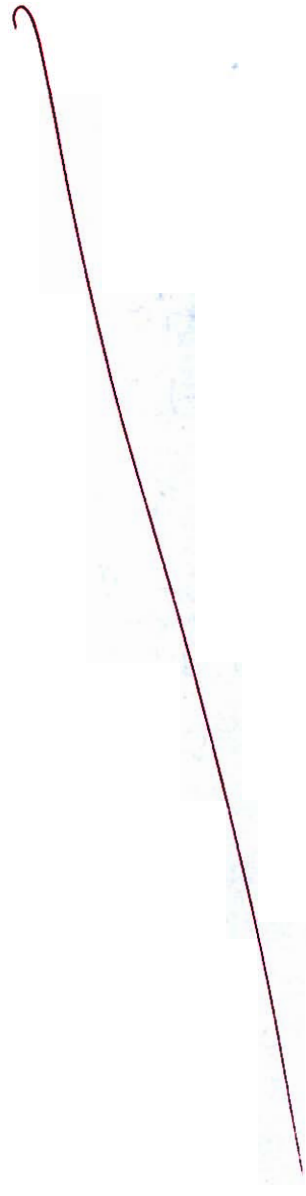
[8 + 4 marks]

(ii) Negative skin friction

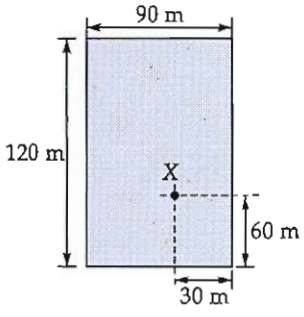


- Negative skin friction occurs when the soil surrounding pile settles more than the pile.
- It Increases the load on the pile
- It occurs in recently fill soil or very soft clay which is consolidated by recent fill.

2



Q.1 (e) The plan of a proposed soil heap is shown in the figure below. The heap will stand on a thick deposit of soft clay having Poisson's ratio of 0.5 with E-value 13.5 MN/m^2. The uniform pressure on the soil may be taken as 175 kN/m^2. Determine the immediate settlement under the point marked 'x' at the surface of the soil.



Shape of loaded area	Influence factor			
	Flexible			Rigid
	Center	Corner	Average	
Circular / rectangular $\left[\frac{L}{B}\right]$	1	0.64	0.85	0.8
1.0	1.12	0.56	0.95	0.9
1.5	1.36	0.68	1.20	1.09
2.0	1.53	0.77	1.31	1.22
5.0	2.10	0.05	1.83	1.68
10.0	2.52	1.26	2.25	2.02
100.0	3.38	1.69	2.96	2.70

[12 marks]

Immediate settlement

$$S_i = \frac{qB(1-\mu^2)I_f}{E_s}$$

12

q = pressure = 175 kN/m^2

B = least dimension = ~~90m~~

$$S_i = \frac{q(1-\mu^2)}{E_s}\left(I_{f_1}B_1 + I_{f_2}B_2 + I_{f_3}B_3 + I_{f_4}B_4\right)$$

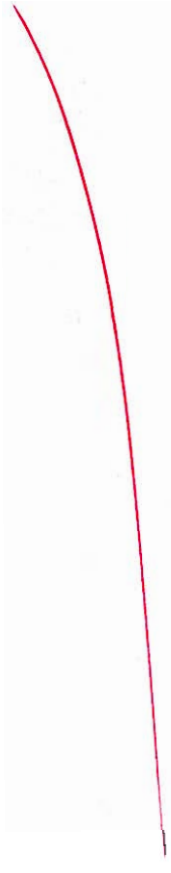
$$= \frac{175(1-0.5^2)}{13.5\times10^3}\left(0.77\times30\times2 + 2\times0.56\times60\right)$$

$$= 1.1025\ \text{m}$$

$$S_i = 1102.5\ \text{mm}$$

Q.2 (a) A wall of 6 m height retains backfill of dry granular soil that weighs 18.5 kN/m^3 has a level surface. When there is no surcharge above the fill, the overturning moment caused by the total active pressure at a point at a base of the wall is 150 kN/meter length of wall. The specifications permit certain amount of uniformly distributed surcharge but state that surcharge must not increase overturning moment by more than 75%. What surcharge can be allowed if the angle of wall friction is 25°?

[20 marks]



Q.2 (b) A 2.5 m square footing carries a safe load of intensity 400 kN/m^2 at a depth of 1 m in sand. The saturated unit weight of sand is 20 kN/m^3 and the unit weight above the water table is 17 kN/m^3. The shear strength parameters are $c = 0$, $\phi = 38°$. Compute the factor of safety with respect to shear failure for the following cases:

(i) The water table is at 5 m below ground level.

(ii) The water table is at 1 m below ground level.

(iii) The water table is at ground level and there is a seepage, acting vertically upwards under a hydraulic gradient of 0.2.

(Take, $N_q = 66.34$ and $N_\gamma = 77.2$)

[20 marks]

Q.2 (c) Derive the expression for change in pore pressure in terms of Skempton's parameters.

[20 marks]

Q.3 (a) (i) A saturated soil has a compression index $C_C = 0.263$. Its void ratio at a stress of 150 kN/m^2 is 1.89 and its permeability is 3.3×10^{-8} cm/sec. Compute the change in void ratio if the stress is increased by 109.5 kN/m^2. For a soil stratum of 4.5 m thick what will be the total settlement? Also determine the time required for 80% consolidation to occur if drainage is one way. (Take $\gamma_w = 9.81$ kN/m^3)

[12 marks]

$\sigma_1 = 150 \text{ kN/m}^2$ $\quad e_1 = 1.89$

$\sigma_2 = 150 + 109.5$ $\quad e_2 = ?$

$= 259.5 \text{ kN/m}^2$

$$C_c = 0.263 = \frac{\Delta e}{\log\left(\frac{\sigma_2}{\sigma_1}\right)}$$

$$0.263 = \frac{1.89 - e_2}{\log\left(\frac{259.5}{150}\right)}$$

$$\boxed{e_2 = 1.827}$$

change in void ratio $= 1.89 - 1.827$

$= 0.063$ Ans

$H_0 = 4.5 \text{ m}$

ΔH = Ultimate or total settlement

$$\Delta H = \frac{C_c H_0}{1 + e_0} \log\left(\frac{\sigma_2}{\sigma_1}\right)$$

$$= \frac{0.263 \times 4.5 \times 10^3}{1 + 1.89} \log\left(\frac{259.5}{150}\right)$$

$$\boxed{\Delta H = 97.48 \text{ mm}}$$

$\%.U = 80\%$

$T_v = 1.781 - 0.933 \log (100 - 80)$

$T_v = 0.5671$

$T_v = \frac{C_v t}{d^2}$

$C_v = \frac{k}{m_v \gamma_w}$

$k \rightarrow$ permeability

$m_v \rightarrow$ coeff of vol^m compress.

$m_v = \frac{a_v}{1+e_0} = \frac{\Delta e}{\Delta \sigma (1+e_0)}$

12

$m_v = \frac{0.063}{109.5(1+1.89)}$

$m_v = 1.99 \times 10^{-4}\ m^2/kN$

$C_v = \frac{3.3 \times 10^{-10}}{1.99 \times 10^{-4} \times 9.81}\ m^2/s$

$C_v = 1.6897 \times 10^{-7}\ m^2/s$

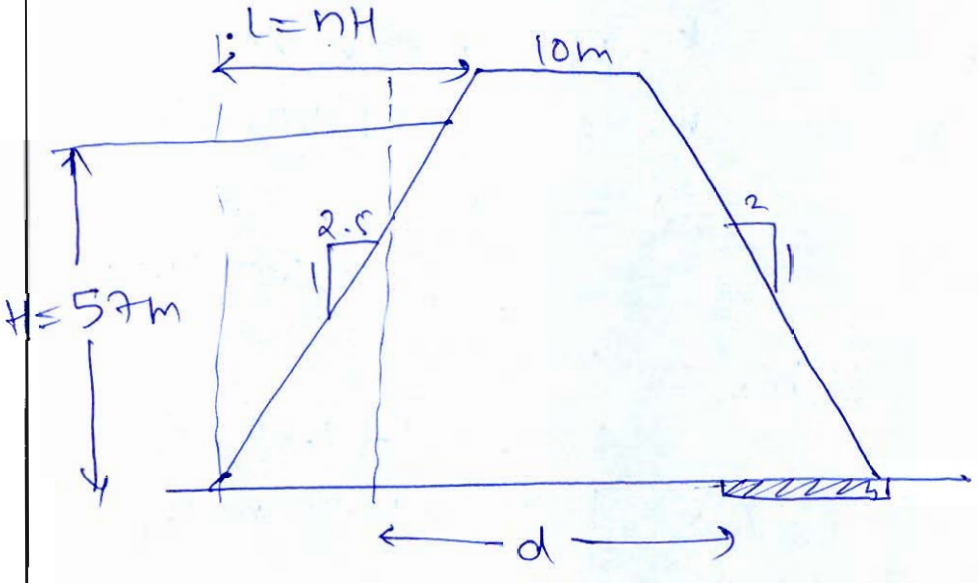
$0.5671 = \frac{1.6897 \times 10^{-7} \times t \times 365 \times 8640}{4.5^2}$

~~$t = 78$~~ $t = 2.155$ years

Q.3 (a) (ii) Calculate the seepage through an earthen dam resting on an impervious foundation. The relevant data are given below:

Height of the dam = 60 m
Upstream slope = 2.5 : 1 [H : V]
Downstream slope = 2 : 1 [H : V]
Feeboard = 3 m
Crest width = 10 m
Length of drainage blanket = 90 m
Coefficient of permeability of the embankment material in
X-direction = 8×10^{-7} m/s
Y-direction = 6×10^{-7} m/s

[8 marks]



