MADE EASY

India's Best Institute for IES, GATE & PSUs

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 ☐

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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	46
Q.2	11
Q.3	54
Q.4	—
Section-B	
Q.5	19
Q.6	51
Q.7	—
Q.8	—
Total Marks Obtained	181

Signature of Evaluator: Rkumar

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.

- Excellent work in Geotech.
- Good work in Section-B also.
- presentation is good.
- Keep revising the Concepts.
- Keep it up.

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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]

$\omega_N = 19\%$, $\gamma_b = 19.33$ kN/m^3; $G = 2.7$;

Dry unit weight, $\gamma_d = \frac{\gamma_b}{1+\omega} = \frac{19.33}{1+0.19}$

$\gamma_d = 16.24$ kN/m^3

For 'e' → $\gamma_d = \frac{G\gamma_\omega}{1+e}$ → $e = \frac{(2.7)(9.81)}{16.24} - 1$

$e = 0.631$

By $Se = \omega G$ → $S = \frac{(2.7)(19)}{0.631}$

∴ Degree of saturation $S = 81.35\%$

soil gets saturated ⇒ $S = 100\%$.

∴ water content, $\omega_1 = \frac{(S)(e)}{G} = \frac{(100)(0.631)}{2.7}$

$\omega_1 = 23.37\%$

∴ Dry ~~unit~~ density, $\rho_d = \frac{G\rho_\omega}{1+e} = \frac{(2.7)(1)}{1+0.631}$ ... ($\rho_\omega = 1$ g/cc)

∴ $\rho_d = 1.655$ g/cc

Bulk ~~Buoyant~~ unit weight, $\gamma_b = (\gamma_d)(1+\omega_1)$

$\gamma_d = \rho_d \times 10^3 \times 9.81 = 16.24$ kN/m^3

$\gamma_b = (16.24)(1+0.2337) = 20.035$ kN/m^3

$\gamma_b = 20.035$ kN/m^3

Saturated unit weight $= \gamma_{sat} = \gamma_b$ as soil saturated

$\gamma_{sat} = 20.035$ kN/m^3

Buoyant unit weight ⇒ submerged unit weight

$\gamma' = \gamma_{sat} - \gamma_w = 20.035 - 9.81$

$\boxed{\gamma' = 10.225 \, kN/m^3}$

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Q.1 (b) The following data were recorded in a falling head permeability test.
Sample thickness = 2.75 cm = L
Diameter of soil sample = 8.2 cm = D
Diameter of stand pipe = 9.5 mm = d.
Initial head of water in stand pipe = 100 cm = h_1
Water level in the stand pipe after 3 hours 35 minutes = 75 cm = h_2
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]

Area of sample $\rightarrow A = \frac{\pi}{4}D^2 = \frac{\pi}{4}(8.2)^2 = 52.81 \, cm^2$

Area of stand pipe $\rightarrow a = \frac{\pi}{4}(0.95)^2 = 0.7088 \, cm^2$

time $t = 3hr \; 35 mins = 215 \, min$

By falling head test, coefficient of permeability (K) is

$$K = \frac{aL}{At} \cdot \ln\left(\frac{h_1}{h_2}\right) = \frac{0.7088}{52.81} \times \frac{2.75}{215} \ln\left(\frac{100}{75}\right)$$

$$\therefore K = 4.938 \times 10^{-5} \, cm/min = 0.0296 \, mm/hr$$

void ratio changes from $e_1 = 0.73$ to $e_2 = 0.91$

we know, $K \propto \frac{e^3}{1+e}$.

$$\therefore \frac{K_2}{K_1} = \frac{e_2^3}{e_1^3} \times \frac{1+e_1}{1+e_2}$$

$$\frac{K_2}{4.938 \times 10^{-5}} = \left(\frac{0.91}{0.73}\right)^3 \times \frac{1.73}{1.91}$$

$$K_2 = 8.666 \times 10^{-5} \, cm/min$$

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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]

(i)

(1) • ~~As~~ Initially as water content increases, it works as lubricant and helps in compacting soil.

• This follows upto a critical moisture content known as optimum moisture content.

• After this, ~~the~~ water starts replacing soil solids thus reducing its ~~compaction~~ dry density.

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(2) • As soil gets compacted, volume of voids decreases.

• Thus void ratio of soil decreases ~~and~~ this leads to decrease in permeability of soil.

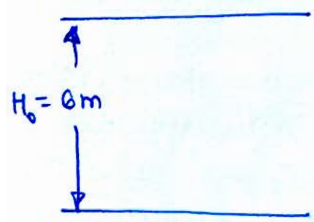
• Thus more the compaction lesser the permeability.

• But permeability is more on ~~wet side~~ when the water content is more than OMC.

(3) • Calcium chloride is used to stabilize acidic soils as it is basic in nature.

• Calcium chlorides neutralizes acidic ions in soil thus reducing its acidity.

(ii)



Initial stress at clay

$\bar{\sigma}_0 = 254 \ kN/m^2$

Increases in stress,

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

$C_c = 0.5$.

As clay is saturated ($S=1$), initial void ratio (e_0) is

$$e_0 = \frac{G\omega}{S} = \frac{(2.7)(0.45)}{1}$$

$$e_0 = 1.215.$$

Ultimate settlement,

$$\Delta H = \frac{C_c H_0}{1+e_0} \log_{10}\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$$

$$= \frac{(0.5)(6)}{1+1.215} \log_{10}\left(\frac{254+112}{254}\right)$$

$$\boxed{\Delta H = 0.2148m = 214.8mm}$$

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]

(i) Foundation design in swelling soils →.

(1) To reduce swelling effect, ~~under-remeadened~~ under reamed piles are most suitable.
· These piles also ~~proves~~ to be economical in comparison to other methods.

(2). We can also try to reduced swelling effect by making water content of soil equal to critical moisture content.
· By chemical stabilization also swelling effect can be reduced.

