223/300

MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-3 : Section A : Strength of Materials [All Topics]

Section B : Highway Engineering-1 + Surveying and Geology-1 + Geo-technical & Foundation Engineering - 2 + Environmental Engineering - 2 [Part syllabus]

Name : ....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ 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	56
Q.2	39
Q.3	45
Q.4	
Section-B	
Q.5	40
Q.6	
Q.7	43
Q.8	
Total Marks Obtained	223/300

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.

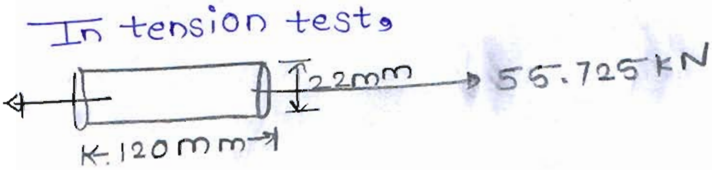
Section A : Strength of Materials [All Topics]

1 (a) A cylindrical specimen of 22 mm diameter is subjected to uniaxial tension over a gauge length of 120 mm. Under an applied axial load of 55·725 kN, the specimen undergoes an elongation of 0.0765 mm. Subsequently, a torsion test is performed on another specimen of identical material and diameter, wherein an applied torque of 130·150 kN-m produces an angular twist of 0.018 radians over a length of 250 mm. Determine:

(i) Poission ratio of the material.
(ii) Shear modulus.
(iii) Bulk modulus.
(iv) Young's modulus of elasticity.

[12 marks]

In tension test,



$\delta l = 0.0765\ mm$

$\delta l = \frac{PL}{AE} \longrightarrow 0.0765\ mm = \frac{55.725 \times 10^3 N * 120\ mm}{\frac{\pi}{4} \times 22^2 (mm^2) \times E\ (N/mm^2)}$

E = young's modulus $= 229.95 \times 10^3\ (N/mm^2)$

$= \boxed{229.95\ GPa}$

In torsion test,

$\theta = 0.018$ radians $= \frac{TL}{GJ} = \frac{130.15 \times 10^6 \times 250\ (N\,mm^2)}{G * \frac{\pi}{32} \times 22^4\ (mm^4)}$

$G = 78599.73\ (N/mm^2)$

$\boxed{G = 78.599\ GPa}$ → shear modulus

$E = 2G(1+\mu)$

$229.95 = 2 \times 78.599\ (1+\mu)$

$\boxed{\mu = 0.462}$ → poissons ratio.

10

$E = 3K(1-2\mu)$

$K = \frac{229.95}{3(1-2\times0.462)} = \boxed{1030.37\ GPa}$

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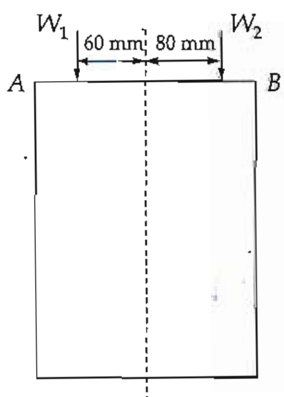
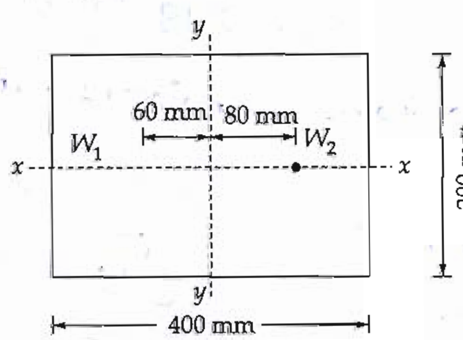
Q.1 (b) A short wooden pillar is rectangular in section 400 mm × 200 mm. It carries at the top, two point loads W_1 and W_2 in vertical plane as shown in figure below. If the stress is throughout compressive and extreme stress on the side in which W_1 acts i.e. at A is four times the extreme intensity on the other side i.e. at B, then compute the value of W_1 if W_2 = 50 kN.

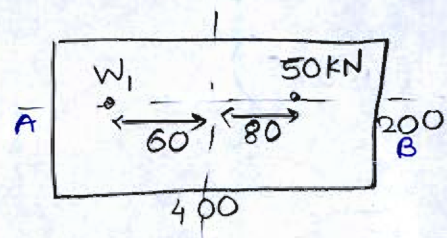


(Elevation view)



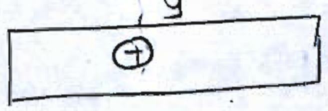
(Plan view)

[12 marks]

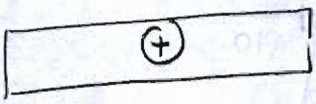


$(M_y)_{50} = 50 * 80 * 10^{-3}$ KNm $= 4$ KNm

$(M_y)_{W_1} = W_1 * 60 \times 10^{-3}$ KNm $= \frac{3W_1}{50}$

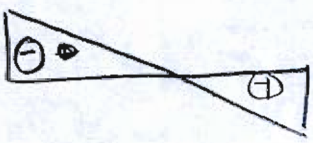


$\frac{50}{A} = \frac{50 \times 10^3 \text{ N}}{400 \times 200 \text{ mm}^2} = 0.625 \text{ N/mm}^2$

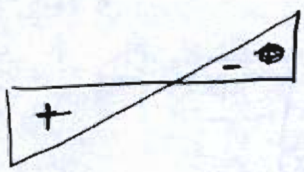


$\frac{W_1}{A} = \frac{W_1 \times 10^3}{400 \times 200}$ N/mm^2 {W_1 in KN}

$= \frac{W_1}{80}$ N/mm^2



$\sigma = \frac{My}{I_{yy}} = \frac{4 \times 10^6 \times 200}{\frac{200 \times 400^3}{12}} = 0.75 \text{ N/mm}^2$



$\frac{\left(\frac{3W_1}{50}\right) * 200 * 10^6}{\frac{200 \times 400^3}{12}} = \frac{9W_1}{800}$ N/mm^2

~~$(\sigma_A) = -0.625 - \frac{W_1}{80} + 0.75 - \frac{3W_1}{1280}$~~

~~$= +0.125 - \frac{19W_1}{1280} < 0 \rightarrow$ (comp)~~

~~$\sigma_B = -0.625 - \frac{W_1}{80} - 0.75 + \frac{3W_1}{1280}$~~

~~$= -1.375 - \frac{13W_1}{1280}$.~~

~~$\sigma_A = 4\sigma_B$~~

~~$-\frac{19W_1}{1280} + 0.125 = 4\left(-1.375 - \frac{13W_1}{1280}\right)$~~

~~$W_1 = 218.18$ KNm~~

i.e

$\sigma_A = 0.625 + \frac{W_1}{80} - 0.75 + \frac{9W_1}{800} = \frac{19W_1}{800} - 0.125 > 0$ $\rightarrow$ comp

$\sigma_B = 0.625 + \frac{W_1}{80} + 0.75 - \frac{9W_1}{800} = \frac{W_1}{800} + 1.375$ $\rightarrow$ comp

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$\sigma_A = 4\,\sigma_B$

$$\left(\frac{19W_1}{800} - 0.125\right) = 4\left(\frac{W_1}{800} + 1.375\right)$$

$$\underline{W_1 = 300\,kN}$$

$\sigma_A = 7\ N/mm^2 > 0 \rightarrow \therefore$ comp.

$\sigma_B = 1.75\ N/mm^2 \longrightarrow$ comp.

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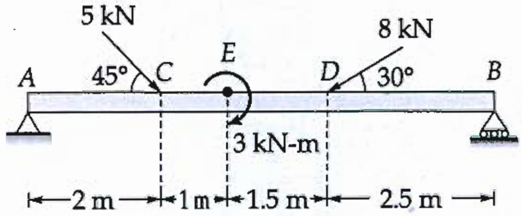
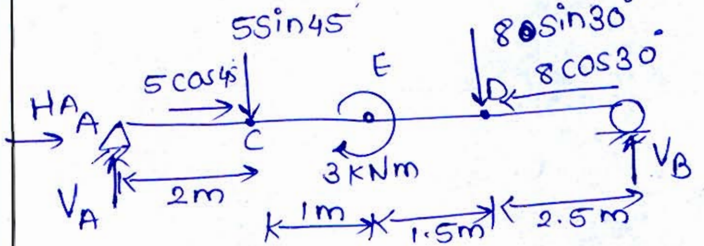
1 (c) A beam is loaded as shown in the figure. Find the reactions at the supports. Draw the BMD and SFD.