Base width = $10 + 60 \times 2.5 + 60 \times 2$

$= 280$ m

d = Base width − filter length − $0.7L$

~~$L = h$~~ $L = nH$

$L = 2.5 \times 57 = 142.5$ m

$d = 280 - 90 - 0.7 \times 142.5$

$d = 90.25$ m

Convert it into equivalent sec^n

$$d = d_T\sqrt{\frac{K_x}{K_y}} \Rightarrow d_T = d\sqrt{\frac{K_y}{K_x}}$$

$$d_T = 90.25\sqrt{\frac{6\times10^{-7}}{8\times10^{-7}}} = 78.15\text{ m}$$

Seppage discharge $q = K'S$

$$S = \sqrt{d_T^2 + H^2} - d_T$$

$$= \sqrt{78.15^2 + 57^2} - 78.15$$

$$S = 18.58\text{ m}$$

$$K' = \sqrt{K_x K_y} = \sqrt{8\times10^{-7}\times6\times10^{-7}}$$

$$K' = 6.928\times10^{-7}\text{ m/s}$$

seepage discharge per m length

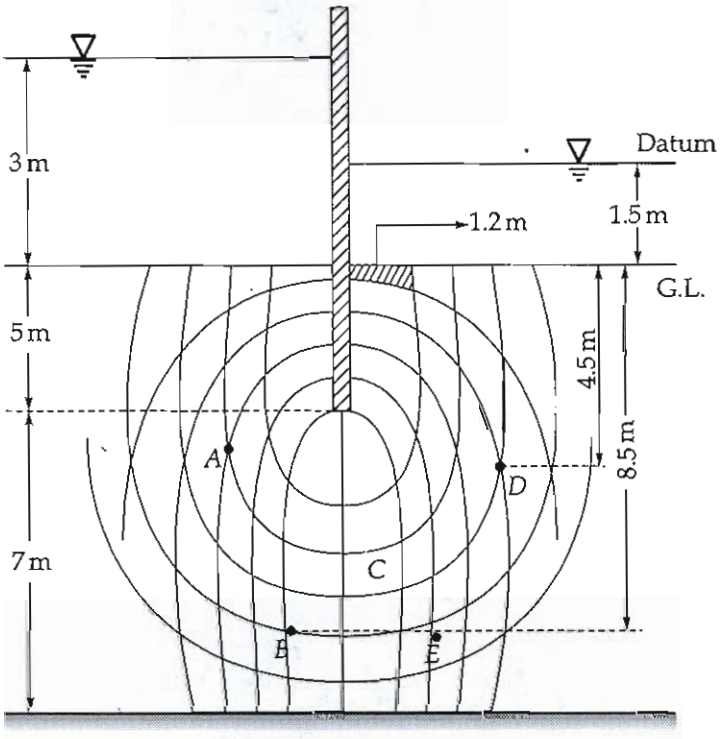
$$= 6.928\times10^{-7}\times18.58$$

$$q = 1.2872\times10^{-5}\text{ m}^3/\text{s/m length}$$

Ans

Q.3 (b) (i) A sheet pile is driven upto a depth of 5 m in a bed of sand having coefficient of permeability in x-direction and z-direction equals to 0.002 cm/sec and 0.0025 cm/sec respectively. An impervious clay layer exists at a depth of 12 m below the ground level. The sheet pile is retaining water upto 3 m on upstream side and upto 1.5 m on downstream side as shown in figure.

(Take, $\gamma_w = 9.81$ kN/m^3)



Determine:

1. The quantity of seepage loss per unit width.
2. The seepage pressure at the points A, B, C, D and E.
3. The pore water pressure at the points B and D.
4. Exit gradient when minimum distance between equipotential lines at downstream ends is 1.2 m.
5. Factor of safety against piping. Given, $G = 2.67$ and porosity $(\eta) = 0.35$.

[15 marks]

$K_x = 0.002$ cm/s $\quad K_z = 0.0025$ cm/s

Head difference $H = 3 - 1.5$

$H = 1.5$ m

No. of flow channels $N_f = 6$

No. of equipotential drop $N_d = 12$

(i) The quantity of seepage loss per unit width $q = K' H \frac{N_f}{N_d}$

$$q = \sqrt{2\times10^{-5} \times 2.5\times10^{-5}} \times 1.5 \times \frac{6}{12}$$

$$q = 1.677 \times 10^{-5}\ m^3/s/m \text{ width}$$

(ii) seepage pressure at point A, B, C, D, E
$= (H - n\Delta h)\gamma_w$

14 n = no. of equipotential drop for concerned point

$$\Delta h = \frac{H}{N_d} = \frac{1.5}{12} = 0.125\,m$$

seepage Pressure at A $= (H - 3\Delta h)\gamma_w$
$= (1.5 - 0.125\times3)9.81$
$= 11.036\ KN/m^2$

seepage Pressure at B $= (1.5 - 5\times0.125)9.81$
$= 8.58\ KN/m^2$

seepage Pressure at C $= (1.5 - 7\times0.125)9.81$
$= 6.13\ KN/m^2$

seepage pressure at D $= (1.5 - 9\times0.125)9.81$
$= 2.452\ KN/m^2$

seepage pressure at E $= (1.5 - 8\times0.125)9.81$
$= 4.905\ KN/m^2$

(iii) Total Head = Seepage pressure or seepage Head

pore pressure at B = $(TH - DH)\gamma_w$

$= ((1.5 - 5\times0.125) - (-10))\,9.81$

$= 106.68\ KN/m^2$

pore pressure at D

$= [(1.5 - 10\times0.125) - (-6)]\,9.81$

$= 61.3125\ KN/m^2$

(iv) exit gradient $i_{exit} = \frac{\Delta h}{l}$

$= \frac{0.125}{1.2} =$

$\boxed{i_{exit} = 0.10416}$

(v) $i_{cr} = \left(\frac{G-1}{1+e}\right)$ $\qquad e = \frac{n}{1-n}$

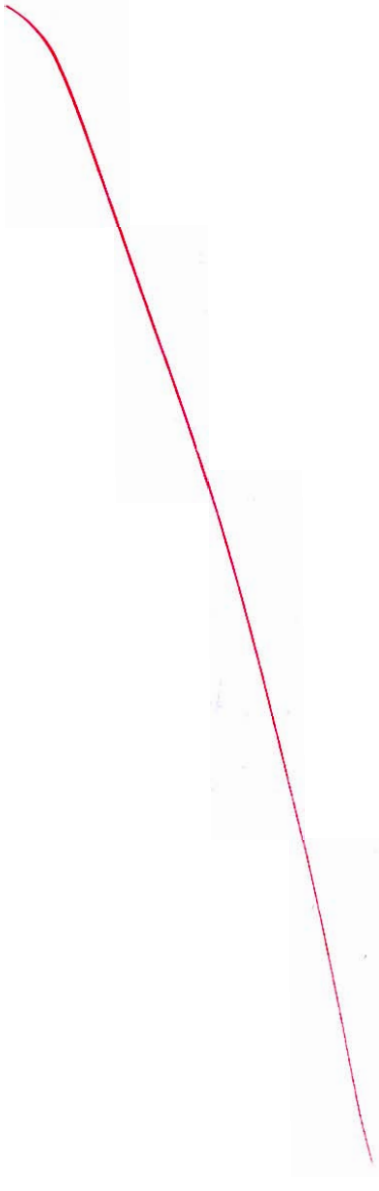
$e = \frac{0.35}{1-0.35} = 0.5384$

$= \left(\frac{2.67-1}{1+0.5384}\right)$

$i_{cr} = 1.08554$

$FOS = \frac{i_{cr}}{i_{exit}} = \frac{1.08554}{0.10416}$

$\boxed{FOS = 10.42}$



Q.3 (b) **(ii)** Write Terzaghi's guidelines for the design of protective filter along with their respective significance.

[5 marks]

(i) $\left(\frac{D_{15}}{D_{85}}\right)_{\text{protected soil}} > 4$ (Base material)

(ii) $\left(\frac{D_{15}}{D_{15}}\right)_{\text{protected soil}} < 20$ (Base material)

(iii) $\left(\frac{D_{50}}{D_{50}}\right)_{\text{protected soil}} < 25$ (Base material)

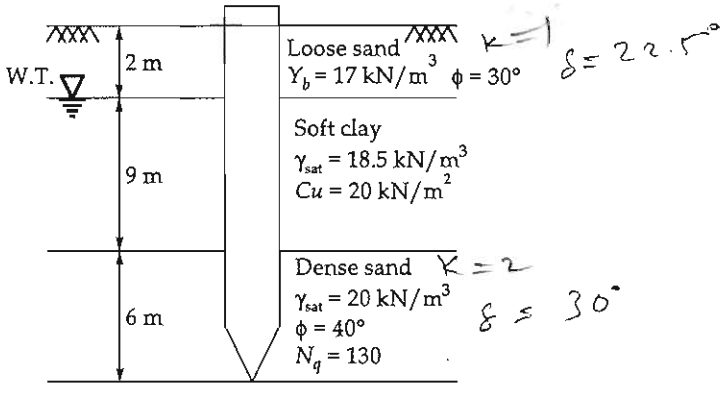
4

→ First criteria is for prevention of surface particle erosion. It is for stopping the erosion & preventing piping failure

→ second criteria is for expulsion of uplift pressure which could damage filter if not removed.

→ 3rd criteria is an additional one.