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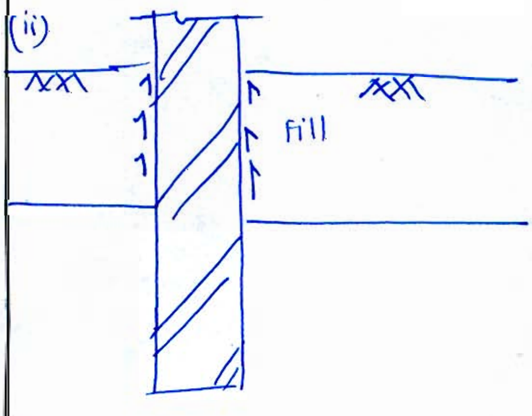
(3) We can plan structure outside the swelling zone.
· Over structures with heavy loads can be provided so that the self weight of structure counters the swelling pressure.

(ii)



· When soil adjacent to pile settles then the friction force generated on piles is in upward direction resulting in reduction in load carrying capacity of pile.

· The settlement of adjacent soil can be because of any reason.

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(1) consolidation due to lowering of water table.
(2) Recent filling of loose soil without compaction.
(3) New construction adjacent to pile

• This negative skin friction is of concern and must be taken into account for safety of structure.

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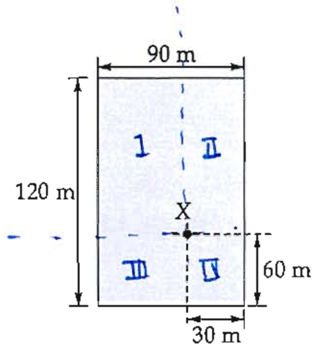
Q.1 (e) The plan of a proposed soil heap is shown in the figure below. The heap will stand on a thick deposit of soft clay having Poisson's ratio of 0.5 with E-value 13.5 MN/m². The uniform pressure on the soil may be taken as 175 kN/m². Determine the immediate settlement under the point marked 'x' at 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]

Dividing area in four parts as shown,

For rectangular area, immediate settlement under corner is given by,

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

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Here, $q = 175\ kN/m^2$

$\mu = 0.5$

$E_s = 13.5\ MN/m^2 = 13.5 \times 10^3\ kN/m^2$.

$B \rightarrow$ least dimension of rectangle.

$I_f \rightarrow$ Influence factor. (at corner).

$\frac{7}{720}$

For 'I' $\rightarrow$ $L = 120 - 60 = 60\,m$; $B = 90 - 30 = 60\,m$.

$\therefore L/B = 1 \Rightarrow I_f = 0.56$.

$$\therefore S_1 = \frac{(175)(60)(1-0.5^2)(0.56)}{13.5\times 10^3} = 0.3267\ m.$$

Similarly for II $\rightarrow$ $L = 60\,m$, $B = 30\,m$

$L/B = 2 \Rightarrow I_f = 0.77$

$$S_2 = \frac{7}{720}(30)(0.77) = 0.2245\ m.$$

For III → $L = B = 60m$ → $L/B = 1$ ⇒ $I_f = 0.56$

$$S_3 = \frac{7}{720}(60)(0.56) = 0.3267m$$

For IV → $L = 60m$, $B = 30m$. ⇒ $I_f = 0.77$

$S_4 = 0.2245m$.

∴ Total immediate settlement under 'x' is

$$S_x = \Sigma S_i = (0.3267 + 0.2245)2$$

$$\boxed{S_x = 1.1024m = 1102.4mm}$$

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]

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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:

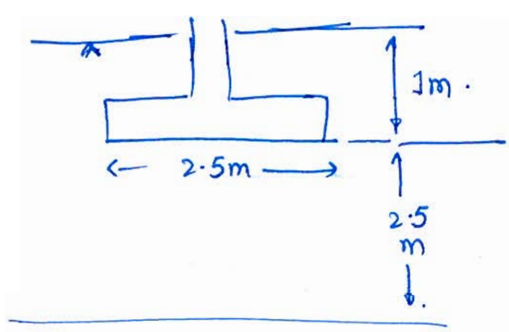
(i) The water table is at 5 m below ground level.

(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]



$q_s = 400\,kN/m^2$.

$\gamma_{sat} = 20\,kN/m^3$

$\gamma_b = 17\,kN/m^3$.

$\phi = 38°$.

$\gamma' = (20-9.81) = 10.19\,kN/m^3$

(i) water table (WT) at 5 m below ground.

$q_u = 1.3\,cN_c + \gamma_b D_f N_q + 0.4\gamma_b B N_\gamma$. — [c = 0]

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$q_{nu} = \gamma_b D_f (N_q - 1) + 0.4\gamma_b B N_\gamma = q_u - \gamma_b D_f$.

$q_{ns} = \dfrac{q_{nu}}{FOS}$

$\therefore q_s = \dfrac{q_{nu}}{FOS} + \gamma_b D_f$

$400 = \dfrac{(17)(1)(66.34-1) + (0.4)(17)(2.5)(77.2)}{FOS} + (17)(1)$

$\therefore$ **FOS = 6.327**

(ii) WT @ 1m below GL.

$q_u = \gamma_b D_f N_q + 0.4\gamma' B N_\gamma$.

$q_{nu} = \gamma_b D_f (N_q - 1) + 0.4\gamma' B N_\gamma$.

$$q_{ns} = 400 + 17(1) = \frac{(17)(1)(66.34-1) + (0.4)(10.19)(2.5)(77.2)}{FOS}$$

$q_s = 2$

$FOS = 4.55$

(iii)

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

[20 marks]

- Skempton's pore pressure parameters are used to find pore water pressure on site where actual measurement is not possible.
- Skempton's pore pressure parameters are

(1) $B = \frac{\Delta u_c}{\Delta \bar{\sigma}_c} = \frac{\Delta u_c}{\Delta \bar{\sigma}_3}$

- This shows change in pore water pressure with change in all round pressure.

