SUMMER – 15 EXAMINATIONS

Subject Code: 17304 **Model Answer- Strength of Materials** **Total Pages: 01 / 40**

Important Instruction to Examiners:-

1) The answers should be examined by key words & not as word to word as given in the model answers scheme.

2) The model answers & answers written by the candidate may vary but the examiner may try to access the understanding level of the candidate.

3) The language errors such as grammatical, spelling errors should not be given more importance.

4) While assessing figures, examiners, may give credit for principle components indicated in the figure.

5) The figures drawn by candidate & model answer may vary. The examiner may give credit for any equivalent figure drawn.

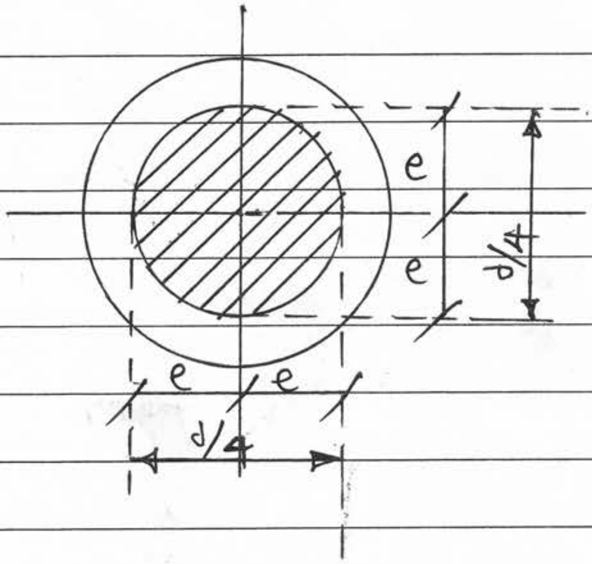
5) Credit may be given step wise for numerical problems. In some cases, the assumed contact values may vary and there may be some difference in the candidate's answers and model answer.

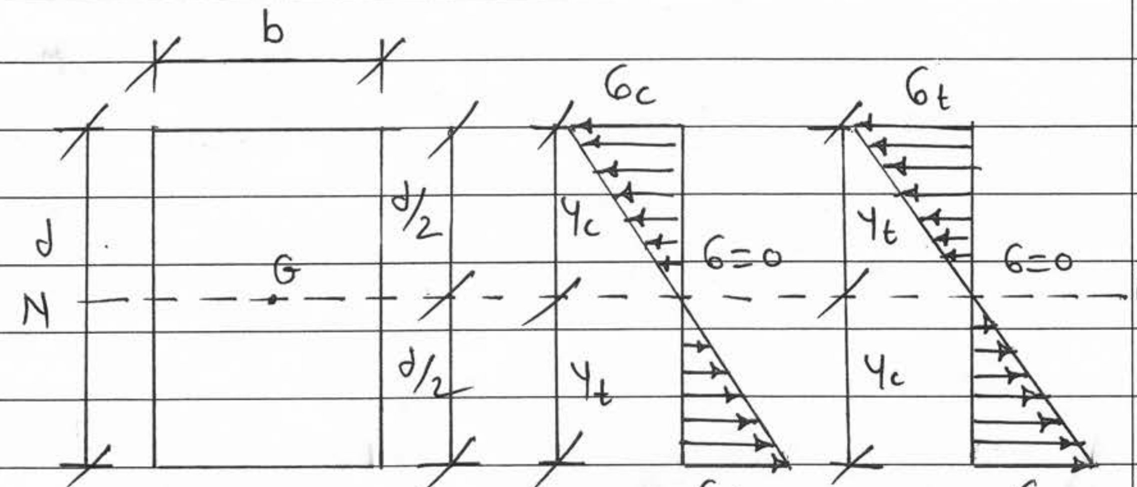
6) In case of some questions credit may be given by judgment on part of examiner of relevant answer based on candidates understanding.

7) For programming language papers, credit may be given to any other programme based on equivalent concept.