[12 marks]



$\Sigma F_H = 0 \longrightarrow H_A + 5\cos 45° = 8\cos 30°$

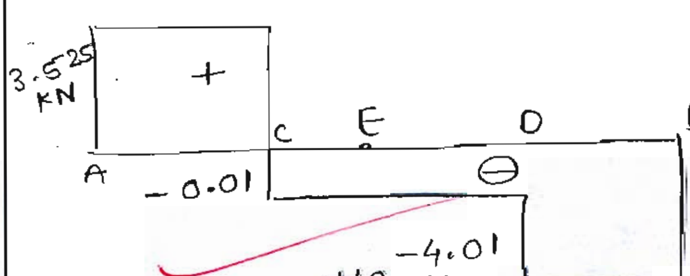
$\boxed{H_A = 3.392 \text{ kN}}$

$\Sigma F_V = 0 \longrightarrow V_A + V_B = 5\sin 45° + 8\sin 30°$

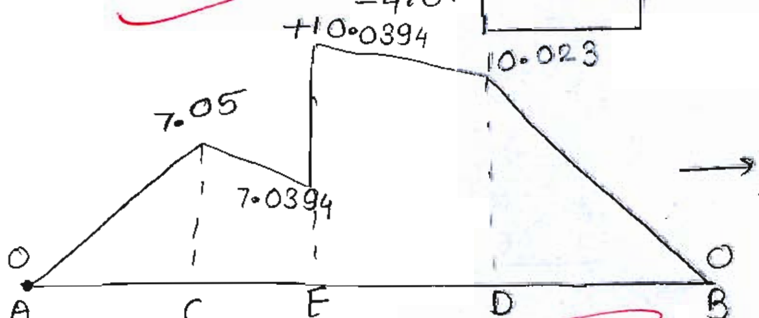
$\Sigma M_A = 0. \longrightarrow 5\sin 45 \times 2 + 3 + 8\sin 30° \times 4.5 = V_B \times 7$

$\boxed{V_B = 4.01 \text{ kN}}$

$\boxed{V_A = 3.525 \text{ kN}}$



→ Shear force diagram.



→ BMD.

12

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.1 (d) A solid rectangular beam of width 200 mm and depth 300 mm is subjected to a transverse shear force of 100 kN.

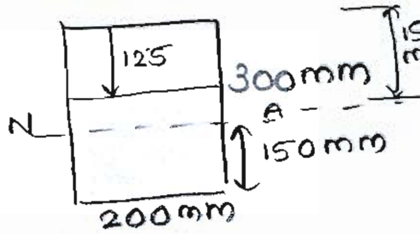
Determine:

(i) Average shear stress in the section.

(ii) Maximum shear stress developed.

(iii) Shear stress at a point located 125 mm from the top.

[3 + 3 + 6 = 12 marks]



$V = 100\,kN$

(i) avg. shear stress $= \dfrac{V}{A} = \dfrac{100\times10^3}{300\times200} = \boxed{1.667\ N/mm^2}$ 3

(ii) max^m shear stress developed $= 1.5\,\tau_{avg}$ (For rectangular section)

$= 1.5\times1.667 = \boxed{2.5\ N/mm^2}$ 3

(iii) $(\tau)_{@y=125} = \dfrac{Vq}{It}$ $\left\{ q = A\bar{y} \right.$

$\tau = \dfrac{100\times10^3 * (125\times200 * (150 - \frac{125}{2}))}{\frac{200\times300^3}{12}\times200}$

$\boxed{\tau = 2.43\ N/mm^2}$ 6

Q.1 (e) State the assumptions of Euler's theory of columns. Derive the Euler crippling load for a strut hinged at both the end supports.

[4 + 8 = 12 marks]

(i) Assumptions of euler theory are:

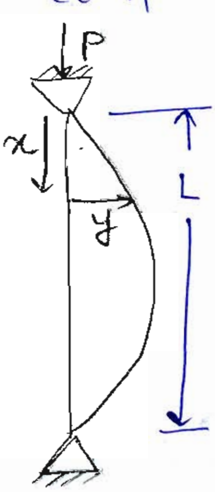
(i) Column is straight & slender.

(ii) Column is homogeneous, isotropic & elastic

(iii) Load is passing through centroid of column & it is also passing through longitudinal axis of column.

(iv) Effect of compression is not considered as important as compared effect of bending.

2



$(BM)_{xx} = -P \times y \Rightarrow$ & $M = EI\frac{d^2y}{dx^2}$

$\therefore EI\frac{d^2y}{dx^2} + Py = 0$

$\left(D^2 + \frac{P}{EI}\right)y = 0 \longrightarrow$ roots are $0 + \sqrt{\frac{P}{EI}}\,i$, $0 - \sqrt{\frac{P}{EI}}\,i$

$\therefore y = e^{0x}\left(C_1\cos\sqrt{\frac{P}{EI}}\,x + C_2\sin\sqrt{\frac{P}{EI}}\right)x$

$y = C_1\cos\left(\sqrt{\frac{P}{EI}}\right)x + C_2\sin\left(\sqrt{\frac{P}{EI}}\,x\right) \neq C_1$

@ $x = 0$, $y = 0 \longrightarrow C_1 = 0$.

$\therefore$ ~~cos~~ @ $x = L$, $y = 0$.

$\therefore C_2\sin\sqrt{\frac{P}{EI}} \times L = 0$ { $C_2 \neq 0$.

$\therefore \sin\sqrt{\frac{P}{EI}} \times L = 0$ $\quad \{\sin(n\pi) = 0\}$

$\therefore \sqrt{\frac{P}{EI}} \times L = n\pi$

$$\boxed{P = \frac{n^2\pi^2 EI}{L^2}}$$

{ $EI \rightarrow$ flexural rigidity of column.

8

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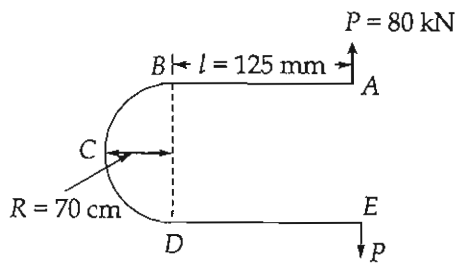
Q.2 (a) A circular bar of diameter 10 mm is bent into a U-shaped configuration consisting of a curved portion of radius 70 cm and two straight limbs, each of length 125 mm, as shown in Fig. Equal loads of 80 kN are applied at the free ends A and E. Determine the relative displacement between points A and E.

Take: E = 200 GPa, $I = 45 \times 10^6$ mm^4.



[20 marks]

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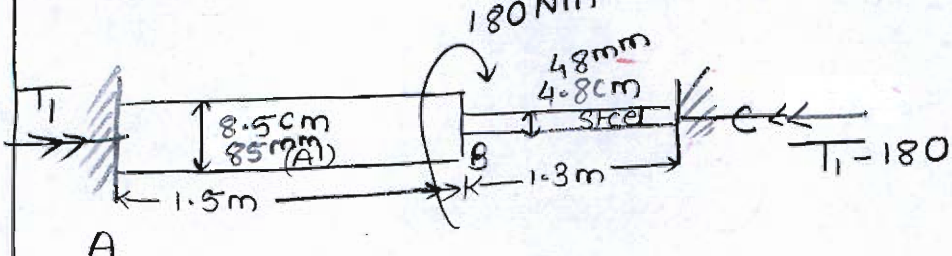
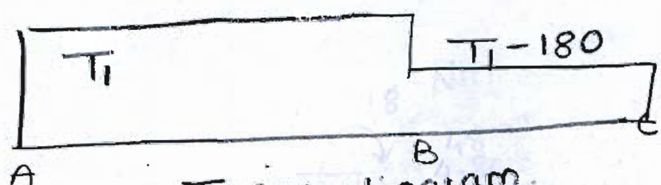
2 (b) Two solid circular shafts, *AB* (aluminium) and *BC* (steel), are rigidly connected at point *B* and fixed to rigid supports at points *A* and *C* respectively. Shaft *AB* has a diameter of 8.5 cm and a length of 1.5 m, while shaft *BC* has a diameter of 4.8 cm and a length of 1.3 m. A torque of 180 N-m is applied at the junction *B*. Determine the maximum shear stress developed in each shaft. Also, calculate the angle of twist at the junction *B*. Take: the modulus of rigidity, $G_{al} = 0.3 \times 10^5$ N/mm² and $G_{st} = 0.9 \times 10^5$ N/mm².