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(2) A →

- This is computed from $\bar{A} = AB$

where $\bar{A} = \frac{\Delta u_d}{\Delta \bar{\sigma}_d} = \frac{\Delta u_d}{\Delta \bar{\sigma}_1 - \Delta \bar{\sigma}_3}$ ... [$\Delta \bar{\sigma}_1$ - change in vertical stress.]

This shows change in pore water pressure due to change in deviator stress.

Thus → Total change in pore water pressure,

$\Delta u = \Delta u_c + \Delta u_d$

$= B(\Delta \bar{\sigma}_3) + \bar{A}(\Delta \bar{\sigma}_1 - \Delta \bar{\sigma}_3)$

$= B(\Delta \bar{\sigma}_3) + AB\Delta \bar{\sigma}_1 - AB\Delta \bar{\sigma}_3$

$$\boxed{\Delta u = B[\Delta \bar{\sigma}_3 + A(\Delta \bar{\sigma}_1 - \Delta \bar{\sigma}_3)]}$$

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]

$e_0 = 1.89$; $\bar{\sigma}_0 = 150$ kN/m^2 $K = 3.3 \times 10^{-8}$ cm/s.

$\Delta\bar{\sigma}_z = 109.5$ kN/m^2.

we know, $C_c = \dfrac{\Delta e}{\log_{10}\left(\dfrac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)}$

∴ change in void ratio, $\Delta e = (0.263)\log_{10}\left(\dfrac{150+109.5}{150}\right)$

$\boxed{\Delta e = 0.0626}$

Thickness of soil, $H_0 = 4.5$ m.

Total settlement, $\Delta H = (H_0)\left(\dfrac{\Delta e}{1+e_0}\right) = (4.5)\left(\dfrac{0.0626}{1+1.89}\right)$

~~$\Delta H = 0.149$ m = 149.06 mm~~ $\boxed{\Delta H = 0.0974 \text{ m} = 97.4 \text{ mm}}$

Percentage consolidation $U = 80\%$.

Time factor $T_v = -0.9332\log_{10}(100-U) + 1.781$

$T_v = 0.5669$.

Also, $T_v = \dfrac{C_v t}{d^2}$ ——— ①

For one way drainage $d = H_0 = 4.5$ m

$C_v = \dfrac{K}{\gamma_w m_v}$ $m_v = \dfrac{\Delta e}{\Delta\bar{\sigma}(1+e_0)} = \dfrac{0.0626}{(109.5)(2.89)}$

$m_v = 1.978 \times 10^{-4}$ m^2/kN

$C_v = \dfrac{3.3\times10^{-8}\times10^{-2}}{(9.81)(1.978\times10^{-4})}$

~~for~~

$c_v = 0.17 \times 10^{-6}$ m²/s.

$\therefore$ From ① → $0.5669 = \dfrac{(0.17 \times 10^{-6})\, t}{(4.5)^2}$

$t = 67527794.12$ sec

$t = 781.57$ days $= 2.14$ years

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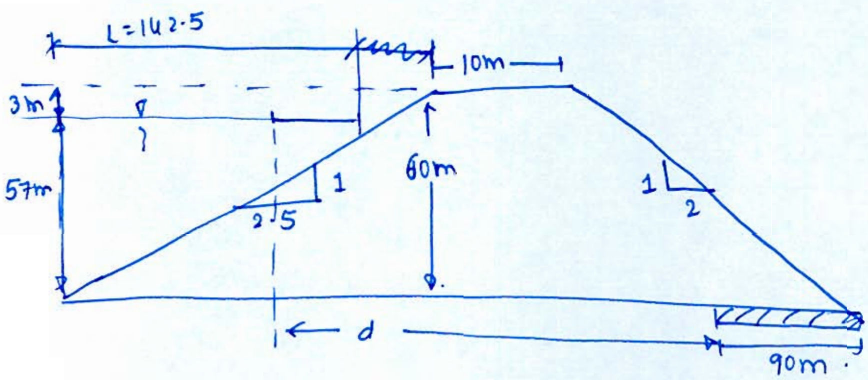
Q.3 (a) (ii) Calculate the seepage through an earthen dam resting on an impervious foundation. The relevant data are given below:

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]



Upstream water depth $H = 60 - 3 = 57m$

$L = 57 \times 2.5 = 142.5m$.

Base width = $60 \times 2.5 + 10 + 60 \times 2 = 280m$.

8

Required d = Base width − Filter length − 0.7L.

$= 280 - 90 - 0.7 \times 142.5 = 90.25m$.

As $K_x = 8 \times 10^{-7}$ m/s and $K_y = 6 \times 10^{-7}$ m/s.

$d_T = d\sqrt{\frac{K_y}{K_x}} = 90.25\sqrt{\frac{6}{8}}$

$d_T = 78.158m$

Equivalent coefficient of permeability $K' = \sqrt{K_x K_y}$

$K' = 6.928 \times 10^{-7}$ m/s.

Seepage through dam, $q = K' \cdot S$.

$S = \sqrt{d_T^2 + H^2} - d_T = \sqrt{(78.158)^2 + (57)^2} - 78.158$

$s = 18.577 m.$

$\therefore q = 6.928 \times 10^{-7} \times 18.577 = 128.702\ m^3/s/m \times 10^{-7}$