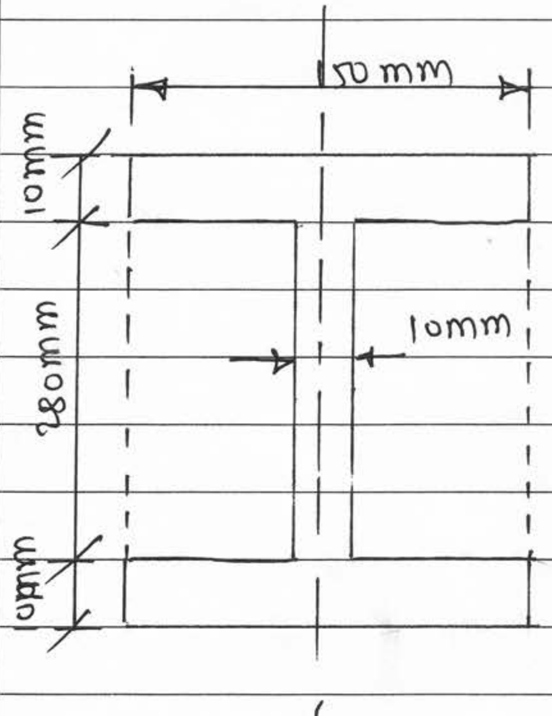
Important notes to examiner

Q.NO	SOLUTION	MARKS
Q-1 A		
a)	i> Fatique : it is property of material by virtue of it resists the failure of material under fluctuating or repeated loading	01 M
	ii> creep : the continues deformation of material which undergoes with time due to application of external steady load is called creep.	01 M
b)	i> principal plane : are the two planes where the normal stress (σ) is the maximum or minimum and no shear stresses.	01 M
	ii> principal stress : The normal stresses (σ) acting on the principal planes.	01 M
c)	$-F = \dfrac{\delta M}{\delta x}$	01 M
	the rate of change of bending moment is equal to shear force	01 M
	if $\dfrac{\delta F}{\delta x} = 0$, bending moment is maximum which shows the point of max. B.M and point of zero shear or the point of changing the sign of S.F	

Q .NO	SOLUTION	MARKS
(d)	Assumption in theory of bending	
	i) The value of young's modulus of Elasticity is same in tension and compression	½M for any four
	ii) The material of beam is homogenous and isotropic.	
	iii) The Transverse sections which were plane before bending remain plane after Bending also.	
	iv) the Beam intially straight and all longitudinal fillament bend into circular arcs with common centre of curvature.	
	v) The radius of curvatures large as compare to the dimensions of the cross-section	
	vi) Each layer of the Beam is free to expand ~~to~~ or contract independently of the layer, above or below it.	
e)	core of section for circular column.	
		02M

Q .NO	SOLUTION	MARKS
f)	$E = 3K(1-2\mu)$ where as	01 M
	$E = 2G(1+\mu)$ E = young's modulus	01 M
	K = Bulk modulus	
	G = Shear modulus	
	μ = poisson's ratio	
g)	i> $\theta = 45^\circ$	01 M
	$\theta = 135^\circ$ are angle where tangential stress is maximum	01 M
h)	Bending stress Distribution diagram for rectangular section for simply supported & cantilever Beam.	
		01 M for (fig-b)
	a) Beam section	
	b) Bending stress variation diagram for simply supported Beam	01 M for (fig-c)
	c) Bending stress variation for cantilever beam	

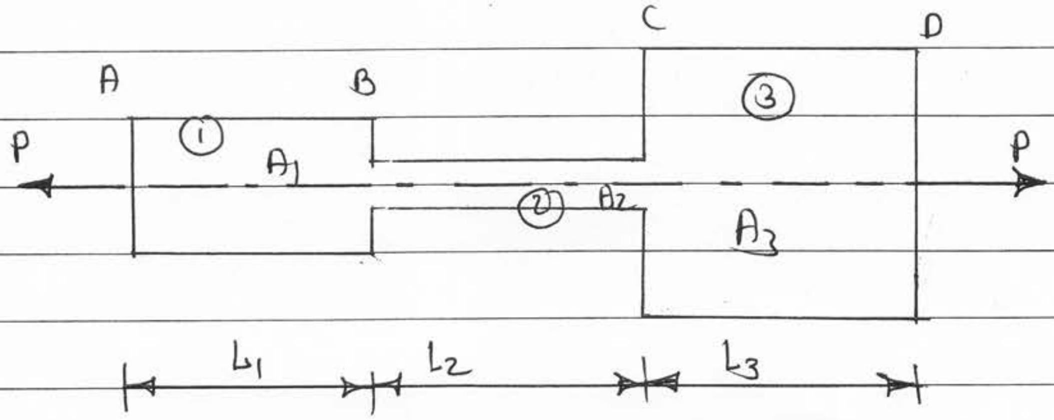
Q.NO	SOLUTION	MARKS
Q-1-B)		
a)	given :-	
	i) $P = 40\,kN$ ii) $\sigma_{permissible} = 150\,Mpa$	
	we have	
	$\sigma = \frac{P}{A} = \frac{P}{\frac{\pi}{4} \times d^2}$	01 M
	∴ put the value of 'P' & 'σ'	
	$150 = \frac{40 \times 10^3}{\frac{\pi}{4} \times d^2}$	01 M
	∴ $d^2 = \frac{40 \times 10^3}{\frac{\pi}{4} \times 150}$	01 M
	$d^2 = \frac{40 \times 10^3}{117.81}$	
	$d^2 = 339.52$	
	$\boxed{d = 18.43\,mm}$	01 M
b)	given data :-	
	i) $d = 1\,m$ ii) Fluid pressure $= 1.5\,N/mm^2$	
	$\sigma_{tensile} = 450\,N/mm^2$ factor of safety $= 4.5$	
→	since hoop stress is twice the longitudinal stress, pipe will fail if the hoop stress exceeds the working stress.	