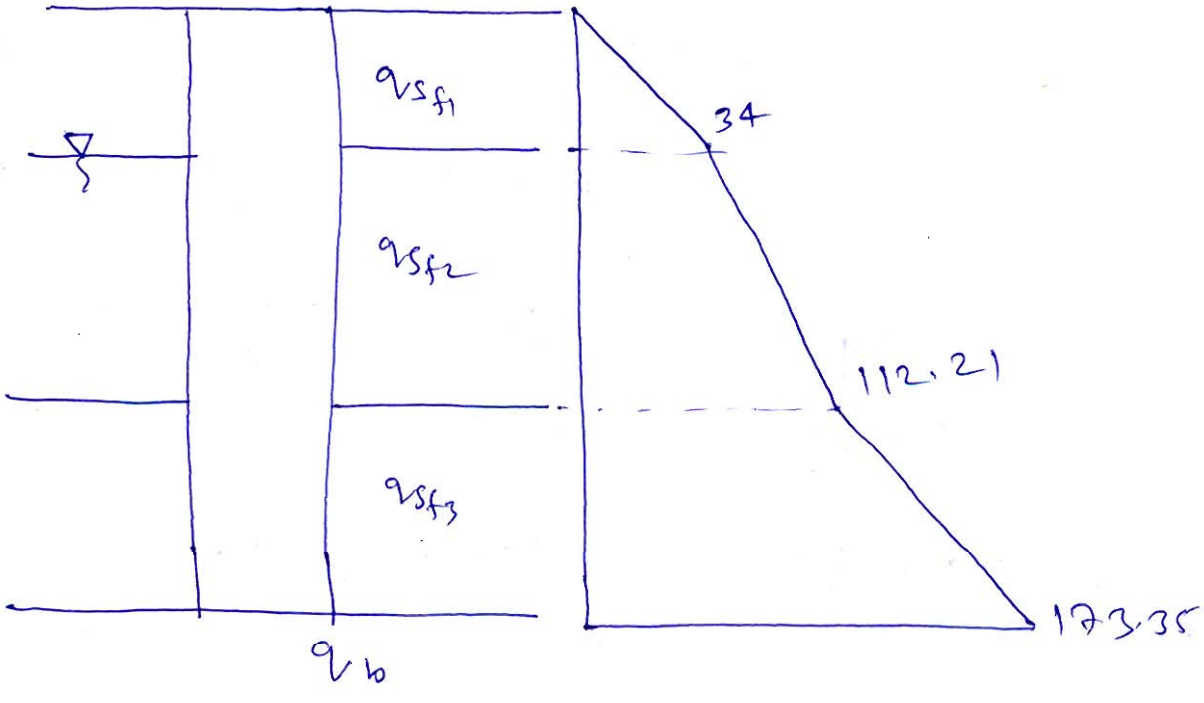
Q.3 (c) Determine the ultimate pile-load capacity of 50 cm diameter pile shown in the figure below:



The angle of friction between pile and soil is 0.75 times of angle of internal friction of soil. The earth pressure coefficient for loose sand is 1 and for dense sand is 2. Adhesion factor for soft clay is taken as 1.

[20 marks]

$d = 0.5\,m$



$Q_{up} = q_b A_b + q_{sf_3} A_1 + q_{sf_2} A_2 + q_{sf_1} A_3$

$q_b = (\bar{\sigma}_{v\,base})\, N_q$

$= 173.35 \times 130 = 22535.5\ kN/m^2$

$< 11000\ kN/m^2$

So $q_b = 11000\ kN/m^2$

$$q_{sf_1} = K(\bar{\sigma}_{vavg}) \tan\delta$$

$$= 1 \times \left(\frac{0+34}{2}\right) \tan 22.8$$

$$q_{sf_1} = 7.041 \text{ kN/m}^2$$

$$q_{sf_2} = \alpha \bar{C}_u = 1 \times 20 = 20 \text{ kN/m}^2$$

$$q_{sf_3} = K(\bar{\sigma}_{vavg}) \tan\delta$$

$$= 2 \times \left(\frac{112.21 + 173.35}{2}\right) \tan 30$$

$$= 164.868 \text{ kN/m}^2 > 100 \text{ kN/m}^2$$

$$q_{sf_3} = 100 \text{ kN/m}^2$$

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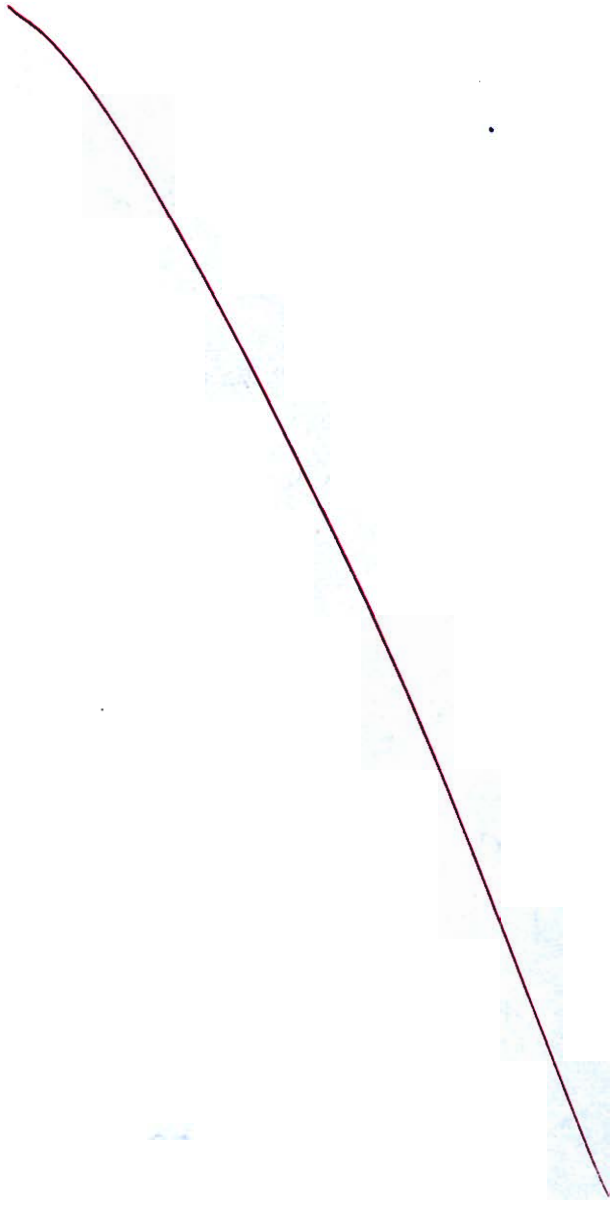
$$Q_{up} = q_b A_b + q_{sf_1} A_1 + q_{sf_2} A_2 + q_{sf_3} A_3$$

$$= 11000 \times \frac{\pi}{4}(0.5)^2 + 7.041 \times \pi(0.5) \times 2$$

$$+ 20 \times \pi(0.5) \times 9 + 100 \times \pi(0.5) \times 6$$

$$= 2159.575 + 22.119 + 282.74 + 942.477$$

$$Q_{up} = 3406.911 \text{ kN}$$



Q.4 (a) **(i)** Explain in brief about free swell test and bulking of sand.

(ii) A group of nine piles, 12 m long and 250 mm in diameter is to be arranged in a square form in a clay soil with an average unconfined compressive strength of 60 kN/m^2. Work out the centre to centre spacing of the piles for a group efficiency factor of 1. Neglect bearing at the tip of piles.

(Assume adhesion factor $\alpha = 0.9$)

[8 + 12 marks]

(i) → Free swell test

- Free swell test used for finding increase in volm without applying stress
- 10cc of soil is taken which is finer than 425μ sieve.
- It is poured in 50 cc of distilled water.
- left undisturbed for 24 hrs
- After 24 hrs the increase in volume is noted
- It is due to fact soil absorb water.

$$\text{Free swell} = \frac{V_f - V_i}{V_i} \times 100$$

Bentonite → 1200 – 2000%.

Kaolinite → 80%.

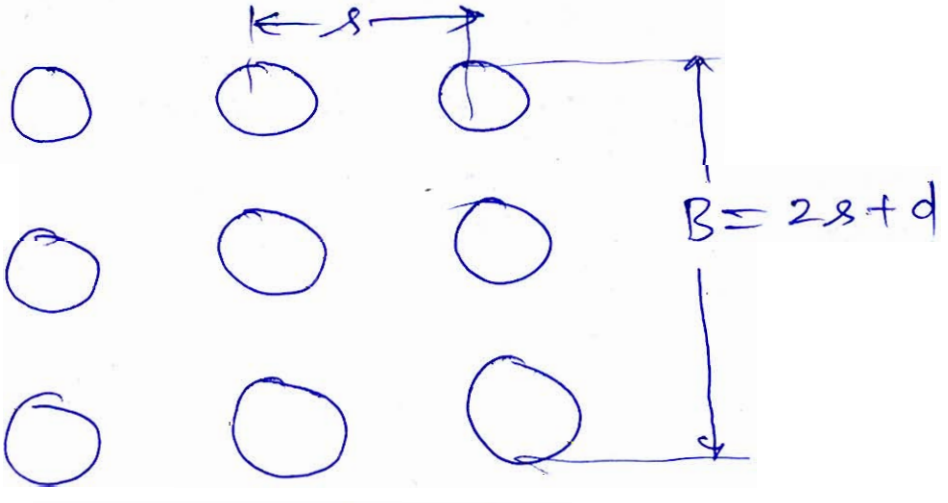
Illite → 30 – 50%

→ Bulking of Sand

- Sand if moistened shows Volm increase considerably.
- If left in a heap increase volm
- It is due to the capillary action of water. which induces apparent cohesion

- Apparent cohesion help in forming cluster of soil.
- Bulking depends on water content
- It is maximum at 5 — 6 % of moisture content.
- If soil gets less than full saturated the mensi brokes & sand reduces volm.