$$q = 1.287 \times 10^{-5}\ m^3/s/m$$

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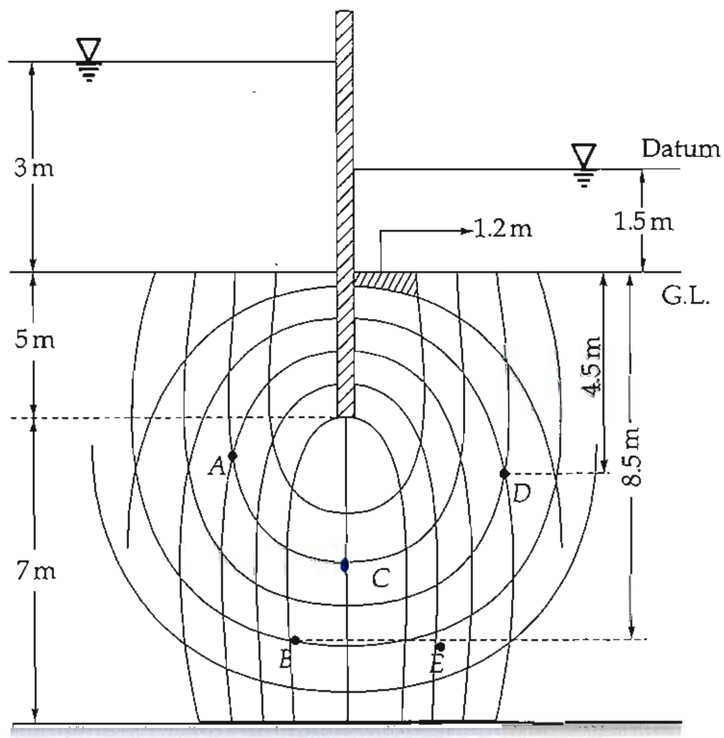
Q.3 (b) (i) A sheet pile is driven upto a depth of 5 m in a bed of sand having coefficient of permeability in x-direction and z-direction equals to 0.002 cm/sec and 0.0025 cm/sec respectively. An impervious clay layer exists at a depth of 12 m below the ground level. The sheet pile is retaining water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

(Take, γ_w = 9.81 kN/m³)



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 (η) = 0.35.

[15 marks]

$K_x = 0.002$ cm/s ; $K_z = 0.0025$ cm/s.

Equivalent coefficient of permeability $K' = \sqrt{K_x K_z}$

$K' = 2.236 \times 10^{-3}$ cm/s

(1) Quantity of seepage loss per unit width

$q = K' H \frac{N_f}{N_D}$.

$H = 3 - 1.5 = 1.5$ m.

$N_f \rightarrow$ No. of flow channels = 6

$N_D \rightarrow$ No. of potential drops = 12

$\therefore q = (2.236 \times 10^{-5})(1.5)(\frac{6}{12})$

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

(2) Seepage pressure at any point, $SP = (SH)\gamma_w$.

$SH = TH_e - n \cdot \Delta h$.

~~TH entry~~ $TH_e \Rightarrow$ Total head at entry = 3−1.5 = 1.5 m

$\Delta h = \frac{TH_e}{N_D} = \frac{1.5}{12} = \frac{3}{24} = \frac{1}{8}$ m.

$n \rightarrow$ No. of drops till that point

Point	n	seepage ~~press~~ head (m)	seepage pressure
A	3	$1.5 - 3 \times \frac{1}{8} = 1.125$	11.036 kN/m²
B	5	$1.5 - 5 \times \frac{1}{8} = 0.875$	8.584 kN/m²
C	6	0.75	7.357 kN/m²
D	10	0.25	2.453 kN/m²
E	8	0.5	4.905 kN/m²

(3) Pore water pressure = seepage pressure

At B → $u_B = 8.584$ kN/m²

At D → $u_D = 2.453$ kN/m².

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(4) Exit gradient, $i_e = \frac{\Delta h}{l_{exit}} = \frac{1/8}{1.2}$

$i_e = 0.1041$

(5) FOS against piping = $\frac{i_{cr}}{i_{exit}}$

critical gradient, $i_{cr} = \frac{G-1}{1+e} = (G-1)(1-\eta)$

$i_{cr} = (2.67-1)(1-0.35) = 1.0855$

$\therefore$ FOS = $\frac{1.0855}{0.1041}$

FOS = 10.427

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

[5 marks]

(1) $\frac{(D_{15})_{Filter}}{(D_{85})_{soil}} < 5$ — ~~Allows~~ Protects particle from escaping due to water pressure.

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(2) $4 < \frac{(D_{50})_{Filter}}{(D_{50})_{soil}} < 20$ — Allows water to escape thus reduces ~~seep~~ pore pressure.

(3) $\frac{(D_{15})_{Filter}}{(D_{15})_{soil}} < 20$.

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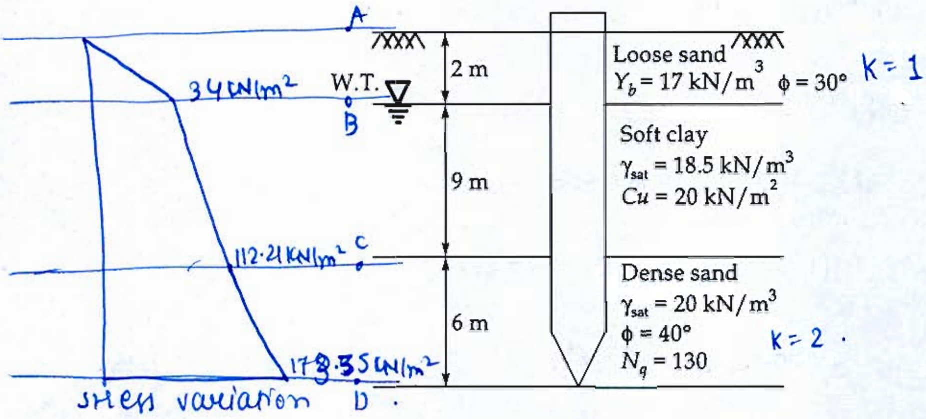
Q.3 (c) Determine the ultimate pile-load capacity of 50 cm diameter pile shown in the figure below:



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]

~~Stress at →~~ Effective stress at

A → $\bar{\sigma}_A = 0$

B → $\bar{\sigma}_B = 17 \times 2 = 34\ \text{kN/m}^2$

C → $\bar{\sigma}_C = 34 + (18.5 - 9.81)(9) = 112.21\ \text{kN/m}^2$

D → $\bar{\sigma}_D = 112.21 + (20 - 9.81)(6) = 173.35\ \text{kN/m}^2$.