Q.NO	SOLUTION	MARKS
	$\therefore$ Hoop stress $(\sigma_c) = \dfrac{\text{ultimate stress}}{\text{factor of safety}}$	½ M
	$= \dfrac{450}{4.5} = 100\ N/mm^2$	½ M
	$\sigma_c = \dfrac{pd}{2t}$	01 M
	$100 = \dfrac{1.5 \times 1000}{2 \times t}$	01 M
	$\therefore$ Thickness of pipe $\boxed{t = 7.5\ mm}$	01 M
c)		
	given data : B = 150 mm H = 300 mm b = width of shaded portion (150-10) = 140 mm	½ M for fig
	h = height of shaded portion (300-2x10) = 280 mm	½ M for given data
	i) $I_{xx} = \dfrac{BH^3}{12} - \dfrac{bh^3}{12} = \dfrac{1}{12}[BH^3 - bh^3]$	01 M
	$I_{xx} = \dfrac{1}{12}[150 \times 300^3 - 140 \times 280^3]$	01 M
	$\boxed{I_{xx} = 81.39 \times 10^6\ mm^4}$	01 M

Q .NO	SOLUTION	MARKS

Q-2(a)

i> uniformly varrying section showing anial load

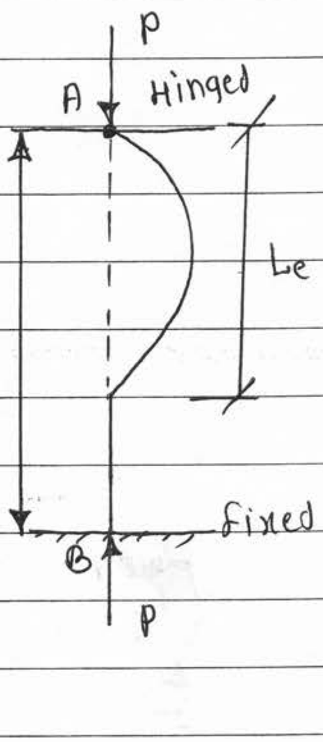


02 M

where as P = anial load

A_1, A_2, A_3 & $L_1\ L_2\ L_3$ are the c/s area & length of section 1 2 3

ii>



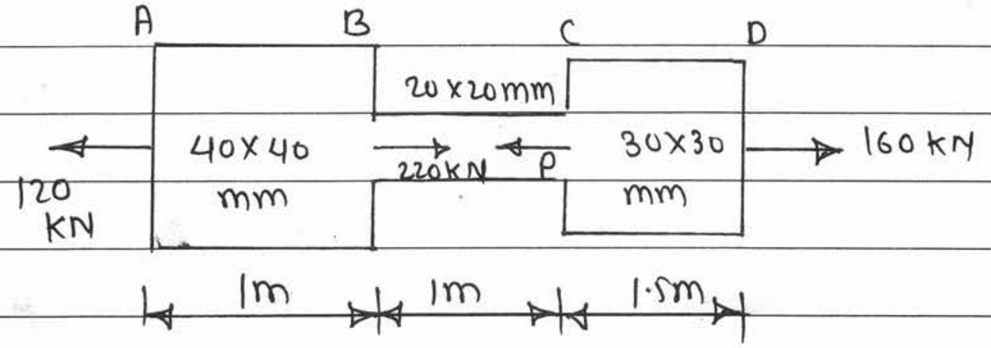
01 M for fig

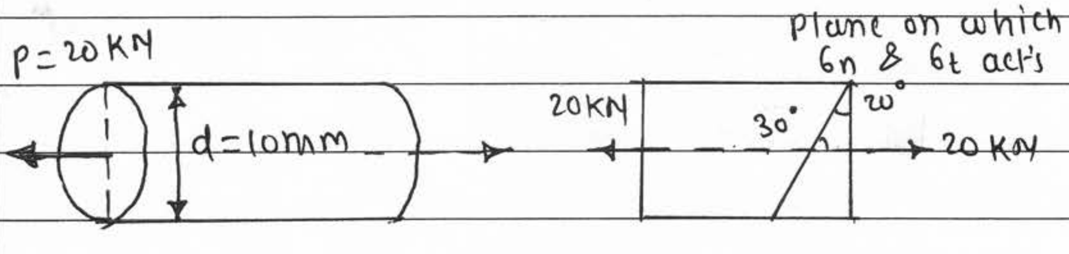
effective length