(ii)



Neglect bearing

$\eta = 100\ \%$

$n Q_{up} = Q_{ug}$

$Q_{ug} = \frac{1}{2} C 4BL$ (Neglected bearing)

$= \frac{60}{2} \times 4 \times B \times 12$

$Q_{ug} = 1440B$

$Q_{up} = \$ \alpha C \pi d L$

$= 0.9 \times \frac{60}{2} \times \pi \times 0.25 \times 12$

$= 254.469$ kN

$9 \times 254.469 = 1440 B$

(10)

$B = 1.59$ m

$B = 2s + d = 1.59$

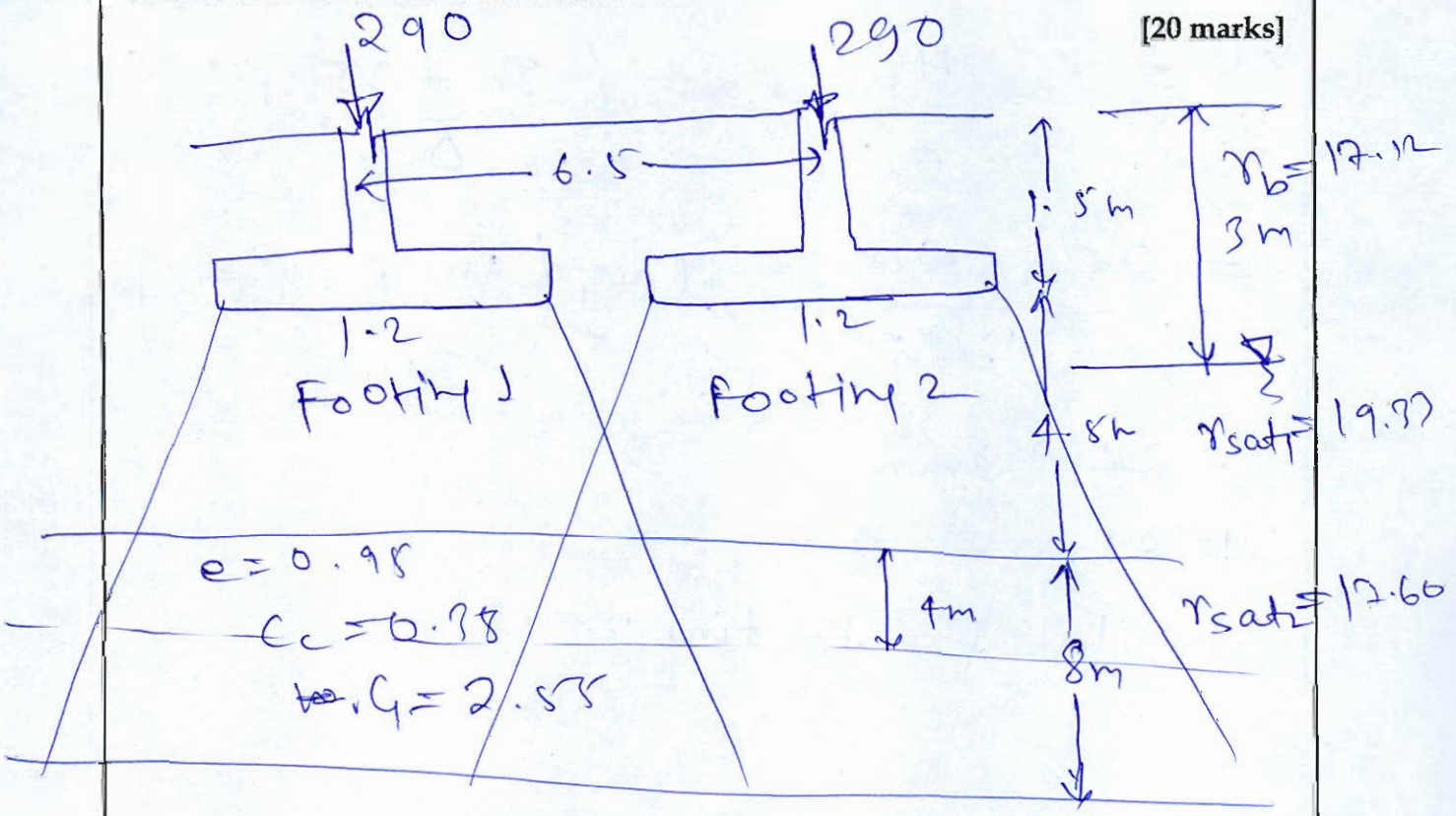
$2s + 0.25 = 1.59$

$s = 0.670$ m

$s = 670$ mm centre to centre Spacing

min^m spacing $= 3d = 750$ mm

Q.4 (b) Two column footings 1.2 m × 1.2 m each, spaced at 6.5 m centre to centre and located at a depth of 1.5 m in sand layer of thickness 6 m, transmit a building load of 290 kN each. A 8 m thick compressible clay stratum is found to be present below the sand layer. Below the clay layer is found a stiff impervious stratum. The water table is existing at 3 m below the ground surface. Sandy soil is having specific gravity of 2.65, void ratio of 0.7 and moisture content (above water table) of 12%. The clay soil is having a specific gravity of 2.55, average void ratio of 0.95 and coefficient of compression of 0.38. Determine the ultimate settlement of the column. **[20 marks]**



$$\gamma_b = \frac{2.65(1+0.12)\times 9.81}{1+0.7} = 17.12 \text{ KN/m}^3$$

$\gamma_{sat_1} = 19.33$ KN/m³ $\quad \gamma_{sat_2} = 17.60$ KN/m³

For Footing 1

$\overline{\sigma_0} = 3 \times (17.12) + 3(19.33 - 9.81) + 4(17.60 - 9.81)$

$\overline{\sigma_0} = 111.38$ KN/m²

Assuming 2V : 1H Distrb^n

For footing 1

$$\Delta\sigma = \frac{290}{(1.5 + 2\times\frac{1}{2}\times 8.5)^2} + \frac{3}{2\pi}\times\frac{290}{(8.5)^2}\left(\frac{1}{1+\left(\frac{6.5}{8.5}\right)^2}\right)^{5/2}$$

$$= 2.9 + 0.6061$$

$$\Delta\sigma \approx 3.506 \text{ kN/m}^2$$

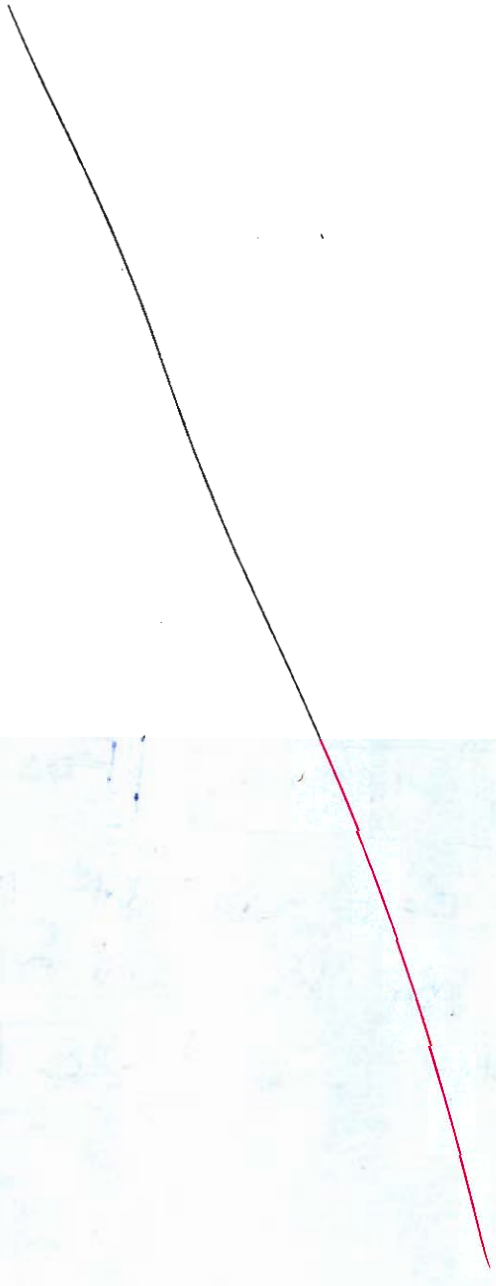
$$\Delta H = \frac{C_c H_0}{1+e_0}\log\left(\frac{\bar{\sigma}_0 + \Delta\sigma}{\bar{\sigma}_0}\right)$$

$$= \frac{0.38\times 8000}{1.95}\log\left(\frac{111.38+3.506}{111.38}\right)$$

$$= 20.98 \text{ mm}$$

$$\Delta H \approx 21 \text{ mm}$$

Similar for footing 2 also



Q.4 (c) A 10 m deep cutting has side slope of 1.5 : 1 (H:V). The soil was tested and found to have the cohesion of 25.7 kN/m^3 void ratio of 0.8 and angle to internal friction of 14°. Determine the factor of safety w.r.t. to cohesion, against failure of the slope, when;

(i) water level in the cut rises up to full height.

(ii) water level goes down suddenly.

Specific gravity of soil is 2.7.

For the given slope, stability numbers for different angles of internal friction is given below,

ϕ	S_n
6°	0.122
7°	0.116
14°	0.074

[20 marks]

~~C = 25.5~~ $C = 25.7$ kN/m^2

$e = 0.8$

$\gamma_{sat} = \left(\frac{2.7 + 0.8}{1 + 0.8}\right) 9.81$

$\gamma_{sat} = 19.075$ kN/m^3

(i) for ~~to~~ $\phi = 14°$

$S_n = 0.074$ from table

$FOS = \frac{C}{H_c \gamma_{sat} S_n} = \frac{25.7}{10 \times 9.265 \times 0.074}$

~~FOS = 1.820~~ FOS = 3.74

Hence FOS against failure when water level in the cut rises upto full height is ~~1.80~~ 3.74