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Ultimate pile load capacity, $Q_u = q_{eb} \cdot A_b + q_s A_s$.

~~$q_{eb} A_b = 0$ .... [A_{Bot} Area at base = 0].~~

$q_{eb} = (\bar{\sigma}_v)_{base} \cdot N_q = \bar{\sigma}_D \cdot N_q = (173.55)(130)$

$= 22535.5\ \text{kN/m}^2 > 11000\ \text{kN/m}^2$

$\therefore q_{eb} = \{11000\}\ \text{kN/m}^2$

$\therefore q_{eb} A_b = (11000)\left(\frac{\pi}{4}\right)(0.5)^2 = \underline{2159.84\ \text{kN}}$. —— (1)

For $q_s A_s = Q_{sf}$ .. ~~[$\delta = 0.75\phi$]~~.

~~For In AB → $q_s =$~~ Given that $\delta = 0.75\phi$

In AB → $K = 1$, $\delta = 22.5°$.

$q_s = (\bar{\sigma}_v)_{avg} \cdot K \cdot \tan\delta = \left[\frac{0 + 34}{2}\right][1] \tan 22.5$

$q_s = 7.041\ kN/m^2 < 100\ kN/m^2$ ∴ okay

∴ $(Q_{AB})_s = (7.041)(\pi)(0.5)(2) = 22.123\ kN.$

For BC → clay soil

$q_s = \alpha \bar{c} = (1)(20) = 20\ kN/m^2$

∴ $(Q_{BC})_s = (20)(\pi)(0.5)(9) = 282.743\ kN.$

For CD → $K = 2$; $\delta = 0.75 \times 40 = 30°$.

∴ $q_s = (2)(\tan 30°)\left(\frac{112.21 + 173.35}{2}\right) = 164.87 > 100\ kN/m^2$

∴ $q_s = 100\ kN/m^2$

∴ $(Q_{CD})_s = (100)(\pi)(0.5)(6) = 942.478\ kN.$

∴ Total skin friction, $Q_{sf} = 22.123 + 282.743 + 942.478$

$Q_{sf} = 1247.341\ kN$

Ultimate capacity $Q_u = 2159.84 + 1247.341$

$Q_u = 3407.181\ kN$

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]

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]

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]

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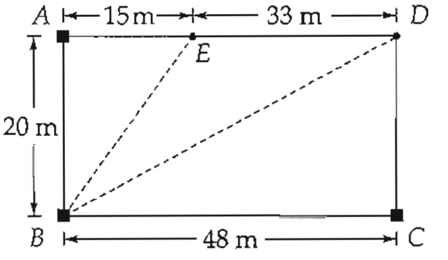
Section B : Highway Engineering-1 + Surveying and Geology-1 + Strength of Materials-2 + Environmental Engineering-2

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]

Height of instrument at

(1) E → $HI_E = RL_A + 1.855 = 120 + 1.855$

$HI_E = 121.855 m$

(2) D → $HI_D = 120 + 2.427 \Rightarrow HI_D = 122.427 m$.

Elevation of B → $RL_{B_1} = HI_E - 0.808 = 121.855 - 0.808$

$RL_{B_1} = 121.047 m$

wrong concept

$RL_{B_2} = HI_D - 1.368 = 122.427 - 1.368$

$RL_{B_2} = 121.059 m$

∴ correct elevation of B ⇒ $RL_B = \frac{RL_{B_1} + RL_{B_2}}{2}$

$RL_B = 121.053 m$

correct elevation at C ⇒ $RL_C = HI_D - 1.666$

$= 122.427 - 1.666$

$RL_C = 120.761 m$

staff reading at 'C' from 'E' be S_{CE}.

$\therefore \quad RL_C = HI_E - S_{CE}$

$120.761 = 121.855 - S_{CE}$.

$\boxed{S_{CE} = 1.094 m}$

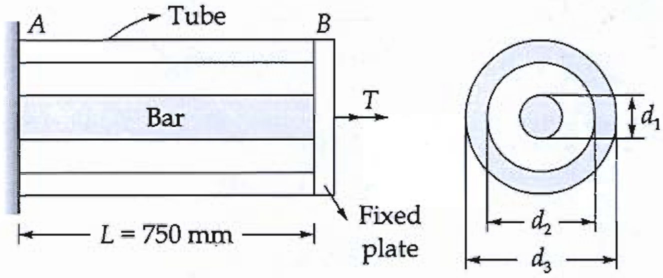
Q.5 (b) Distinguish between Telford's and Macadam's method of road construction in terms of subgrade slope, foundation stones, base course, surface course and thickness of cross-section. Also what technological lessons do you derive from macadam pavement?

[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]

This is parallel combination →

Angle of twist same in bar & tube

$\therefore \quad \theta_b = \theta_t$.

$$\frac{(T_b) L}{G J_b} = \frac{(T_t)(L)}{G J_t}.$$

$$\frac{T_b}{\frac{\pi}{32}(35)^4} = \frac{T_t}{\frac{\pi}{32}(47.5^4 - 40^4)} \Rightarrow T_b = 0.593\, T_t. \quad —①$$

Also → $T_b + T_t = 450$ N-m.

$\therefore$ From ① → $T_t(1.593) = 450$

$T_t = 282.49$ N-m — Torque in tube

$T_b = 167.51$ N-m — Torque in bar.

Maximum shear stress in

(1) bar → $\tau_1 = \frac{16 T_b}{\pi d_1^3} = \frac{(16)(167.51 \times 10^3)}{\pi(35)^3}$

$\tau_1 = 19.89$ N/mm²

(a) Tube $\tau_2 = \frac{16 T_t}{\pi d_o^3 \left[1-\left(\frac{d_i}{d_o}\right)^4\right]} = \frac{(16)(282.49\times10^3)}{(\pi)(47.5)^3\left[1-\left(\frac{40}{47.5}\right)^4\right]}$

$\tau_2 = 27\ N/mm^2$

(ii) Angle of rotation → At end of plate.