$$L_{eff} = \frac{L}{\sqrt{2}}$$

01 M for formula

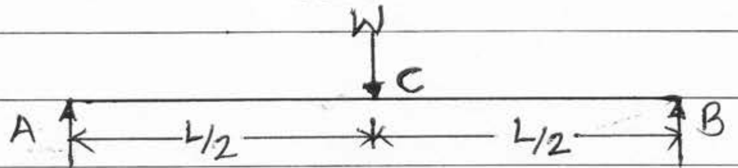
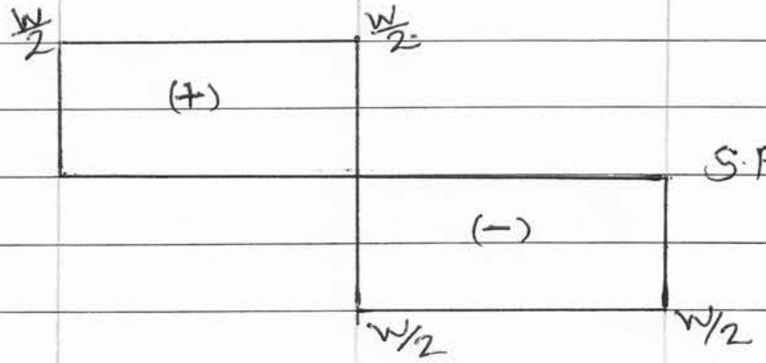
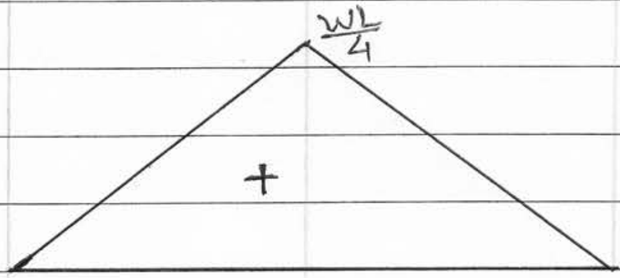
Q .NO	SOLUTION	MARKS
b)	Assumption's in Euler's column Theory	
	i) The material of the column is perfectly homogeneous and isotropic	01 M (for each any four)
	ii) The column is initially straight and of uniform lateral dimensions	
	iii) The load on the column is exactly axial.	
	iv) The column is long and fails due to buckling or bending only.	
	v) The self weight of the column is neglected.	
	vi) The column is stressed upto the limit of proportionality.	
c)	given data	
	$L = 300\,mm$ $d = 20\,mm$	
	$t = 100^\circ C$ Total extension $= 0.4\,mm$	
	$E = 2\times10^5\,N/mm^2$ & $\alpha = 12\times10^{-6}/^\circ C$	½M
	Total extension of the rod = free expansion + Extension δL due to force 'P'	
	$0.4 = (L\alpha t) + \delta L$ due to force 'P'	½M
	$0.4 = (300\times12\times10^{-6}\times100) + \delta L$	
	$0.4 = 0.36 + \delta L$	
	$\therefore \boxed{\delta L = 0.04\,mm}$	½M