[20 marks]





Torque diagram.

$$\theta_{C/A} = \theta_{C/B} + \theta_{B/A} = 0 \quad \& \quad \theta = \frac{TL}{GJ}$$

$$\therefore 0 = \frac{T_1 \times 1.5 \times 10^3 (mm) \times 10^3 \,(Nmm)}{0.3 \times 10^5 \left(\frac{N}{mm^2}\right) * \frac{\pi}{32} 85^4 (mm^4)} + \frac{(T_1 - 180)(Nmm) \times 1.3 \times 10^3 \times 10^3}{0.9 \times 10^5 \times \frac{\pi}{32} \times 48^4}$$

$$T_1 \times 9.7565 \times 10^{-6} = \cancel{(T_1 - 180)}\,(180 - T_1) \times 2.7716 \times 10^{-5}$$

$$T_1 \times 0.97565 = (180 - T_1) \times 2.7716.$$

$$\boxed{T_1 = 133.1344 \text{ Nm}}$$

$$\therefore \boxed{T_2 = T_1 - 180 = -46.8655 \text{ Nm}}$$

$$(\tau_{max})_{AB} = \frac{16T}{\pi d^3} = \frac{16 \times 133.134 \times 10^3 \text{ Nmm}}{\pi \times 85^3 \text{ mm}^3}$$

$$= 1.104 \text{ N/mm}^2$$

$$(\tau_{max})_{BC} = \frac{16 \times 46.8655 \times 10^3}{\pi \times 48^3} = 2.158 \text{ N/mm}^2$$

$$\theta_{B/A} = \frac{TL}{GJ} = \theta_B - \cancel{\theta_A}^{0}$$

$$\theta_B = \frac{133.1344 \times 10^3 \,(Nmm) \times 1.5 \times 10^3 mm}{0.3 \times 10^5 \,(N/mm^2) * \frac{\pi}{32} \times 85^4 \,(mm^4)}$$

$$\boxed{\theta_B = 1.2989 \times 10^{-3}} \text{ radians}$$

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2 (c) A short tubular specimen having an internal diameter of 3.5 cm and an external diameter of 5 cm fails in compression under a load of 230 kN. When a 3 m long specimen of the same tube is tested as a strut with both ends fixed, the failure load is found to be 1,80,000 N. Assuming that the crushing stress in Rankine's formula is obtained from the first test, determine the value of the Rankine constant (α).

[20 marks]

For compression test,

$$\sigma_{crushing} = \frac{230\times10^3 \text{ N}}{\frac{\pi}{4}\times(50^2-35^2)\text{mm}^2} \qquad \left(\sigma_c = P/A\right.$$

$$\sigma_c = 229.682 \text{ N/mm}^2$$

For failure load of 1,80,000N

Acc, to rankine failure is combined result of bending & crushing.

$$\therefore \frac{1}{P} = \frac{1}{P_c} + \frac{1}{P_{euler}} \qquad \left\{ \begin{array}{l} P \rightarrow \text{rankine load} \\ P_c \rightarrow \text{crushing load} \\ P_e \rightarrow \text{euler load} \end{array} \right)$$

$$P = \frac{P_c \cdot P_e}{P_c + P_e} = \frac{P_c}{1 + P_c/P_e}$$

$$P = \frac{\sigma_c \times A}{1 + \frac{\sigma_c \times \cancel{A}}{\frac{\pi^2 E \cancel{A}}{\lambda^2}}} \qquad \left\{ \begin{array}{l} P_e = \text{euler load} = \frac{\pi^2 E A r^2}{l_e^2} \\ P_e = \frac{\pi^2 E A}{\lambda^2} \end{array} \right.$$

$$P = \frac{\sigma_c \times A}{1 + \left(\frac{\sigma_c}{\pi^2 E}\right)\lambda^2} = \frac{\sigma_c \times A}{1 + a\lambda^2} \qquad \left\{ a = \text{rankine constant} \right\}$$

$$1,80,000\,N = \frac{\sigma_c \times A}{1+a\lambda^2} = \frac{229.682 \times \frac{\pi}{4} \times (50^2-35^2)}{1+a\lambda^2}$$

λ = slenderness ratio $= \frac{l_e}{K}$

K = radius of gyration $= \sqrt{\frac{I}{A}} = \sqrt{\frac{\pi/64(50^4-35^4)}{\frac{\pi}{4}(50^2-35^2)}}$

$K = 15.258\,mm$

$\lambda = \frac{3 \times 1000 \times 0.5}{15.258}$ $\left\{ l_e = l/2 \rightarrow \text{for both ends fixed} \right.$

$\lambda = 98.307$

$\therefore \quad 1,80,000 = \frac{230 \times 10^3}{1 + a \times 98.307^2}$

$$\boxed{a = 2.8742 \times 10^{-5}}$$

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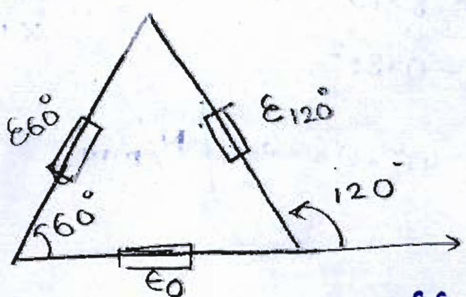
.3 (a) For a delta strain rosette mounted on an aluminium specimen, the following strain readings are recorded:

$\epsilon_{0^\circ} = -100\ \mu$, $\epsilon_{60^\circ} = +700\ \mu$, $\epsilon_{120^\circ} = -600\ \mu$

Determine the principal strains, the corresponding principal stresses.

Take, Young's modulus for aluminium, $E = 0.8 \times 10^5$ N/mm², Poisson's ratio for aluminium, $\mu = 0.32$.

[20 marks]



$\varepsilon_{0^\circ} = -100\mu = \varepsilon_x$.

$\varepsilon_{90^\circ} = \varepsilon_y$

$\cancel{\varepsilon_{60^\circ}}\ \varepsilon_{x'} = \left(\frac{\varepsilon_x+\varepsilon_y}{2}\right) + \left(\frac{\varepsilon_x-\varepsilon_y}{2}\right)\cos 2\theta + \frac{\phi_{xy}}{2}\sin 2\theta$

By strain transformat^n eq^n.