$\phi = \frac{T_b L}{G J_b} = \frac{(167.51)(10^3)(750)}{(80\times10^3)(\frac{\pi}{32})(35)^4}$

$\phi = 0.01066\ rad = 0.6107^\circ$

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Torsional stiffness of composite bar,

$K_T = \frac{T}{\phi} = \frac{450\times10^3}{0.01066}$

$K_T = 42.21\times10^6\ N\text{-}mm$

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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 –

· It is the minimum velocity ~~which~~ scours off any particle of solid settled at bottom of sewer.

3

· It also does not allow solid particles to settle at bottom.

· Thus it is important to prevent blockage of sewer and maintain smooth function of sewerage system.

- Thus while designing it is desired that during minimum flow, sewage must ~~have~~ ~~at~~ flow with atleast self cleansing velocity.

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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]

(1) volume of reactor be V

$$VX = \frac{Y Q_0 (S_0 - S_e)\theta_c}{1 + K_d \theta_c}$$

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

$\therefore$ $V = 6086.96\ m^3$

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~~(2) $\theta_c = \frac{VX}{Q_w X_r + (Q_0 \ldots}$~~

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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]

- For stopping sight distance, braking distance is ~~cal~~ ~~computed~~ computed as

$$D_B = \frac{V^2}{254[\eta_B f \pm S]}$$

Here $\eta_B \rightarrow$ Braking efficiency
$f \rightarrow$ friction coefficient
$S \rightarrow$ slope of road.

If ascending slope then braking distance value reduces while ~~in~~ the descending slope increases its value.

- Thus stopping sight distance is inversely related to slope of road surface.

- Formula mentioned makes it clear that as braking efficiency increases, braking distance reduces.
- Thus efficiency of brakes is also inverseley reated to SSD.

4

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

Speed of overtaking vehicle = 65 kmph $= V_a$

Speed difference between the vehicles = 15 kmph $= \Delta V$

Acceleration of overtaking vehicle = 3.28 kmph/sec $= a$

Perception time of driver of overtaking vehicle = 2 seconds $= t_r$

Length of overtaking vehicle = 6 m $= l$.

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]

speed of overtaken vehicle →

$V_B = V_A - \Delta V = 65 - 15 \Rightarrow V_B = 50$ kmph.

(1) length of safe OSD →

$OSD = d_1 + d_2 + d_3$

$d_1 = 0.278 V_b \cdot t_r = 0.278 \times 50 \times 2 \Rightarrow d_1 = 27.8$ m

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$d_2 = 0.278 V_b T + \frac{1}{2} a T^2$

T → overtaking time $= \sqrt{\frac{4s}{a}}$

a → acceleration = 3.28 kmph/sec = ~~3.28×~~ 0.911 m/s²

s → space headway

As per IRC → $S = 0.2 V_B + l = (0.2)(50) + 6 = 16$ m

$T = \sqrt{\frac{4 \times 16}{0.911}} = 8.38$ sec.