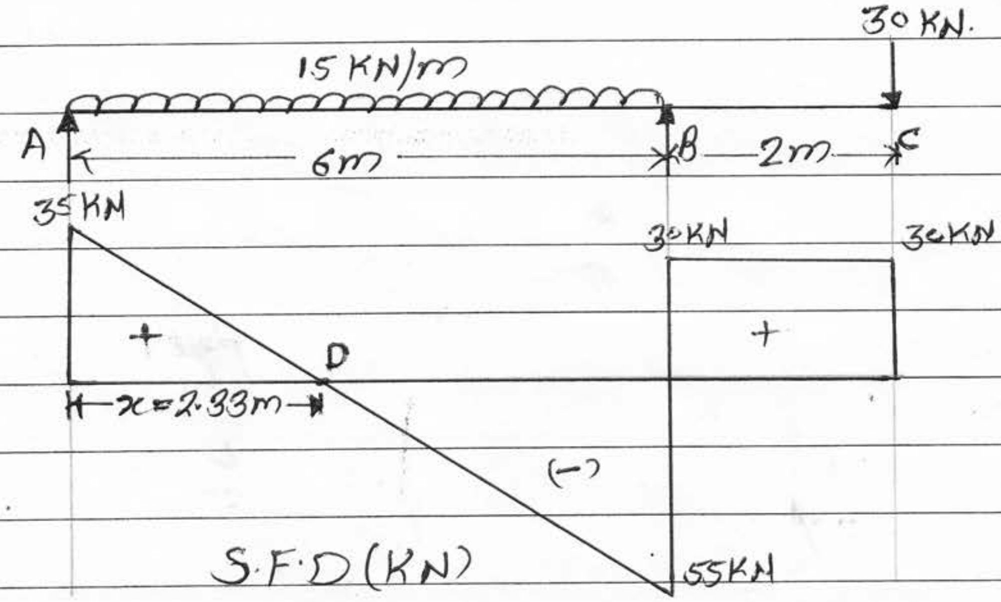
Q .NO	SOLUTION	MARKS
Q-2 (c) (continued)	But	
	$\delta L = \frac{P \cdot L}{AE}$	½M
	$0.04 = \frac{P \times 300}{\left(\frac{\pi \times 20^2}{4}\right) \times 2 \times 10^5}$	½M
	$\therefore P = \frac{0.04 \times \left(\frac{\pi}{4} \times 20^2\right) \times 2 \times 10^5}{300}$	½M
	$\therefore P = 8.377 \times 10^3$ N <u>or</u> $P = 8.377$ kN	01M
d)		
	i) let $A_1 = 40 \times 40 = 1600\,mm^2$ $L_1 = 1m = 1000mm$ $A_2 = 20 \times 20 = 400mm^2$ $L_2 = 1m = 1000mm$ $A_3 = 30 \times 30 = 900mm^2$ $L_3 = 1.5m = 1500mm$	
	ii) To find unknown value of 'P' $\Sigma fx = -120 + 220 - P + 160$ $\boxed{P = 260\ KN}$ (←)	01M
	iii) $\delta L = \delta L_1 + \delta L_2 + \delta L_3$ $\delta L = \frac{P_1 L_1}{A_1 E} + \frac{P_2 L_2}{A_2 E} + \frac{P_3 L_3}{A_3 E}$	01/2 M