$\varepsilon_{60^\circ} = 700\mu = \left(\frac{-100+\varepsilon_y}{2}\right) + \left(\frac{-100-\varepsilon_y}{2}\right)\cos 2\times 60^\circ + \frac{\phi_{xy}}{2}\sin 2\times 60$

$1400 = \varepsilon_y(1-\cos 120^\circ) + \phi_{xy}\sin 120^\circ - 50$ — (1)

$\varepsilon_{120^\circ} = -600 = \left(\frac{-100+\varepsilon_y}{2}\right) + \left(\frac{-100-\varepsilon_y}{2}\right)\cos 240^\circ + \frac{\phi_{xy}}{2}\sin 240^\circ$

$-1200 = \varepsilon_y(1-\cos 240^\circ) + \phi_{xy}\sin 240^\circ - 50$. — (2)

By solving eqn ① & ②

$\varepsilon_y = \underline{100\,\mu}$

$\phi_{xy} = \underline{1501.11\,\mu}$

$\varepsilon_{P_1}/\varepsilon_{P_2}$ = principle stresses

$$= \left(\frac{\varepsilon_x+\varepsilon_y}{2}\right) \pm \frac{1}{2}\sqrt{(\varepsilon_x-\varepsilon_y)^2+\phi_{xy}^2}$$

$$= \left(\frac{-100+100}{2}\right) \pm \frac{1}{2}\sqrt{(-100-100)^2+(1501.11)^2}$$

$$= \pm\,743.863\,\mu$$

∴ considering plane stress condition.

$$\sigma_{P_1} = \frac{E}{(1-\mu^2)}(\varepsilon_{P_1}+\mu\varepsilon_{P_2}) = \frac{0.8\times10^5}{1-0.32^2}\left(743.863-0.32\times743.863\times10^{-6}\right)$$

$\cancel{= 450.82\times}$ (N/mm²)

$$\boxed{\sigma_{P_1} = 45.0826}$$

$$\sigma_{P_2} = \frac{E}{(1-\mu^2)}(\varepsilon_{P_2}+\mu\varepsilon_{P_1}) = \frac{0.8\times10^5}{1-0.32^2}\left(-743.863+0.32\times743.863\times10^{-6}\right)$$

$$\boxed{\sigma_{P_2} = -45.0826}\ \text{N/mm}^2$$

20

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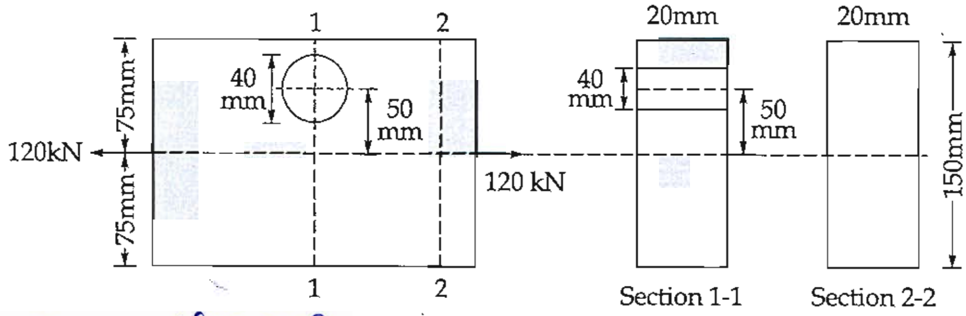
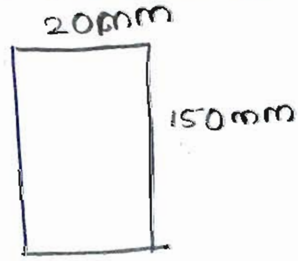
Q.3 (b) A 150 mm × 20 mm steel plate is subjected to a pull of 120 kN along its longitudinal centroidal axis. A hole of 40 mm diameter is drilled through the plate whose centre is 50 mm from the original longitudinal axis of the bar as shown is figure. Determine the extreme stress induced at section 1-1 and 2-2.



[20 marks]

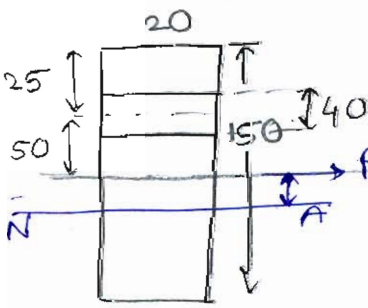
For section 2-2



$$\sigma = \frac{P}{A} = \frac{120\times10^3}{150\times20} = 40\ N/mm^2 \text{ (tension)}$$

$$\sigma_{top} = \sigma_{bottom} = 40\ N/mm^2$$

For section ①-①



(CG) ⇒ centroid from top.

$$\cancel{150\times20}$$

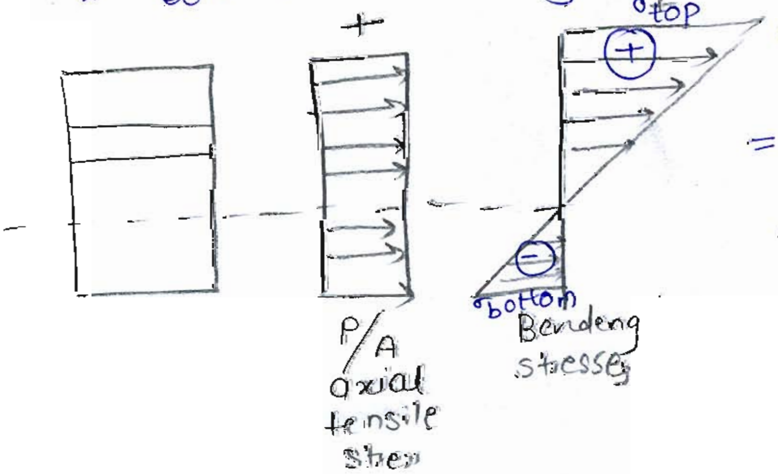
$$(A\bar{y})_{Total} = (A\bar{y}) + (A\bar{y})_{missing}$$

$$150\times20\times75 = (150-40)\times20\times\bar{y} + 40\times20\times25$$

$$\bar{y} = 93.1818\ mm.$$

∴ The tensile force is not passing through CG. tensile stresses

∴ will create bending + ~~te~~ axial



& $M = P\times e$

$= 120\ kN \times (93.1818 - 75) \times10^3$

$= 218.181\times10^4\ Nmm$

(i) axial stress $= P/A = \frac{120\times10^3}{(150-40)\times20} = +54.54\ N/mm^2$

(ii) $I = \cancel{20\times15}\ I_{total} - I_{hole}$

$= \frac{20\times150^3}{12} + (150\times20)\times(93.1818-75)^2 - \left(\frac{20\times40^3}{12} + 20\times40 * (93.1818-25)^2\right)$

$= 27.91\times10^5\ mm^4$

$\sigma_{top} = \frac{My}{I} = \frac{218.181\times10^4 (Nmm)\times 93.1818\ mm.}{27.91\times10^5\ mm^4}$

$\sigma_{top} = +72.843\ N/mm^2$

$\sigma_{bottom} = -\frac{218.181\times10^4\times(150-93.1818)}{27.91\times10^5} = -44.416\ N/mm^2$

$\therefore (\sigma_{top})_{total} = 72.843 + 54.54 = 127.383\ N/mm^2$ tension

$(\sigma_{bottom})_{total} = -44.416 + 54.54 = 10.123\ N/mm^2$ (tension)

14

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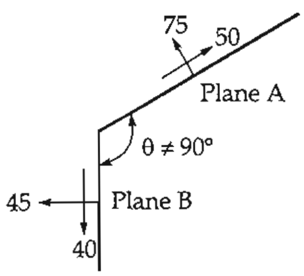
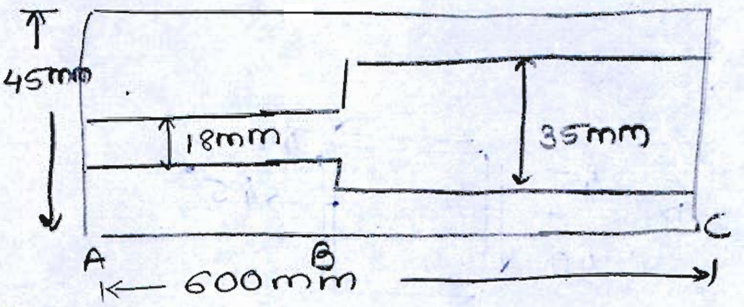
Q.3 (c) (i) A circular shaft *ABC*, having a total length of 60 cm and an external diameter of 45 mm, is hollow for its entire length. Over a portion *AB*, the shaft has an internal diameter of 18 mm, while over the remaining portion *BC*, the internal diameter is 35 mm. If the maximum permissible shear stress in the shaft is limited to 75 N/mm^2. Determine the maximum power that can be transmitted by the shaft when it rotates at a speed of 250 rpm. Further, if the angle of twist in the portion having 18 mm bore is equal to that in the portion having a 35 mm bore, determine the lengths of the shaft portions bored to 18 mm and 35 mm diameters.