∴ $d_2 = (0.278)(50)(8.38) + (\frac{1}{2})(0.911)(8.38)^2$

$d_2 = 148.48$ m

d_3 = Distance covered by vehicle on other lane

$d_3 = (0.278)(V_A)T = 0.278 \times 65 \times 8.38$

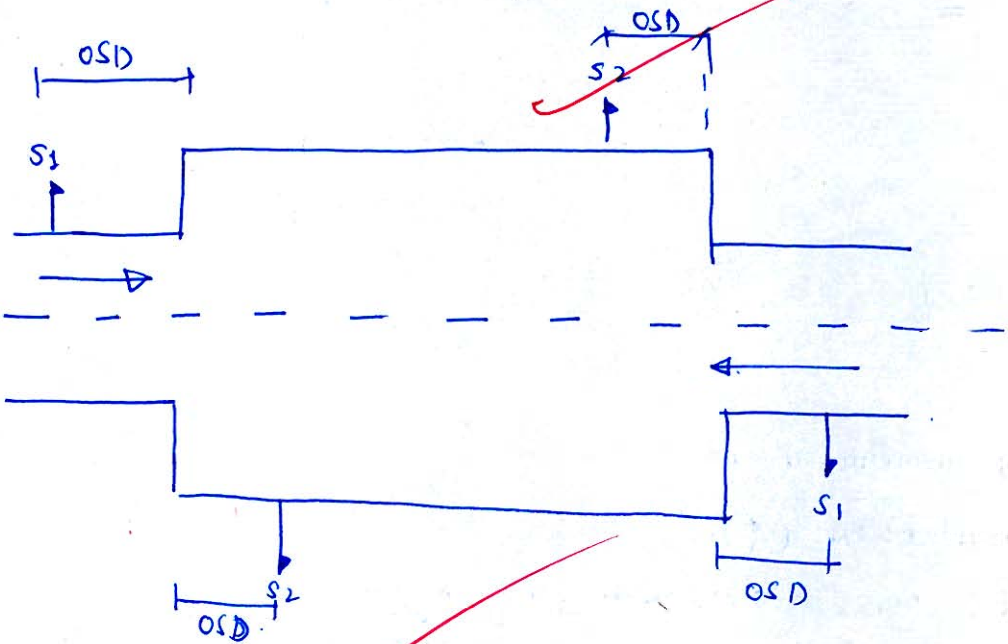
$d_3 = 151.427$ m

$\therefore$ OSD = 27.8 + 148.48 + 151.427

OSD = 327.71 m

(2) Minimum length of overtaking zone = 3 × OSD = **983.121 m**

(3) Desirable length = 5 × OSD = **1638.535 m.**

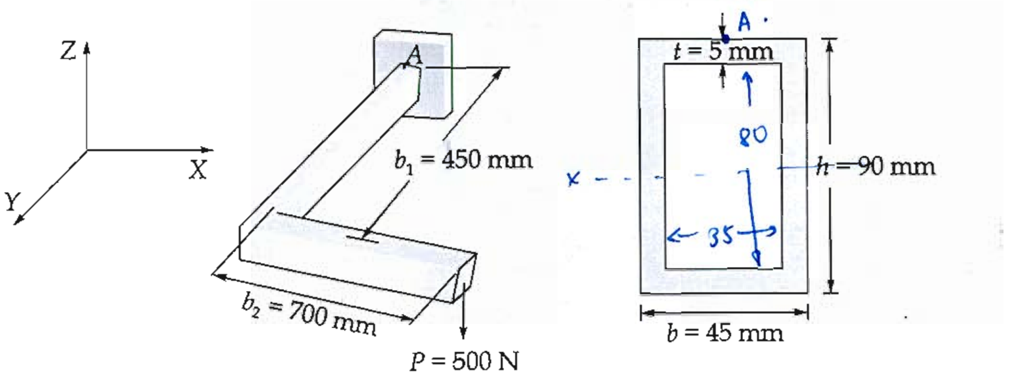


overtaking zone diagram.

S_1 → sign post 1 → overtaking zone ahead

S_2 → Sign post 2 → 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]

Forces and moments at A →

$R_A = 500\text{N} = 0.5 \text{ kN}$ (↑).

$M_A = (0.5)(0.45) = 0.225$ kN-m (about x-axis)

$T_A = (0.5)(0.7) = 0.35$ kN-m (Torque in anticlockwise sense).

Bending stress at 'A' →

$$\sigma_A = \frac{M}{I}y = \frac{0.225\times10^6}{I_{xx}}(45)$$

$$I_{xx} = \frac{(45)(90)^3}{12} - \frac{(35)(80)^3}{12} = 124.04\times10^4 \text{ mm}^4.$$

$$\therefore \sigma_A = \frac{0.225\times10^6\times45}{124.04\times10^4} \Rightarrow \sigma_A = 8.163 \text{ N/mm}^2 \text{ (Tensile)}$$

Direct shear stress, $\tau_1 = \dfrac{R_A \cdot A\cdot\bar{y}}{bI}$

$\tau_1 = 0$ as 'A' at extreme top location.

Torsional shear stress, $\tau_2 = \dfrac{T}{2A_m t}$.

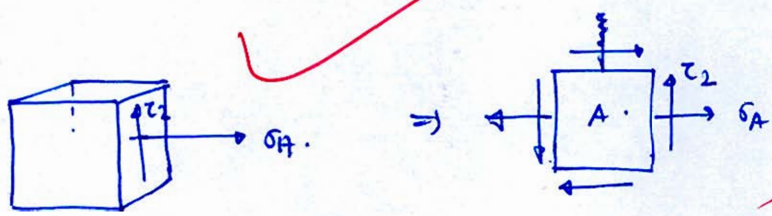
For hollow section →

A_m → Area about mean line = $(90-5)(45-5)$

$A_m = 3400\ mm^2$

t → thickness = 5mm

$$\therefore \quad \tau_2 = \frac{0.35\times10^6}{(2)(3400)(5)} = 10.29\ N/mm^2$$



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(A)

Principal stress at A →

$$\sigma_{1/2} = \left(\frac{\sigma_A+0}{2}\right) \pm \sqrt{\left(\frac{\sigma_A}{2}\right)^2+(\tau_2)^2}$$

$$\sigma_{1/2} = \frac{8.163}{2} \pm \sqrt{\left(\frac{8.163}{2}\right)^2+(10.29)^2} = 4.081 \pm 11.07$$

$\sigma_1 = 4.081 + 11.07 = \boxed{15.151\ N/mm^2}$ ← Maximum tensile stress

$\sigma_2 = 4.081 - 11.07 = \boxed{-6.989\ N/mm^2}$ ← Maximum compressive stress.

Maximum shear stress, $\boxed{\tau_{max} = 11.07\ N/mm^2}$

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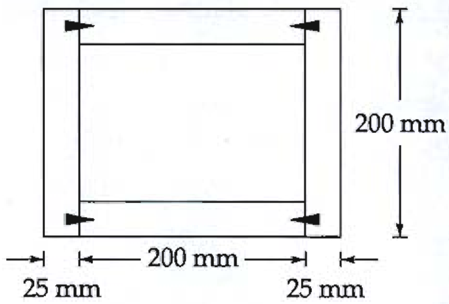
Q.6 (b) **(ii)** The box beam shown in figure is made up of four 200 mm × 25 mm wooden planks connected by screws. Each screw can safely transmit a shear force of 1400 N. Estimate the minimum necessary spacing of screws along the length of the beam if the maximum shear force transmitted by the cross-section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



[5 marks]

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

Staff at *P* :

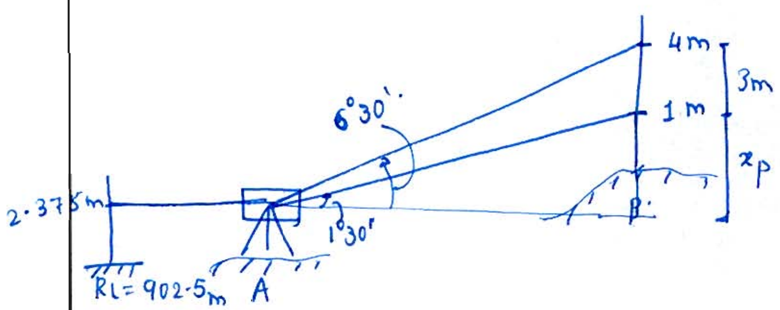
1°30′ to the 1-m mark and 6°30′ to the 4-m mark

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]



Height of instrument at A

$HI = RL + BS$

$= 902.5 + 2.375$

$HI = 904.875 m$

Let ~~DAP~~ 'D_1' be distance between A and P.