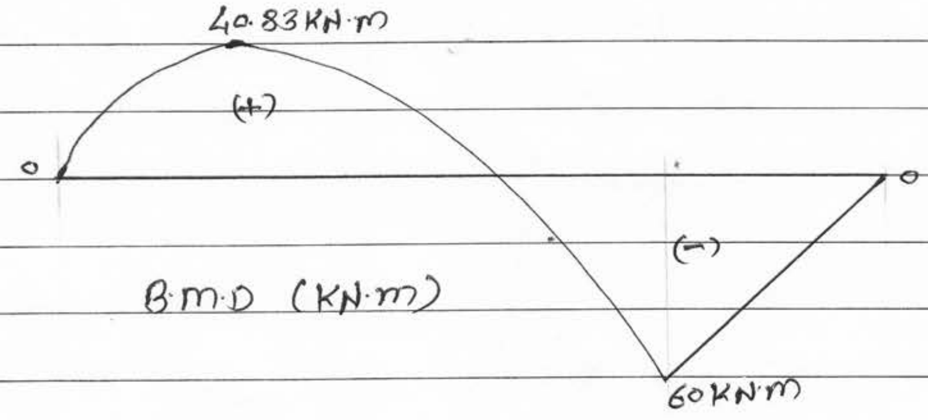
Q .NO	SOLUTION	MARKS
	$\delta L = \frac{1}{E}\left[\frac{P_1 L_1}{A_1} + \frac{P_2 L_2}{A_2} + \frac{P_3 L_3}{A_3}\right]$	1/2 M
	$= \frac{1}{2\times10^5}\left[\frac{(120\times10^3)\times1000}{1600} + \frac{(-100\times10^3)\times1000}{400} + \frac{(160\times10^3)\times1500}{900}\right]$	01 M
	$= \frac{1}{2\times10^5}\left[75\times10^3 - 250\times10^3 + 266.67\times10^3\right]$	
	$\boxed{\delta L = 0.458\ mm}$	01 M
e)	given data $d = 10\ mm$ P_x = axial pull = 20 KN = 20×10^3 N, $\sigma_y = 0$, $q = 0$	
		1/2 M
	i) $A = \frac{\pi}{4}\times d^2 = \frac{\pi}{4}\times 10^2 = 78.539\ mm^2$	1/2 M
	ii) $\sigma_x = \frac{P_x}{A} = \frac{20\times10^3}{78.539} = 254.65\ N/mm^2$	1/2 M
	$\theta = 90° - 30° = 60°$	

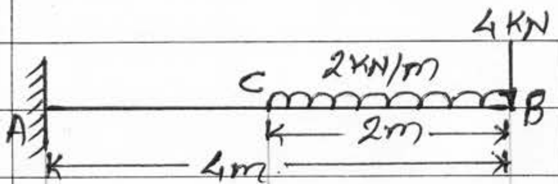
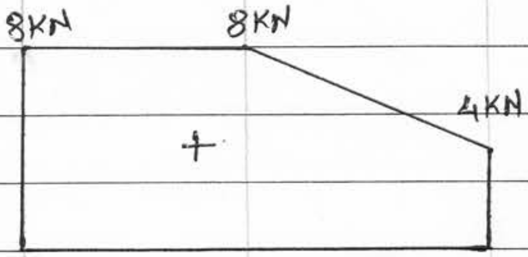
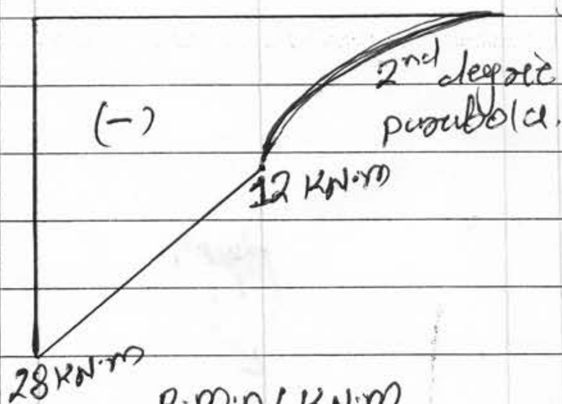
Q .NO	SOLUTION	MARKS
	iii) To find normal stress (σ_n) and tangential stress (σ_t)	
	$\sigma_n = \left(\frac{\sigma_x + \sigma_y}{2}\right) + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos 2\theta + q \cdot \sin 2\theta$	½M
	$= \left(\frac{254.65 + 0}{2}\right) + \left(\frac{254.65 - 0}{2}\right)\cos(2\times 60^\circ) + 0$	
	$\sigma_n = \frac{254.65}{2} + \frac{254.65 - 0}{2}\cos 120^\circ$	
	$\boxed{\sigma_n = 63.66\ N/mm^2 \quad (\text{Tensile})}$	½M
	$\sigma_t = \left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 2\theta - q \cdot \cos 2\theta$	½M
	$= \left(\frac{254.65 - 0}{2}\right)\sin(2\times 60^\circ) - 0$	½M
	$\sigma_t = \frac{254.65}{2}\sin 120^\circ$	
	$\boxed{\sigma_t = 110.266\ N/mm^2}$	½M
f)	given data : $L = 3m = 3000mm$ $d = 1m = 100mm$ $t = 15 mm$, $P = 1.5\ N/mm^2$ $E = 2\times 10^5\ N/mm^2$ $\mu = 0.25$	½M
	i) To find circumferential strain (e_c) $e_c = \frac{Pd}{4tE}(2-\mu)$	½M