(iii) For Sudden drawdown

$$\phi' = \frac{\gamma_{sub}}{\gamma_{sat}} \phi$$

$$\phi' = \frac{(19.078 - 9.81)}{19.078} \times 14^\circ$$

$$\phi' = 6.8^\circ$$

20

By Interpolation

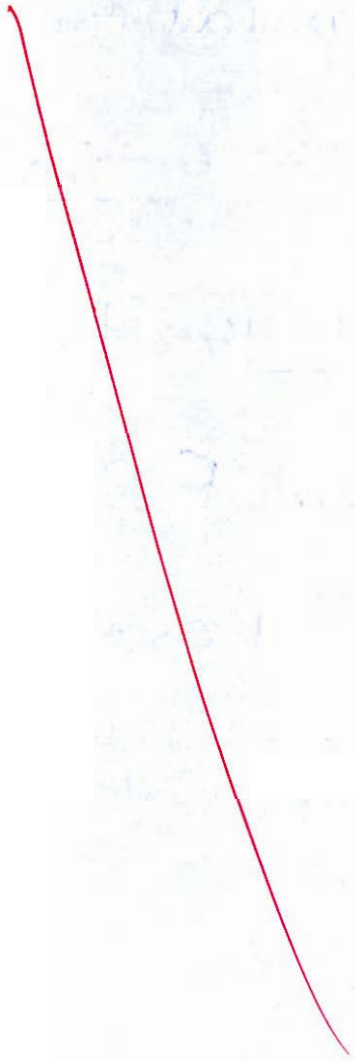
$$\frac{6 - 7}{0.122 - 0.116} = \frac{6 - 6.8}{0.122 - S_n}$$

$$S_n = 0.1172$$

~~$FOS = \frac{C}{\gamma_{sat} H}$~~ $FOS = \frac{C}{\gamma_{sat} S_n H}$

$$FOS = \frac{25.2}{19.078 \times 0.1172 \times 10}$$

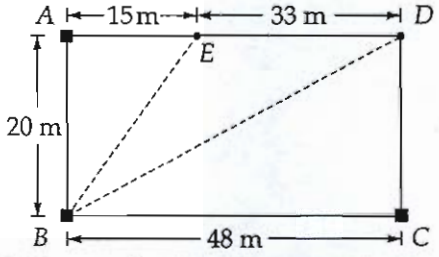
$$FOS = 1.149$$



Section B : Highway Engineering-1 + Surveying and Geology-1 + Strength of Materials-2 + Environmental Engineering-2

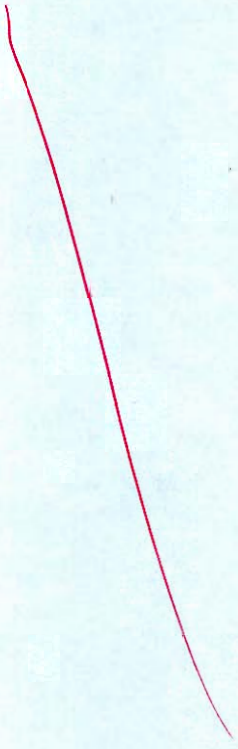
Q.5 (a) Figure given below shows a rectangle *ABCD*, in which *A*, *B* and *C* are the stations where staff readings were obtained with a level set up at *E* and *D*. The observed readings are tabulated as shown.

Level at	Staff reading at		
	A	*B*	*C*
E	1.855	0.808	–
D	2.427	1.368	1.666



If *A* is a benchmark having an elevation of 120 m, calculate the correct elevations of *B* and *C*. Also find the missing staff reading at *C* from instrument location *E*.

[12 marks]



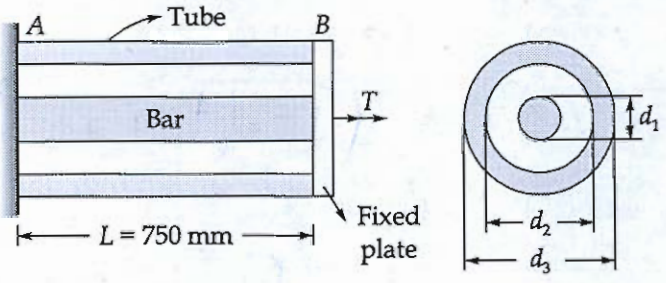
Q.5 (b) Distinguish between Telford's and Macadam's method of road construction in terms of subgrade slope, foundation stones, base course, surface course and thickness of cross-section. Also what technological lessons do you derive from macadam pavement?

[12 marks]

Q.5 (c) A solid steel bar of diameter $d_1 = 35$ mm is enclosed by a steel tube of outer diameter $d_3 = 47.5$ mm and inner diameter $d_2 = 40$ mm as shown in figure. Both bar and tube are held rigidly by a support at end A and joined securely to a rigid plate at end B. The composite bar which has a length $L = 750$ mm is twisted by a torque $T = 450$ N-m acting on the end plate. Determine:

(i) The maximum shear stress τ_1 and τ_2 in the bar and tube respectively.

(ii) The angle of rotation ϕ (in degrees) of the end plate and torsional stiffness K_T of the composite bar, assuming the shear modulus of steel as 80 GPa.



[12 marks]

As shafts are parallel so angle of Twist will be same for both shaft

$$\theta_1 = \theta_2$$

$$\frac{T_1 L}{G J_1} = \frac{T_2 L}{G J_2}$$

$d_1 = 35$ mm $\quad d_2 = 40$ mm $\quad d_3 = 47.5$ mm

$$\frac{T_1}{\frac{\pi}{32}(35)^4} = \frac{T_2}{\frac{\pi}{32}(47.5^4 - 40^4)}$$

$$\boxed{T_2 = 1.6864\, T_1}$$

$$T_1 + T_2 = 450 \text{ Nm}$$

$$T_1 = 167.51 \text{ Nm}$$

$$T_2 = 282.488 \text{ Nm}$$

$$\tau_1 = \frac{16T_1}{\pi d_1^3} = \frac{16 \times 167.51 \times 10^3}{\pi (35)^3} = 19.89 \text{ MPa}$$

$$\tau_2 = \frac{T_2 \, d_3/2}{\frac{\pi}{32}(d_3^4 - d_1^4)} = \frac{16T_2}{\pi d_3^3 (1-k^4)} \qquad k = \frac{d_2}{d_3}$$

$$= \frac{16 \times 2822.488 \times 10^3}{\pi \times 47.5^3 \left(1 - \left(40/47.5\right)^4\right)}$$

$\tau_2 = 27.017$ MPa

$\tau_1 = 19.89$ MPa

$\tau_2 = 27.017$ MPa

(ii) $\phi = \frac{T_1 L}{G J_1} = \frac{167.51 \times 10^3 \times 750}{80 \times 10^3 \times \frac{\pi}{32}(35)^4}$

$\phi = 0.01066$ rad

$\phi = 0.6113°$

$$K_T = \frac{T}{\theta} = \frac{450}{0.01066} = 42.213 \text{ kN/rad}$$

Units are wrong

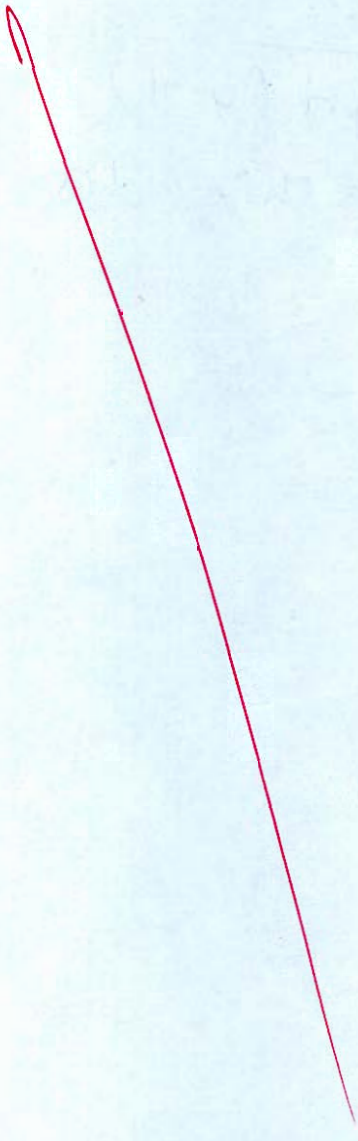
Q.5 (d) Explain the importance of self cleansing velocity in designing of sewers. Derive shield's expression for self cleansing velocity in a sewer.

[12 marks]

→ self cleansing velocity importance

- It is the velocity which must be present in sewer to avoid silting
- If a sewer doesn't have this velocity it will lead to blockage of sewer
- $V_H = 4.5\sqrt{gd(G-1)}$ (2)

→ shield's eqn for self cleansing velocity



Q.5 (e) A completely mixed activated-sludge plant is to treat 10000 m^3/d of industrial wastewater. The wastewater has a BOD_5 of 1200 mg/l that must be reduced to 200 mg/l prior to discharge to a municipal sewer. Pilot-plant analysis indicates that a mean cell-residence time of 5 days maintaining MLSS concentration of 5000 mg/l produces the desired results. The value for Y i.e. decimal fraction of food mass converted to biomass is determined to be 0.7 kg/kg and value of K_d is found to be 0.03 day^{-1}. Determine:

(i) Volume of reactor.

(ii) Mass and volume of solids wasted each day.

(iii) Sludge recirculation ratio.

Assume an underflow concentration of 15 kg/m^3 from secondary clarifier.

[12 marks]

$Q = 10000\ m^3/d$

$S_o = 1200\ mg/l$

$S = 200\ mg/l$

$\theta_c = 5\ days$

$X = 5000\ mg/l$

$Y = 0.7\ kg/kg \qquad K_d = 0.03\ d^{-1}$

(i) As we know

$$VX = \frac{Q_o(S_o - S)Y\theta_c}{1 + K_d\theta_c}$$

$$V \times 5000 = \frac{10000(1200 - 200)0.7 \times 5}{1 + 5 \times 0.03}$$

$$\boxed{V = 6086.95\ m^3}$$

(ii) Sludge Age $\theta_c = \dfrac{VX}{(Q_o - Q_w)X_e + Q_w X_u}$

$X_e \simeq 0$

$X_u = \dfrac{15\ kg/m^3}{10000\ m^3/d} \qquad X_u = \dfrac{10000}{15}$

$$\theta = \frac{VX}{Q_w X_u}$$

Mass of solid wasted per day

$$= \frac{6086.95 \times 5000 \times 10^3}{5 \times 10^6}$$

8

$$Q_w X_u = 6086.95 \text{ kg/d}$$

Volume of sludge wasted per day $= \frac{6086.95 \text{ kg/d}}{15 \text{ kg/m}^3}$

$$Q_w = 405.79 \text{ m}^3/\text{d}$$

(iii) Sludge Recirculation Ratio

$$R = \frac{X}{X_u - X} = \frac{5000}{15000 - 5000}$$

$$R = 0.5$$

Q.6 (a) (i) Write a short notes on the effects of following factors in determining the stopping sight distance.

1. Efficiency of brakes.
2. Slope of the road surface.

[6 marks]

(1) Efficiency of brakes

$$\eta = \frac{f}{f_{max}} \Rightarrow \boxed{f = \eta f_{max}}$$

Brake distance $L_B = \frac{V^2}{254 f} = \frac{V^2}{254 \eta f_{max}}$

4

As we can see that Brake distance is inversly proportional to the efficiency of brakes.