(ii) At a point in a material subjected to two dimensional stresses, the stresses on a certain plane are 75 N/mm^2 (tension) and 50 N/mm^2 (shear) and on another plane the stresses are 45 N/mm^2 (tension) and 40 N/mm^2 (shear) as shown in figure. Find the principal stresses.



(All values are in N/mm^2)

[10 + 10 = 20 marks]



$\tau_{max} = 75 N/mm^2$
$N = 250 rpm$
$\theta_{AB} = \theta_{BC}$

(i) $\theta = \frac{TL}{GJ}$

$\theta_{AB} = \theta_{BC} \longrightarrow \frac{\cancel{T} \times L_{AB}}{\cancel{G} \times J_{AB}} = \frac{\cancel{T} \times L_{BC}}{\cancel{G} \times J_{BC}}$

$L_{AB} = L_{BC} * \frac{\frac{\pi}{32}(45^4 - 18^4)}{\frac{\pi}{32}(45^4 - 35^4)}$

$L_{AB} = 1.536 L_{BC}$ —— (1)

& $L_{AB} + L_{BC} = 600$ mm —— (2)

From eq^n (1) & (2)

$\boxed{L_{AB} = 363.48 \text{ mm}, \quad L_{BC} = 236.519 \text{ mm}}$

(2) $\tau = \frac{T}{J} \cdot r$

for portion AB $\longrightarrow$ $\tau_{max} = 75 = \frac{T * (45/2)}{\frac{\pi}{32}(45^4 - 18^4)}$

$T = 1.3075$ KNm

For portion BC

$\tau_{max} = 75 = \frac{T * (45/2)}{\frac{\pi}{32}(45^4 - 35^4)}$

$\boxed{T = 0.8508 \text{ KNm}}$

∴ safe Torque = 0.8508 KNm

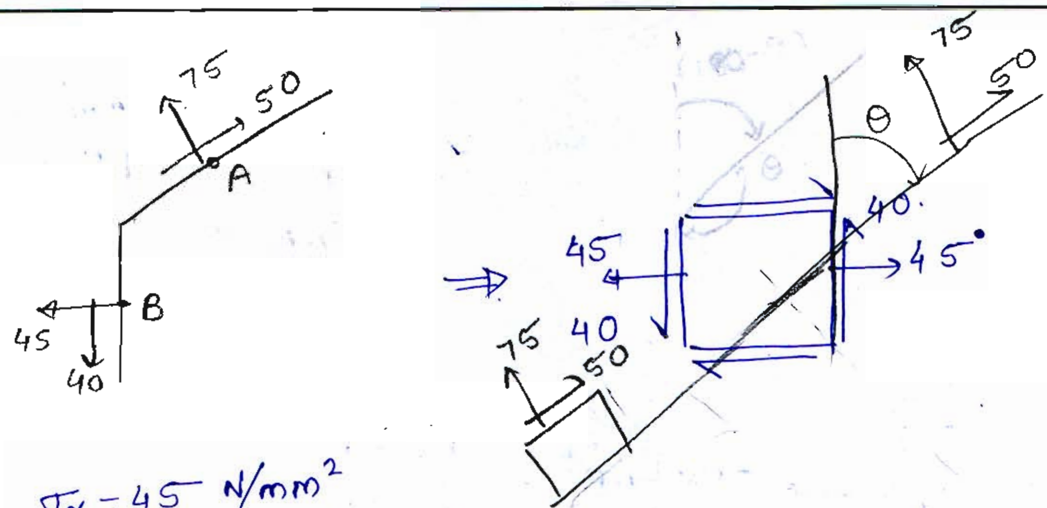
∴ power produced = $T \times \omega = 0.8508 \times 10^3 \times \left(\frac{2\pi \times 250}{60}\right)$

$\left(\because \omega = \frac{2\pi N}{60}\right)$

$\boxed{P = 22.275 \text{ KW}}$

9

(ii)



$\sigma_x = 45\ N/mm^2$

$\tau_{xy} = 40\ N/mm^2$

$\sigma_y = ?$

$(\sigma_{x'})_{@-\theta} = 75\ N/mm^2$ @ $-\theta$ (or)

$(\tau_{x'y'})_{@\theta} = -50\ N/mm^2$ @ $-\theta$

$$\sigma_{x'} = \left(\frac{\sigma_x + \sigma_y}{2}\right) + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos(2(-\theta)) + \tau_{xy}\sin(-2\theta)$$

$$75 = \left(\frac{45 + \sigma_y}{2}\right) + \left(\frac{45 - \sigma_y}{2}\right)\cos 2\theta - \tau_{xy}\sin 2\theta$$

$\cos(-\theta) = \cos\theta$, $\sin(-\theta) = -\sin\theta$

$$150 = (45 + \sigma_y) + (45 - \sigma_y)\cos 2\theta - 40\sin 2\theta \quad (1)$$

$$\tau_{x'y'} = -50 = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin(-2\theta) + \tau_{xy}\cos(-2\theta)$$

$$-50 = +\left(\frac{45 - \sigma_y}{2}\right)\sin 2\theta + \tau_{xy}\cos 2\theta$$

$$100 = (45 - \sigma_y)\sin 2\theta + 40\cos 2\theta \quad (2)$$

$$\frac{100 - 40\cos 2\theta}{\sin 2\theta} = 45 - \sigma_y$$

$$\boxed{\sigma_y = 45 - \frac{100 - 40\cos 2\theta}{\sin 2\theta}} \quad (2')$$

substituting eq^n ② in ①

$$150 = 45\,(1+\cos 2\theta) + \left(45 - \frac{(100 - 40\cos 2\theta)}{\sin 2\theta}\right)(1-\cos 2\theta) - 40\sin 2\theta$$

2

Q.4 (a) A vertical compound tie member is rigidly fixed at its upper end. It consists of a steel rod of length 3.5 m and diameter 24 mm, enclosed within a brass tube of the same length having an internal diameter of 25 mm and an external diameter of 40 mm. The steel rod and the brass tube are securely fastened together at both ends so that they act as a single unit.

The compound member is suddenly subjected to a tensile load when a 25 kN weight falls through a height of 3 mm onto a flange attached to its lower end. Determine the maximum stresses developed in the steel rod and the brass tube. Take the modulus of elasticity as: $E_s = 2 \times 10^5\ \text{N/mm}^2$(steel), $E_b = 1.0 \times 10^5\ \text{N/mm}^2$(brass). Also determine the instantaneous elongation of the tie member.

[20 marks]

Q.4 (b) A bolt is subjected simultaneously to an axial tensile load of 750 kg and a transverse shear load of 400 kg. Using appropriate theories of failure, determine the required diameter of the bolt based on:

Assume a factor of safety of 2.5.

(a) Maximum principal stress theory.

(b) Maximum shear stress theory.

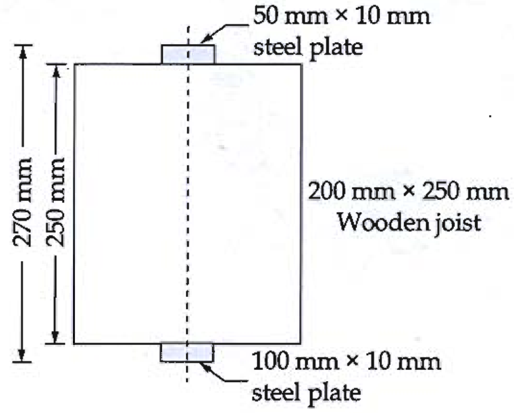
(c) Maximum shear strain energy theory.

(d) Strain energy theory.

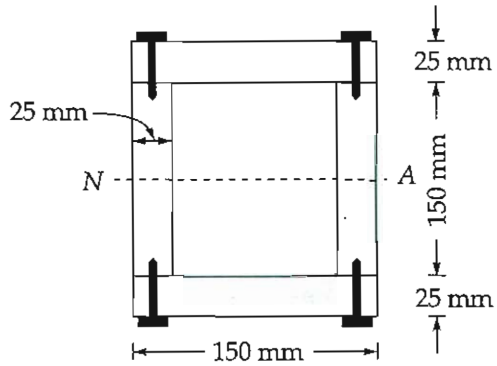
The material properties of the bolt are: Yield strength = 3010 kg/cm^2, μ = 0.33.