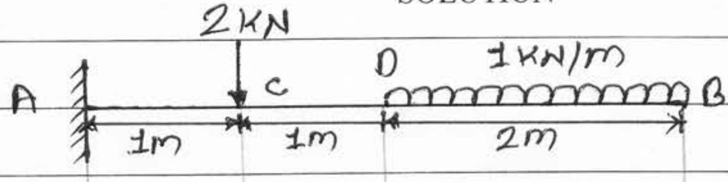
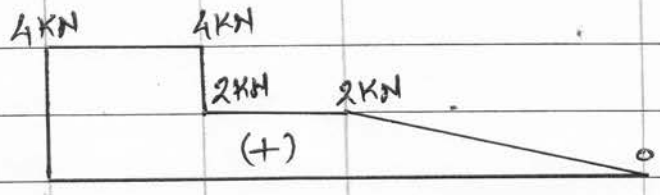
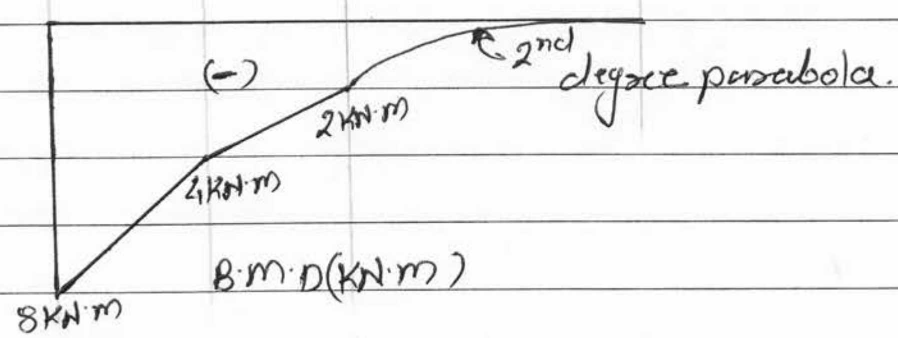
Q .NO	SOLUTION	MARKS
	$= \frac{1.5\times1000}{4\times15\times2\times10^5}(2-0.25)$	½M
	$\boxed{e_c = 2.1875\times10^{-4}}$	½M
	ii) To find longitudinal strain (e_L)	
	$e_L = \frac{pd}{4tE}(1-2\mu)$	½M
	$e_L = \frac{1.5\times1000}{4\times15\times2\times10^5}(1-2\times0.25)$	½M
	$\boxed{e_L = 6.25\times10^{-5}}$	01 M

Q .NO	SOLUTION	MARKS
Q3 a)		
	 S.F.D.	$\frac{1}{2}$ M
	 B.M.D	$\frac{1}{2}$ M
	i) Support reactions	
	a) $\Sigma F_y = 0$.	
	$R_A + R_B = W$ ——(i)	
	b) $\Sigma M @ A = 0$	
	$W \times \frac{L}{2} - R_B \times L = 0$.	
	$\therefore R_B = \frac{WL}{2 \cdot L} = \frac{W}{2}$.	$\frac{1}{2}$ M
	$\therefore R_A = W - R_B = W - \frac{W}{2} = \frac{W}{2}$.	$\frac{1}{2}$ M
	ii) S.F. Calculation	
	S.F at just left of A = 0 KN	
	S.F at just right of A = R_A = $W/2$ KN	
	S.F at just left of C = $\frac{W}{2}$ KN	

Q .NO	SOLUTION	MARKS
Q3a) Cont...	S.F at just Right of C $= \frac{W}{2} - W = -\frac{W}{2}$ KN S.F at just left of B $= -\frac{W}{2}$ KN S.F at just right of B $= -\frac{W}{2} + R_B = 0$ KN	1 M
	iii) B.M calculation B.M at A = B.M at B = 0 KN.m ..... simple support * As the point of Contrashear is under the point Load the maximum B.M will be develope under the point load i.e at C	
	$\therefore$ Max. B.M$_C = R_A \times \frac{L}{2} = \frac{W}{2} \times \frac{L}{2} = \frac{WL}{4}$	$\frac{1}{2}$ M
	* The maximum shear force will be developed at the supports, due to symmetry maximum S.F at support A & B is equal	
	Maximum S.F = R_A or R_B = $\frac{W}{2}$	$\frac{1}{2}$ M
Q3b)	S.F.D (KN)	$\frac{1}{2}$ M