$\tan 1°30' = \frac{x_p}{D_1} \Rightarrow D_1 = \frac{x_p}{\tan 1°30'}$ —(1)

$\tan 6°30' = \frac{x_p + 3}{D_1} \Rightarrow D_1 = \frac{x_p + 3}{\tan 6°30'}$ —(2)

∴ From (1) and (2) → ~~x_p~~ $\frac{x_p}{0.02618} = \frac{x_p + 3}{0.1139}$

$(4.352 - 1)\, x_p = 3$

$x_p = 0.895 m$

RL of P ⇒ $RL_p = HI + x_p - 1 = 904.875 + 0.895 - 1$

$RL_p = 904.77 m$

$D_1 = \frac{0.895}{\tan 1°30'} \Rightarrow D_1 = 34.178 m.$

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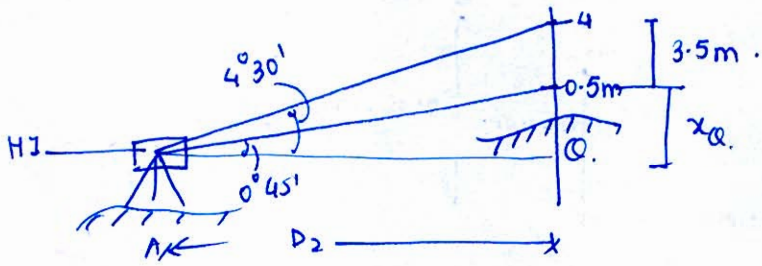


let D_2 be distance between A & Q.

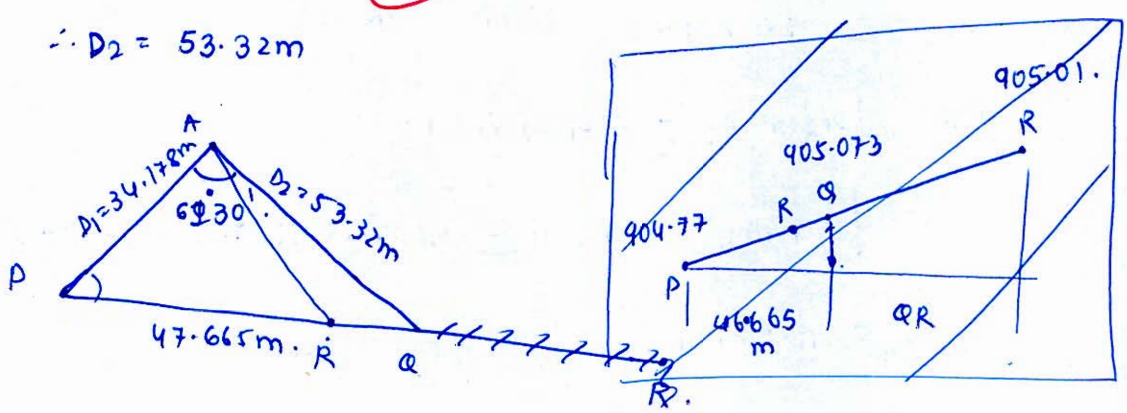
$\therefore \tan 0°45' = \frac{x_Q}{D_2}$ and $\tan 4°30' = \frac{x_Q + 3.5}{D_2}$

$\therefore \frac{x_Q}{\tan 0°45'} = \frac{x_Q + 3.5}{\tan 4°30'} \Rightarrow x_Q = 0.698\ m$

$\therefore$ RL of Q = RL_Q = HI + x_Q − 0.5 = 904.875 + 0.698 − 0.5

$RL_Q = 905.073m$

$\therefore D_2 = 53.32m$



By cosine rule → . Distance PQ

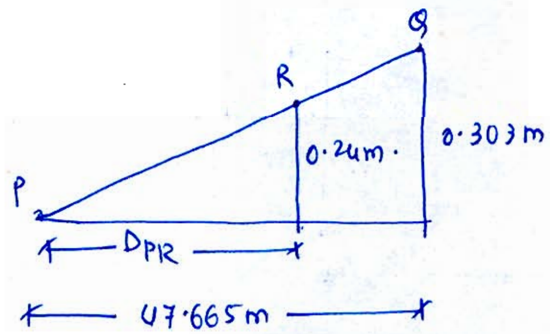
$PQ = \sqrt{D_1^2 + D_2^2 - 2D_1D_2\cos A} = \sqrt{34.178^2 + (53.32)^2 - (2)(34.178)(53.32)\cos 61°30'}$

$PQ = 47.665m$

Elevation difference between →

P & Q , $\Delta H_{PQ} = 905.073 - 904.77 = 0.303m$

P & R , $\Delta H_{PR} = 905.01 - 904.77 = 0.24m$.



By similar triangle, distance between PR is

$$D_{PR} = \frac{47.665}{0.303} \times 0.24 = 37.754m.$$

15

In ΔAPQ by sine rule, $\frac{\sin P}{53.32} = \frac{\sin 61°30'}{47.665}$

$$\therefore \angle P = 79.45°.$$

By cosine rule in ΔPAR, distance AR is

$$D_{AR} = \sqrt{D_{PR}^2 + D_1^2 - 2(D_{PR})(D_1)\cos P}.$$

$$= \sqrt{(37.754)^2 + (34.178)^2 - (2)(37.754)(34.178)(\cos 79.45)}$$

$$D_{AR} = 46.054m$$

Answer →

$RL_P = 904.77m$

$RL_Q = 905.073m$

$D_{AR} = 46.054m.$

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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]

- The deviation of magnetic needle at ~~partide~~ particular place from actual north-south magnetic field is called magnetic declination.

- Magnetic declination can occur due to

(1) Diurnal variation – · This is due to daily variation in magnetic field. This is maximum at equator in summer.

(2) Annual variation – · Magnetic declination takes place due to seasonal variation at particular place.

(3) Secular variation – · This produces maximum declination. It is computed on large time span of 100-150 years.

3

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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]

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

[10 marks]

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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]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work