[20 marks]

Q.4 (c) (i) Find the moment of resistance of the flitched beam section as shown in figure below if the stress in steel and wood are not to exceed 150 N/mm^2 and 7.5 N/mm^2 respectively. Take $E_s = 2 \times 10^5$ N/mm^2 and $E_w = 1 \times 10^4$ N/mm^2.



(ii) The box beam as shown in figure is made up of four 150 mm × 25 mm wooden planks connected by screws. Each screw can safely transmit a shear force of 1250 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 5000 N. Sketch corresponding shear stress distribution across the section.



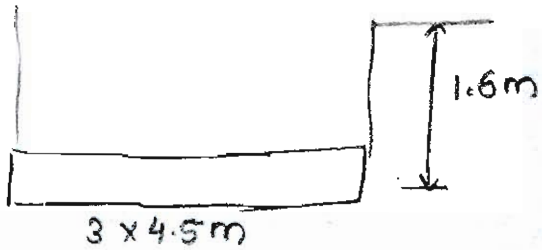
[10 + 10 = 20 marks]

Section B : Highway Engineering-1 + Surveying and Geology-1 + Geo-technical & Foundation Engineering - 2 + Environmental Engineering - 2

Q.5 (a) A rectangular raft foundation measuring 3.0 m × 4.5 m is to be constructed at a depth of 1.6 m below the ground surface. The soil supporting the foundation has a unit weight of 1.65 t/m^3, a cohesion of 1.2 t/m^2, and an angle of internal friction of 21.9°. Assuming shear failure, determine the maximum safe load that the footing can carry using a factor of safety of 2.5. Use Terzaghi's bearing capacity theory. Relevant bearing capacity factors corresponding to the angle of internal friction are provided in the table.

ϕ'	N_c	N_q	N_γ
0°	5.7	1.0	0
5°	6.7	1.4	0.2
10°	8.0	1.9	0.5
15°	9.7	2.7	0.9
20°	11.8	3.9	1.7
25°	13.7	5.9	2.80

[12 marks]



$\gamma = 1.65\ t/m^3$

$C = 1.2\ t/m^2$

$\phi = 21.9^\circ$

$FOS = 2.5$

Here, $\phi = 21.9 < 28^\circ \longrightarrow \therefore$ local ~~shear~~ failure.

$C_m = \frac{2}{3} \times C = \frac{2}{3} \times 1.2 = 0.8\ t/m^2$

$\tan\phi_m = \frac{2}{3}\tan\phi \longrightarrow \phi_m = 15^\circ.$

from table for $\phi_m = 15^\circ \longrightarrow N_c = 9.7,\ N_q = 2.7,\ N_\gamma = 0.9$

For raft footing, $\left\{\frac{D_f}{B} = \frac{1.6}{3} < 1\right\}$

By terzaghi bearing capacity theory,

$q_u = \left(1 + 0.3\frac{B}{L}\right) CN_c + \gamma D_f N_q + 0.5 * \left(1 - 0.2\frac{B}{L}\right) B\gamma N_\gamma.$

$q_u = \left(1 + 0.\frac{3\times3}{4.5}\right) \times 0.8 \times 9.7 + 1.65 \times 1.6 \times 2.7 + 0.5 \times \left(1 - \frac{0.2\times3}{4.5}\right) \times 3 \times 1.65 \times 0.9$

$q_u = 18.37\ t/m^2.$

$q_{nu} = 18.37 - 1.65 \times 1.6 = 15.73\ t/m^2$

$q_{ns} = \frac{q_{nu}}{FOS} = \frac{15.73}{2.5} = 6.292\ t/m^2$

$q_s = q_{ns} + 1.65 \times 1.6 = 8.93\ t/m^2$

$\therefore Q_{safe} = q_s \times A = 8.93 \times (3 \times 4.5) = \boxed{120.5847\ t}$

12

Q.5 (b) Results of two plate load tests corresponding to a settlement of 25.4 mm are given. A circular plate of diameter 0.30 m requires a load of 40 kN, while a circular plate of diameter 0.75 m requires a load of 150 kN. A square column foundation is to be designed to carry a load of 1200 kN with the same allowable settlement of 25.4 mm. Determine the size of the square foundation.

[12 marks]

circular plate $\rightarrow \phi = 0.3m \rightarrow Q_u = 40\ kN$

$\rightarrow \phi = 0.75m \rightarrow Q_u = 150\ kN.$

By Housel approach

$Q_u = Am + Pn$ { m = bearing coefficient, n = shear coefficient, P → perimeter, A → Area }

$40 = \left(\frac{\pi}{4} \times 0.3^2\right) \times m + (\pi \times 0.3) \times n$ — (1)

$150 = \left(\frac{\pi}{4} * 0.75^2\right) \times m + (\pi \times 0.75) \times n$ — (2)

from (1) & (2) $m = 188.628$ ~~n = 8~~ $n = 28.294$

∴ For square footing with same allowable settlement

$Q_u = 1200\ kN = B^2 \times 188.628 + 4 \times B \times 28.294$

$\boxed{B = 2.24\ m}$

12

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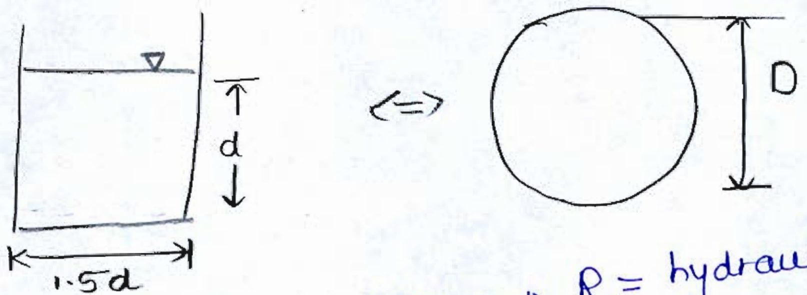
∴ The size of square foundation = 2.4 × 2.4 m.

Q.5 (c) (i) A rectangular sewer having width as 1.5 times of its depth is hydraulically equivalent to a circular sewer. Find the relation between the width of the rectangular sewer and the diameter of the circular sewer.

(ii) In a test conducted for determining the relative stability at 20°C, the period of incubation was found to be 11 days. Calculate the percent of relative stability (*S*).

[8 + 4 = 12 marks]

c
i



(i) For rectangular sewer → R = hydraulic radius

$R = A/P = \frac{1.5d \times d}{2d + 1.5d}$

$R = \frac{3d}{7}$.

(ii) For circular sewer → ~~taking~~ it is running full

$R = \frac{\pi/4\, D^2}{\pi D} = \frac{D}{4}$

For hydraulically equivalent section

$(R)_{rect} = (R)_{circular}$

$\frac{3d}{7} = \frac{D}{4}$

$\boxed{d = \frac{7D}{12}}$

∴ width of rectangular sewer = $B = 1.5d = \frac{7}{8}D$

$\boxed{B = \frac{7D}{8}}$

1

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Q.5 (d) The maximum increase in temperature after the construction of a cement concrete (CC) pavement is expected to be 24°C. If the expansion joint gap is 2.0 cm, determine the required spacing between the expansion and contraction joints using the following data: the coefficient of thermal expansion (α) is 12×10^{-6} per °C, the unit weight of concrete (w) is 2400 kg/m^3, the allowable tensile stress (σ_{at}) is 0.9 kg/cm^2, and the coefficient of interface friction (f) is 1.5.

[12 marks]

(i) For spacing between expansion joint

Considering on expansion half of joint gap is filled

(δ = joint gap)

$$\therefore \quad L\alpha\Delta T = \delta/2$$

$$L = \frac{2\times10^{-2}\ m}{2\times12\times10^{-6}\times24}$$

$$\boxed{L = 34.722\,m} < 140\,m \longrightarrow ok$$

(ii) For spacing between contraction joints

Assuming dowel bars are not provided.

$$S_f = \frac{1}{2}\gamma f L.$$

$$\sigma_{at} = \frac{1}{2}\gamma f L$$

$$0.9\left(\frac{kg}{cm^2}\right) = \frac{1}{2}\times2400\left(\frac{kg}{m^3}\right)\times1.5\times L\ (m).$$

$$0.9*10^4 = \frac{1}{2}\times2400\times1.5\times L$$

4.5m

$$\boxed{L = 5m < 7.5m}$$

$\therefore$ provide expansion jonts with spacing 34.72 m

& contract^n with 5m.