- If Efficiency increases max longitudinal friction will act and hence brake distance will reduce
- If η Decreases min friction will act & Hence brake distance will increase

(2) Slope of road surface

Camber is provided as cross-slope for drainage purpose

Gradient is also provided longitudnal along the raad

$$\text{Gradient} = 2 \times \text{camber}$$

Q.6 (a) (ii) For a two-lane two-way traffic road, the following are the particulars:

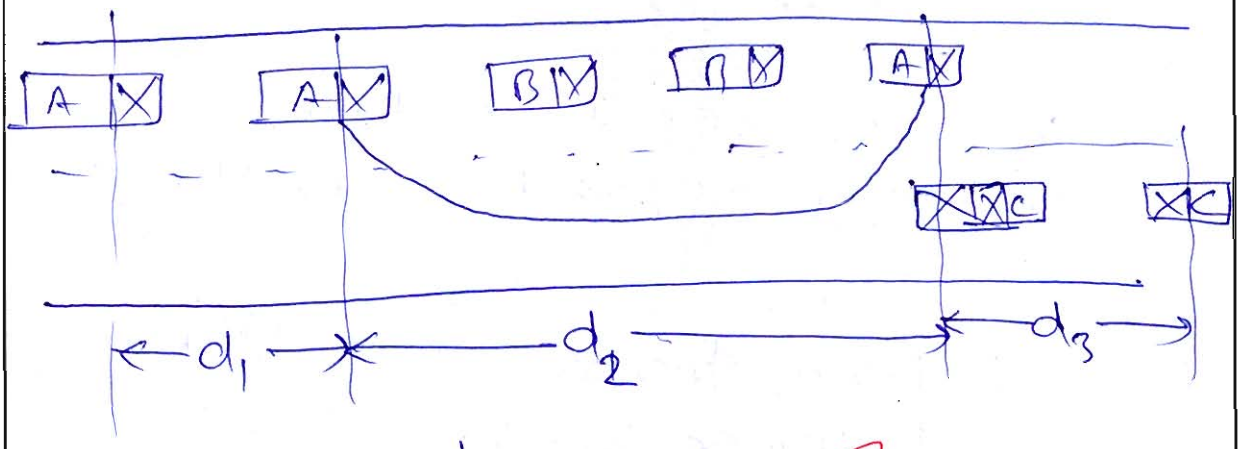
Speed of overtaking vehicle = 65 kmph
Speed difference between the vehicles = 15 kmph
Acceleration of overtaking vehicle = 3.28 kmph/sec
Perception time of driver of overtaking vehicle = 2 seconds
Length of overtaking vehicle = 6 m

Calculate the following:

1. Length of safe OSD.
2. Minimum length of overtaking zone.
3. Desirable length of overtaking zone.

Also, draw the neat sketch of the overtaking zone showing the position of the sign posts.

[14 marks]



$V = 65$ kmph

$V_B = 65 - 15 = 50$ kmph

$a = 3.28 \times \frac{5}{18} = 0.91$ m/s^2

$t_r = 2$ secs

$l = 6$ m

$S = 0.2 V_B + l = 0.2 \times 50 + 6$

$S = 16$ m

$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 16}{0.91}} = 8.38$ secs

$d_1 = 0.278 V_B t_r$

$d_1 = 0.278 \times 50 \times 2 = 27.8$ m

$d_2 = 0.278 V_B T + 2s$

$= 0.278 \times 50 \times 8.38 + 2 \times 16$

$d_2 = 148.482$ m

$d_3 = 0.278 VT$

$= 0.278 \times 65 \times 8.38$

$d_3 = 151.426$ m

(i) length of safe OSD $= d_1 + d_2 + d_3$

$= 27.8 + 148.482 + 151.426$

$= 327.708$ m

(ii) Minimum length of overtaking zone = 3OSD

$= 3 \times 327.708$

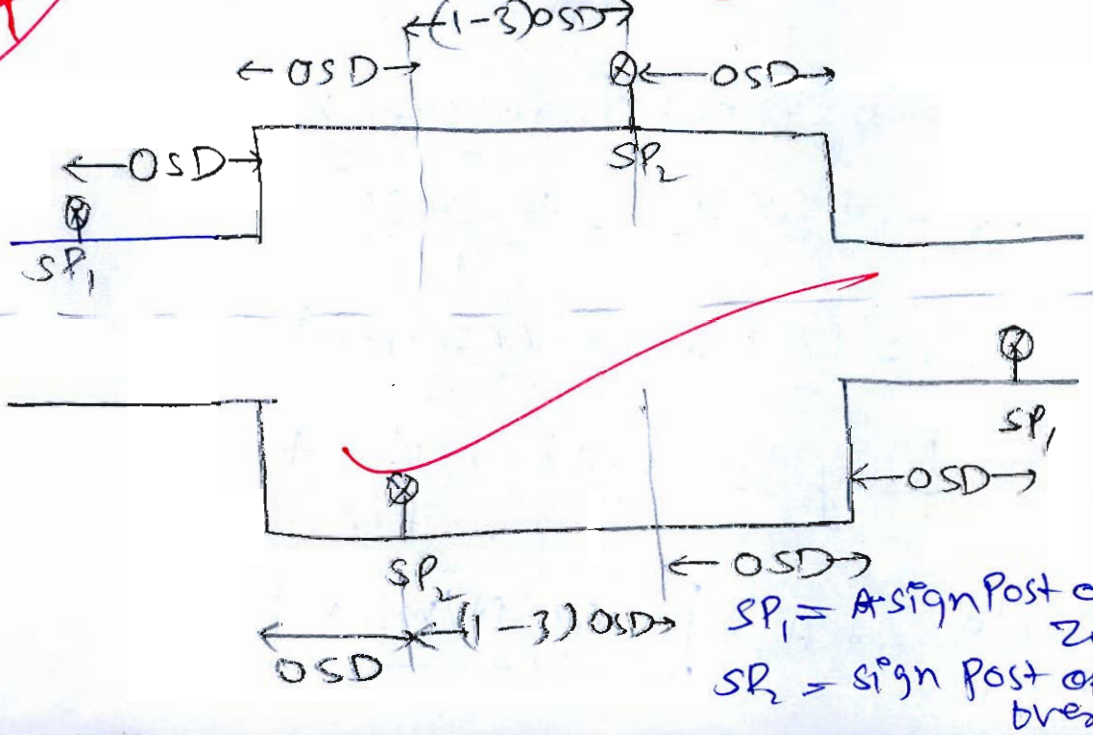
$= 983.12$ m

(iii) Desirable length of overtaking zone = 5OSD

$= 5 \times 327.708$

$= 1638.54$ m

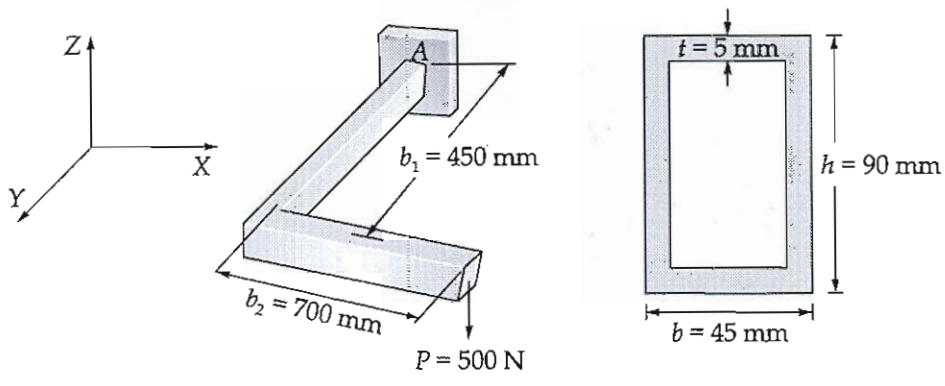
14



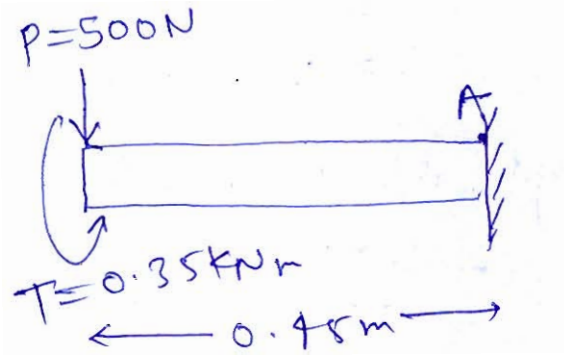
SP_1 = A sign Post of overtaking zone ahead

SP_2 = sign Post of end of overtaking zone

Q.6 (b) (i) An L-shaped bracket lying in a horizontal plane supports a load $P = 500$ N as shown in figure. The bracket has a hollow rectangular cross-section with thickness $t = 5$ mm having outer dimension $b = 45$ mm and $h = 90$ mm. The center line lengths of the arms are $b_1 = 450$ mm and $b_2 = 700$ mm. Considering only the load P, calculate the maximum tensile stress, maximum compressive stress and maximum shear stress at point A, which is located on the top of the bracket at the support.



[15 marks]



→ For maximum tensile stress

Bending Moment at point A $= 0.5 \times 0.45$

$= 0.225$ KNm

Moment of Inertia along X-axis

$$I_X = \frac{45 \times 90^3}{12} - \frac{35 \times 80^3}{12}$$

$$I_X = 1240416.667 \text{ mm}^4$$

$$\sigma_A = \frac{M}{I_x} y = \frac{0.225 \times 10^6 \times 45}{1240416.667}$$

Tensile stress at A $= 8.162$ N/mm^2

→ Compressive stress at A = 0

(because at the top of bracket only tensile force will develop no compressive only bottom points will have compressive stress).