11

Q.5 (e) (i) Differentiate between Plane Surveying and Geodetic Surveying.

(ii) What are the principles of surveying? Explain "working from whole to part."

[6 + 6 = 12 marks]

plane surveying	Geodetic surveying
(i) The curvature of earth is not considered	(i) The curvature of earth is considered
(ii) Used for small area of study	(ii) Used for large area of study
(iii) Generally for Area $< 250\ Km^2$	(iii) For area $> 250\ km^2$
(iv) correction due to curvature of earth, refractions are not required	(iv) Correction due to curvature of earth & slope are applied

(iv) The measurement of survey line of 12 km is taken as it is.	(iv) ~~The~~ On measurement of 12 km, 1 cm measurement extra needs to be applied.
(v) On triangular sum of interior angles of Δ^l is 180°.	(v) For Area of 195.5 km² sum of interior angles of Δ^l is 1 second extra over 180°.

4

Q.6 (a) Explain the different type of Geosynthetics with their primary properties. Do mention atleast one field application of each. What are the key design considerations while selecting them for design?

[20 marks]

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.6 (b) (i) What is meant by "face left" and "face right" of a theodolite? What instrumental errors are eliminated by taking observations on both face left and face right?

(ii) A valley curve of a State Highway is formed by a descending gradient of 1 in 20 meeting an ascending gradient of 1 in 30. Design the length of the valley curve to fulfill both the comfort condition and the headlight sight distance requirement for a design speed of 80 kmph. Assume the allowable rate of change of centrifugal acceleration, $C = 0.60\ \text{m/sec}^3$. Suggest the most suitable shape of the valley curve. Consider reaction time, $t = 2.5$ sec, and coefficient of longitudinal friction, $f = 0.35$.

[8 + 12 = 20 marks]

Q.6 (c) **(i)** An observer standing on the deck of a ship just sees a lighthouse. The top of the lighthouse is 64 m above sea level, and the height of the observer's eye is 16 m above sea level. Find the distance of the observer from the lighthouse.

(ii) Design the size of an oxidation pond for a residential community of 1,200 persons contributing sewage at 150 litres/capita/day. The 5-day BOD of the sewage is 250 mg/L.

Design Constraints:

Organic loading rate in the pond= 250 kg/ha/day.

Length-to-Width ratio (L: B) = 2:1

Assume suitable water depth and calculate the detention time.

(iii) Write about the common defects to be observed in design life of a rigid pavement.

[4 + 8 + 8 = 20 marks]

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Q.7 (a) Determine the Safe load capacity of a driven concrete pile with a diameter of 500 mm and a total length of 18 m. The pile penetrates through a multi-layered soil profile consisting of three distinct strata:

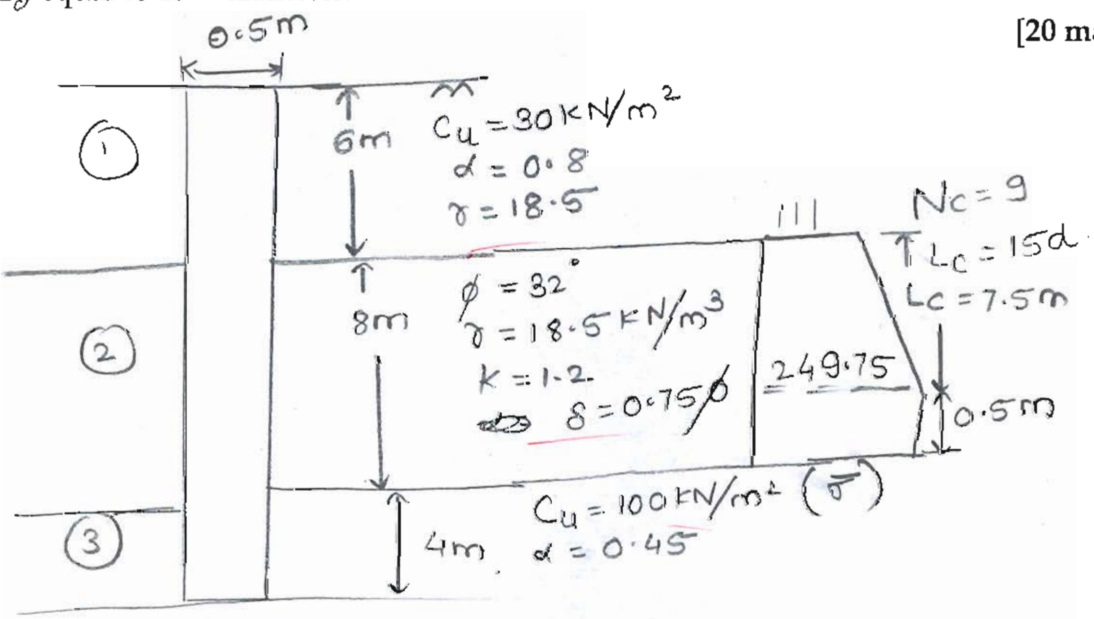
Layer 1 (Top): Soft clay extending from the ground surface to a depth of 6 m. The undrained cohesion is 30 kN/m^2 and the adhesion factor is 0.8. Unit weight is 18.5 kN/m^3.

Layer 2 (Middle): Medium dense sand from 6 m to 14 m depth. The angle of internal friction (ϕ) is 32°, the unit weight is 18.5 kN/m^3, the earth pressure coefficient (k) is 1.2, and the wall friction angle (δ) is 0.75ϕ.

Layer 3 (Bottom): Stiff clay from 14 m to 18 m. The undrained cohesion is 100 kN/m^2, the adhesion factor is 0.45, and the bearing capacity factor (N_c) is 9.

Assume the water table is at great depths and consider the arching effect (critical depth) for the calculations in the sandy layer. For medium dense sand, assume a critical depth (L_c) equal to 15 × diameter.

[20 marks]



for layer 1

$Q_u = 9 C A_b + \alpha \bar{C} A_s$ (clay)

$Q_u = 9 \times 30 \times \frac{\pi}{4} \times 0.5^2 + 0.8 \times 30 \times \pi \times 0.5 \times 6$

$Q_u = 279.209$ kN

for layer 3

$Q_u = 9 C A_b + \alpha \bar{C} A_s$ (clay layer)

$Q_u = 9 \times 100 \times \frac{\pi}{4} \times 0.5^2 + 0.45 \times 100 \times \pi \times 0.5 \times 4$

$Q_u = 459.458$ kN

For sand layer

L_c = critical depth = $15 \times d = 15 \times 0.5 = 7.5$ m

$Q_u = (\bar{\sigma_v})_{base} N_q * A_b + K(\tan\delta)(\bar{\sigma_v})_{avg} A_s$.

(The value of N_q not given)

$(\bar{\sigma_v})_{base} = 249.75 \not< 11000$ kN/m^2 → okay)

$(\bar{\sigma_v})_{avg}$ @ $L_c = \frac{1}{2} \times (111 + 249.75) = 180.375$ kN/m^2

$\therefore K\tan\delta(\bar{\sigma_v})_{avg} \Rightarrow$ @ $L_c = 1.2 * \tan(0.75 \times 32) \times 180.375 = 96.3697 < \cancel{11000}\ 100$ kN/m^2

@ 0.5 m $= 1.2 \tan(0.75 \times 32) \times 249.75 = 133.435 > \cancel{11000}\ 100$ kN/m^2 (NOK)

$\therefore Q_u = \left[249.75 N_q \times \frac{\pi}{4} \times 0.5^2\right] + \left[96.3697 \times \pi \times 0.5 \times 7.5\right] + \left[100 \times \pi \times 0.5 \times 0.5\right]$

{Assume $N_q = 5.9$}

$Q_u = 289.326 + 1135.328 + 78.5398$
$= 1503.19$

$\therefore Q_{unet} = 279.209 + 459.458 + 1503.19$
$= 2241.86$ kN

$Q_{safe} = \frac{Q_u}{FOS}$ {FOS = 2}

$\boxed{Q_{safe} = 1120.93 \text{ kN}}$

13

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Q.7 (b) You are tasked with designing a wastewater treatment facility for a city that generates 1500 L/s of sewage with a 5-day BOD (20°C) of 200 mg/L. The sewage is to be discharged into a stream with a minimum flow rate of 6000 L/s, where the existing BOD is 1 mg/L and the dissolved oxygen (DO) is at 90% of its 9.17 mg/L saturation level. Both the sewage and the stream are at 20°C. Determine the minimum percentage reduction in BOD required at your treatment plant to ensure that the DO concentration in the stream never falls below 4.5 mg/L downstream. Assume de-oxygenation and re-oxygenation coefficients of 0.1 and 0.3 respectively.

[20 marks]

$Q_o = 1500\ l/s$; $BOD_5 = 200 mg/l$

$Q_s = 6000\ l/s$
$BOD_5 = 1\ mg/l$
$DO = 0.9 \times 9.17\ mg/l$
$DO_{sat} = 9.17\ mg/l$

$k_d = 0.1$
$k_r = 0.3$

$Q_{mix} = Q_o + Q_s = 1500 + 6000 = 7500\ l/sec$ — (1)

$(DO)_{mix} \Rightarrow$ taking DO in sewage = 0.

$$(DO)_{mix} = \frac{1500 \times 0 + 6000 \times 0.9 \times 9.17}{7500}$$

$(DO)_{mix} = 6.6024\ mg/l$ — (2)

Let $(BOD_5)_{mix} = S$.

$\therefore$ $BOD_U \Rightarrow$ $S = S_o(1 - 10^{-K_D \times 5})$

$$S_o = \frac{S}{(1 - 10^{-0.1\times5})} = 1.4625 S$$ — (3)

D_o = initial DO deficit $= 9.17 - 6.024 = 3.146\ mg/l$.

$(DO)_{min} = 4.5\ mg/l \longrightarrow \therefore D_C$ = critical deficit $= 9.17 - 4.5 = 4.67\ mg/l$.

$\therefore D_C \le 4.67\ \frac{mg}{l}$

By streter phelp.

$$\left(\frac{S_o}{D_C f}\right)^{f-1} = f\left[1 - (f-1)\frac{D_o}{S_o}\right]$$

$$f = K_R/K_D = \frac{0.3}{0.1} = 3$$

$$\left(\frac{1.40625 \times S}{4.67 \times 3}\right)^{3-1} = 3\left[1 - \frac{(3-1)\times 3.146}{1.4625 S}\right]$$

$S = 4.6728 \text{ mg/l}.$

$\therefore \; BOD_{mix} = 4.6728 = \dfrac{1500 \times (BOD)_{w/w} + 6000 \times 1}{7500}$

$(BOD)_{w/w} = 19.364 \text{ mg/l}.$

$\therefore$ % reduction in $BOD = \dfrac{200 - 19.364}{200} \times 100$

$= \underline{90.318\,\%}$

12

.7 (c) (i) A four-sided closed traverse PQRS has been surveyed with the following lengths and Whole Circle Bearings (WCB). Compute the corrected latitudes and departures using Bowditch rule. Also calculate the angle of closure and its direction.

Line	Length (m)	WCB
PQ	150.00	45°00
QR	125.00	130°00′
RS	160.00	220°30′
SP	132.00	315°00′

(ii) Explain briefly any four test to be performed on bitumen before using pavement construction.

[12 + 8 = 20 marks]

Line	Length (m)	WCB	Latitute	Departure	corrected latitute	corrected departure
PQ	150	45°	106.066	106.066	106.756	104.856
QR	125	130°	-80.348	95.755	-79.772	94.747
RS	160	220°30'	-121.665	-103.911	-120.928	-105.201
SP	132	315°	93.338	-93.338	~~93.73~~ 93.945	-94.402
	$\Sigma l = 567\,m$				$\Sigma L = 0$	$\Sigma D = 0$.

Latitute = lengh × cos θ
Departure = length × sin θ
{ θ = whole circle bearing }

$\Sigma L = e_L$ = error in latitute = -2.609

$\Sigma D = e_D$ = error in departure = 4.572

Acc. to Bowditch

∴ Correction in latitute = $\dfrac{-e_L \times l}{\Sigma l}$

for line PQ

$C_L = \dfrac{-(-2.609) \times 150}{567} = 0.69$

corrected latitute = $L + C_L = 106.066 + 0.69$
$= 106.756$

$C_D = \dfrac{-e_D \times l}{\Sigma l} = \dfrac{-4.572 \times 150}{567} = -1.2095$

∴ Corrected departure = ~~95.755~~ 106.066 − 1.2095 = 104.856.

12

(ii) Test performed on bitumen are

(i) Penetration test ⟶ A plunger is penetrated into the bitumen & penetration upto 0.1mm is measured.

The penetration can be noted as 80-110 meaning the value of penetration is in between 8-11 mm. This test is used for knowing the stiffness of bitumen.

(ii) Flash & fire test → pensky martin equipment is used to measure the temperature of flash & fire point of bitumen. The flash point is temperature at which the bitumen vapours catch fire for a moment. While fire point is point where the entire bitumen catches fire.

(iii) Softening point → Ring & ball apparatus is used to find softening point of bitumen. The bitumen used in field requires desired amount of softness & temperature at which it is achieved is found out by this test

(iv) Viscosity test → Saybolt furol apparatus is used for finding out the viscosity of bitumen. In this test the viscosity is measured in terms of time.

7

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Q.8 (a) (i) A fill 12 m high is to be constructed with a factor of safety of 1.25. The soil has cohesion c = 20 kN/m^2, angle of internal friction ϕ = 15°, and unit weight γ = 17.0 kN/m^3. Determine the required inclination of the filling.

Stability number	**Mobilized friction angle (ϕ_m) = 12°**	
	Inclination i = 30°	Inclination i = 45°
S_n	0.063	0.098

(ii) Write down the ways of improving stability of slopes.

[12 + 8 = 20 marks]

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Q.8 (b) To determine the difference in elevation between two points A and B located on opposite sides of a river, reciprocal levelling was carried out using a tilting level. Observations were taken with the instrument set up near point A and near point B. When the instrument was near point A, the staff readings observed were 1.455 m on point A and 2.685 m on point B. When the instrument was near point B, the corresponding staff readings were 0.925 m on point A and 2.045 m on point B. The horizontal distance between points A and B is 800 m, and the reduced level (RL) of point A is known to be 120.500 m. Based on these observations, determine

(i) Reduced level of point B.

(ii) Total combined error due to curvature and refraction.

(iii) Collimation error of the instrument.

[20 marks]

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8 (c) You are evaluating an existing Activated Sludge facility. The wastewater flow to the plant is 12,000 m^3/day, and the aeration tank volume is 3,000 m^3. The influent and effluent BOD_5 concentrations are 250 mg/L and 25 mg/L, respectively. The mixed liquor suspended solids (MLSS) concentration in the aeration tank is 3,500 mg/L, while the return sludge concentration is 10,000 mg/L. The effluent suspended solids concentration is 15 mg/L. The kinetic parameters include a yield coefficient of 0.5 kg VSS per kg of BOD removed, a decay coefficient of 0.06 day^{-1}, and an MLVSS-to-MLSS ratio of 0.8.

Determine:

(i) Total biomass in Kg to be maintained in aeration tank in steady state condition.

(ii) Total gross biomass in Kg per day created from the consumed BOD.

(iii) Biomass lost due to natural cell death and respiration in Kg per day.

(iv) Net growth of biomass in kg per day.

(v) Its operational sludge age (θ_c).

(vi) Biomass loss in effluent kg per day and biomass to be wasted in kg per day.

(vii) Daily sludge wasting rate (Q_w).

(viii) Recycle ratio (R).

[20 marks]

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Space for Rough Work

Space for Rough Work