→ Shear stress at A

Due to torque ~~$\tau = \frac{TR}{J}$~~

8

$$\tau_1 = \frac{T}{2 A_m t}$$

$A_m = (45-5)(90-5) = 3400\ mm^2$

$$\tau_1 = \frac{0.35 \times 10^6}{2 \times 3400 \times 5}$$

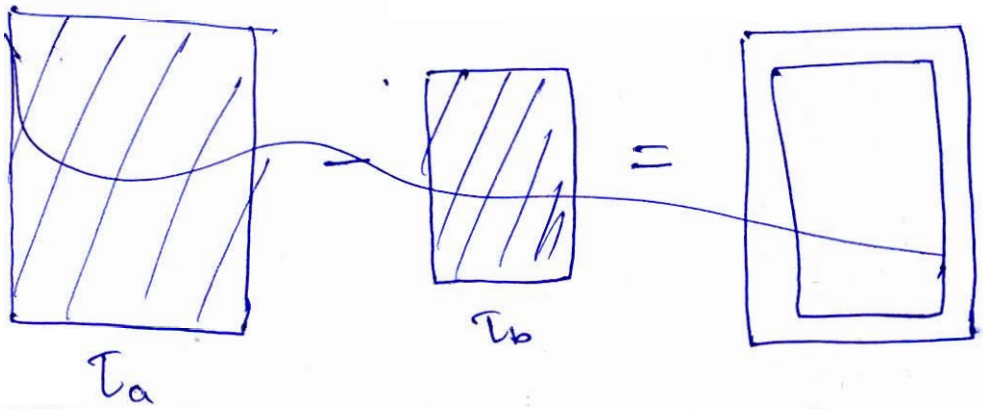
$$\boxed{\tau_1 = 10.294\ N/mm^2}$$

~~Due to direct shear stress~~

~~$\tau_2 = \frac{VA\bar{y}}{Ib}$ or $\frac{3}{2}\tau_{avg}$~~

~~$\tau_2 = 0.5 \times 10^3$~~

~~$\tau_2 = 500$~~

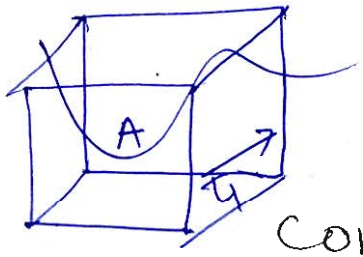


$$\tau_2 = \frac{500 \times 45 \times 45 \times \frac{45}{2}}{\frac{45 \times 90^3}{12} \times 45} - \frac{500 \times 35 \times 40 \times 20}{\frac{35 \times 80^3}{12} \times 35}$$

$$0.18518 -$$

$$\tau_2 = \frac{500 \times (35 \times 5 \times 42.5 + 2 \times 45 \times 5 \times \frac{45}{2})}{1240416.667 \times 10}$$

$$\tau_2 = 0.70792 \text{ N/mm}^2$$



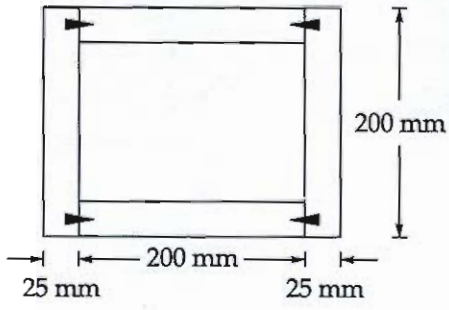
Conclusion

Max shear stress will be 10.294 N/mm

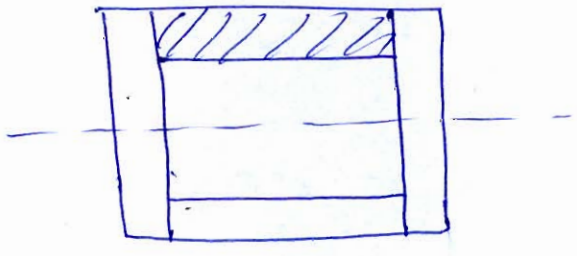
Max Tensile stress will be 8.162 N/mm

Max compresive stress will be 0

Q.6 (b) **(ii)** The box beam shown in figure is made up of four 200 mm × 25 mm wooden planks connected by screws. Each screw can safely transmit a shear force of 1400 N. Estimate the minimum necessary spacing of screws along the length of the beam if the maximum shear force transmitted by the cross-section is 5 kN.



[5 marks]



$$I_{NA} = \frac{250 \times 200^3}{12} - \frac{200 \times 150^3}{12} = 1.10416 \times 10^8 \text{ mm}^4$$

$$\tau = \frac{5 \times 10^3 \times 25 \times 200 \times 87.5}{1.10416 \times 10^8 \times 50} = 0.3962 \text{ N/mm}^2$$

Shear flow = 19.811 N/mm (3)

Spacing × Shear flow = 1400

$$s = \frac{1400}{19.811}$$

$$s = 70.66 \text{ mm}$$

Q.6 (c) (i) From the instrument kept at A, the following vertical angles were observed:

Staff at P :

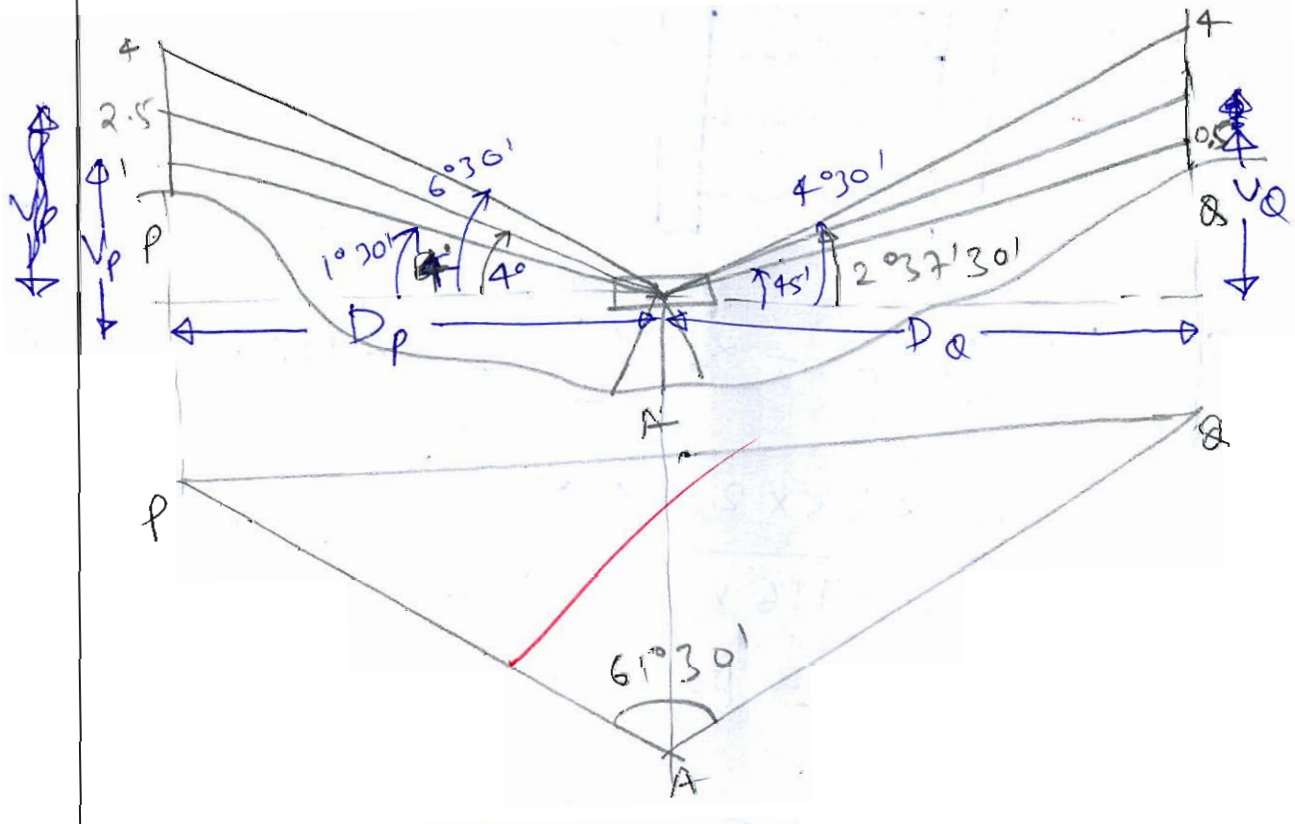
1°30′ to the 1-m mark and 6°30′ to the 4-m mark

Staff at Q :

0°45′ to the 0.5-m mark and 4°30′ to the 4-m mark

The horizontal angle PAQ was measured as 61°30′ and the reading at a benchmark of R.L 902.5 m was 2.375 m. Determine the R.L of points P and Q. If a station 'R' of R.L 905.01 m is to be located along the line joining P and Q, then determine the horizontal distance of 'R' from 'A'. Assume P, Q and R lie on a uniform sloping ground.

[15 marks]



For station P

$$\tan 1°30' = \frac{V_P}{D_P} \quad \text{—(1)}$$

$$\tan 6°30' = \frac{V_P + 3}{D_P} \quad \text{—(2)}$$

By (1) & (2)

$$\tan 6°30' = D_P \tan 1°30' + 3$$

$$D_P$$

$D_P = 34.188$ m

$V_P = 0.89524$ m

RL of point P = $RL_{BM} + BS + V_P - 1m$

$= 902.5 + 2.375 + 0.8952 - 1$

$RL_P = 904.770m$

For staff at Q

$\tan 0°45' = \frac{V_Q}{D_Q}$ — (I) $\quad \tan 4°30' = \frac{V_Q + 3.5}{D_Q}$ — (II)

(8) By (I) & (II)

$\tan 4°30' = \frac{D_Q \tan 0°45' + 3.5}{D_Q}$

$D_Q = 53.344\ m$

$V_Q = 0.6983m$

RL of point Q = $RL_{BM} + BS + V_Q - 0.5$

$= 902.5 + 2.375 + 0.6983 - 0.5$

$RL_Q = 905.073m$

RA = ?

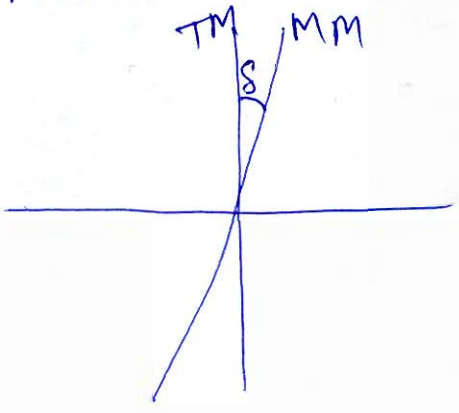
Q.6 (c) (ii) What do you understand by the term 'Magnetic declination'? What are the different variations in magnetic declination? Explain briefly. **[5 marks]**

horizontal (??)

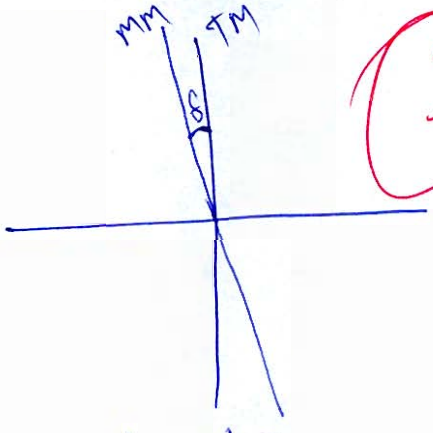
Magnetic declination is angle by which magnetic meridian tilt away from True meridian

OR

The difference of angle b/w magnetic meridian true meridian.



Eastern Declination



Western Declination

3

There are 4 types of variation

1) Diurnal variation: Daily variation in 24 hrs of a day

2) ~~Seasonal~~ Anual variation :- Variation along ~~a season~~ 365 days

3) Secular variation :- variation ~~by 250~~ days

4) Irregular variation :- variation due to climatic changes

Q.7 (a) A shaft is supported in bearing 5 m apart subjected to a bending moment of 15 kNm and transmits power of 80 kW at 2.5 Hz. Find the suitable diameter for the shaft for each of the following cases:

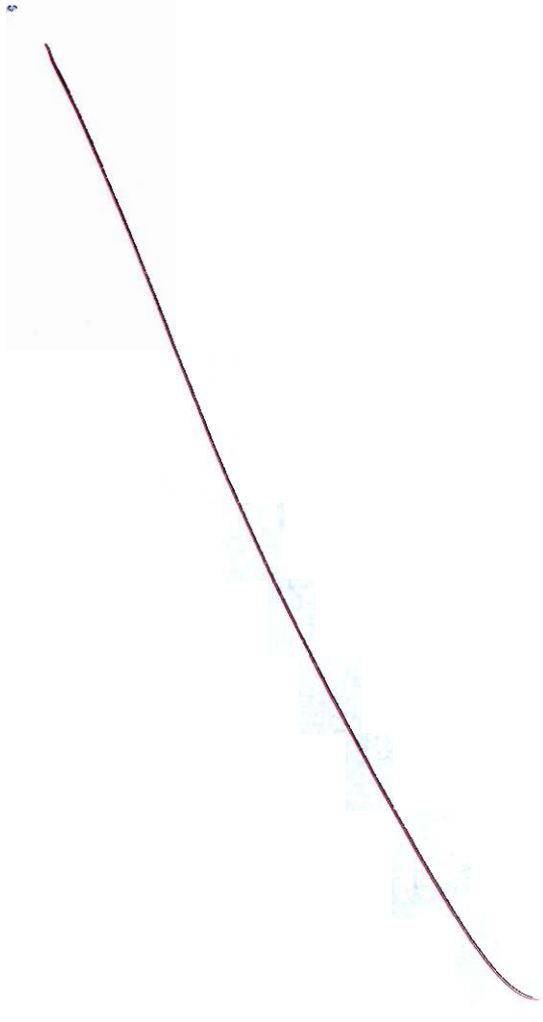
(i) The maximum direct stress shall not exceed 110 N/mm^2.

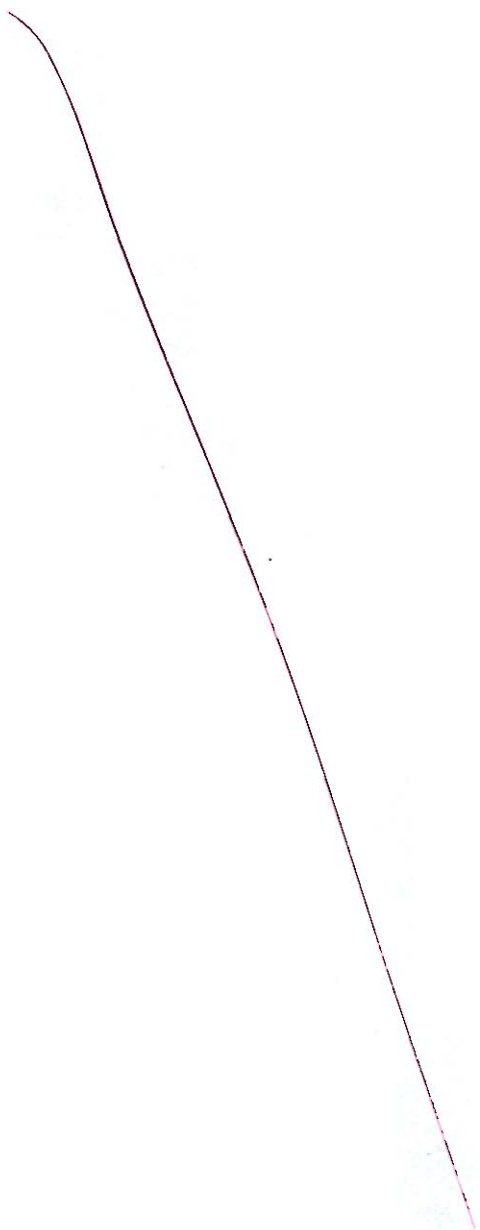
(ii) The maximum shear stress shall not exceed 55 N/mm^2.

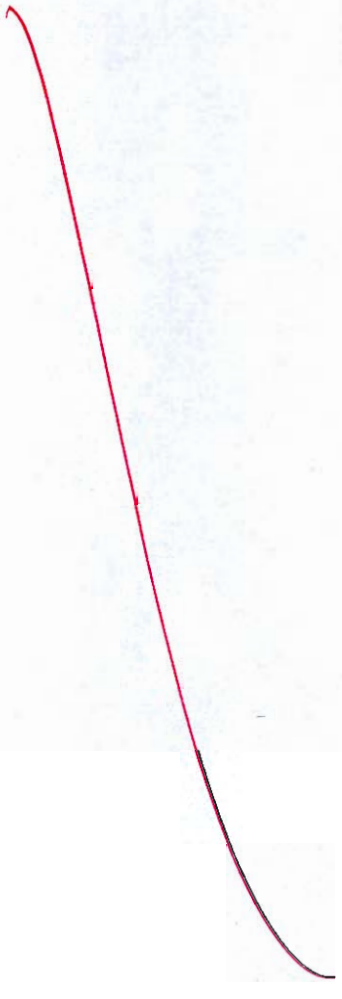
(iii) The stress acting alone to produce the same maximum strain shall not exceed 110 N/mm^2.

(iv) The stress acting alone to store the same maximum strain energy per unit volume, shall not exceed 110 N/mm^2.

[20 marks]







Q.7 (b) (i) Explain nitrogen and sulphur cycle of oxidation of waste organic matter under aerobic conditions with help of diagrams.

[14 marks]

Q.7 (b) **(ii)** The 3 day 37° BOD of a sample of sewage is 300 mg/l. What will be its 5 day 25° C BOD if K_1(base e) at temperature of 20° C is 0.23 per day?

[6 marks]

Q.7 (c) **(i)** A traverse *ABCDEA* was conducted and due to the difficulties in the field, the bearing of line *EA* and the length and bearing of line *DE* could not be measured. To supplement the missing quantities, ranging rods were placed at *A* and *E* and the angle *ADE* was sighted as 20°30′. It is also known that the line *EA* lies in the *N-W* quadrant. From the given data find the missing quantities.

Line	*AB*	*BC*	*CD*	*DE*	*EA*
Length (m)	302.5	288.2	199.5	Missing	201.2
Bearing	N74°15′E	S60°30′E	S30°45′W	Missing	Missing

[15 marks]

Q.7 (c) (ii) Briefly explain the operations involved in setting up the plane table.

[5 marks]

Q.8 (a) On a highway, a rising gradient of 1 in 50 meets a falling gradient of 1 in 400 at a reduced level of 150 m. Assume the eye level of driver to be 1.125 m above the road surface and the height of the obstacle to be 0.10 m. If the sight distance is 300 m and vertical point of curve is taken as origin, then determine:

(i) Equation of summit curve taking origin at vertical point of curve.

(ii) Position of summit point of curve from origin.

(iii) R.L. of vertical point of curve.

(iv) R.L. of vertical point of tangency.

(v) R.L. of point lying on curve which is just below vertical point of intersection.

[20 marks]

Q.8 (b) (i) A beam of uniform section and length $2L$ is simply supported at its ends and carries a symmetrical triangular loading of which the intensity varying from zero at each end to w at the centre. Determine the slope at distance $L/2$ from left end and deflection at a distance of $\frac{3L}{4}$ from left end.

[12 marks]

Q.8 (b) (ii) A steel ring of rectangular cross-section 6.50 mm wide by 4 mm thick has a mean diameter of 250 mm. A narrow radial saw cut is made and tangential separating forces of 4 N are applied at the cut in the plane of the ring. Determine the additional separation due to these forces. Take $E = 2.1 \times 10^5$ N/mm^2.

[8 marks]

Q.8 (c) (i) What are different methods used for land filling in dry areas? Discuss them.

[10 marks]

Q.8 (c) **(ii)** Determine the amount of air required to oxidise completely 500 kg of waste having the chemical equation $C_{50}H_{100}O_{40}N$.
(Assume oxygen in air is 23 percent by mass)

[10 marks]

○○○○

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work