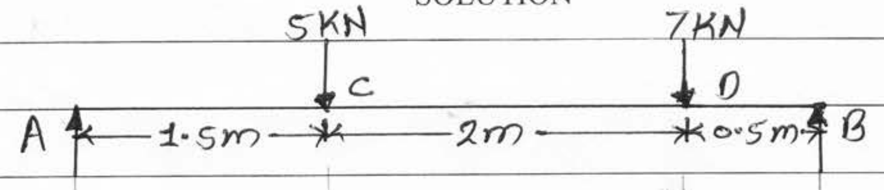
Q .NO	SOLUTION	MARKS
Q3 b) Cont...		$\frac{1}{2}$M
	i) Support reaction	
	a) $\Sigma Fy = 0$	
	$R_A + R_B = (15 \times 6) + 30 = 120$ KN —— (i)	
	b) $\Sigma M@A = 0$	
	$(15 \times 6 \times 3) + (30 \times 8) - R_B \times 6 = 0$	
	$510 = 6 R_B$	
	$\therefore R_B = 85$ KN	1M
	$\therefore R_A = 35$ KN	
	ii) S.F. calculation	
	S.F at just left of A = 0 KN	
	S.F at just right of A = R_A = 35 KN	
	S.F at just left of B = $35 - (15 \times 6) = -55$ KN	1M
	S.F at just right of B = $-55 + 85 = 30$ KN	
	S.F at just left of C = 30 KN	
	S.F at just right of C = $30 - 30 = 0$ KN.	
	Let D be the point of Contrashear.	
	from similar triangles	
	$\frac{35}{x} = \frac{55}{6-x}$	

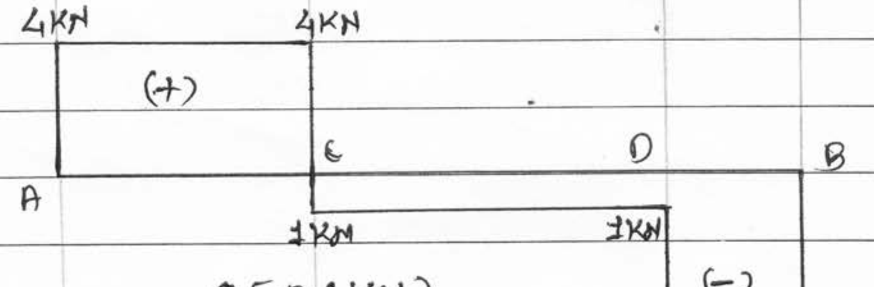
Q.NO	SOLUTION	MARKS
Q3b Cont...	$\therefore x = \frac{35\times6}{35+55} = 2.33$ m from A.	
	iii> B.M. Calculation	
	B.M at A = 0 simple support	
	B.M at C = 0 free end of overhang.	1M
	B.M at D = $R_A\times2.33 - (15\times2.33\times\frac{2.33}{2})$	
	B.M at D = 40.83 KN.m	
	B.M at B = $R_A\times6 - (15\times6\times3)$ = −60 KN.m.	
Q3c>		1M for S.F.D & B.M.D
	i> Support reactions	
	a> $\Sigma F_y = 0$; $R_A = 4+(2\times2) = 8$ KN	1M
	 S.F.D (KN)	
	ii> S.F. calculation	
	S.F at just left of A = 0 KN	
	S.F at just right of A = R_A = 8KN	
	S.F at just C = 8KN	1M
	S.F at just left of B = 8 − (2×2) = 4KN	
	S.F at just right of B = 4 − 4 = 0 KN.	
	 B.M.D (KN.M)	
	iii> B.M. calculation	
	B.M at B = 0 ... free end	
	B.M at C = −4×2 − 2×2×1 = −12 KN.m	1M
	B.M at A = −4×4 − 2×2×3 = −28 KN.M	

Q .NO	SOLUTION	MARKS
Q3 d)		
		$\frac{1}{2}$ M
	S.F.D (KN)	
		$\frac{1}{2}$ M
	B.M.D (KN.m)	
	i) Support reaction	
	a) $\Sigma F_y = 0$; $R_A = 2 + (1 \times 2) = 4 KN.$	1M
	ii) S.F. Calculation	
	S.F at Left of A = 0 KN	
	S.F at right of A = R_A = 4KN	
	S.F at left of C = 4KN.	
	S.F at right of C = 4 − 2 = 2KN	1M
	S.F at D = 2KN.	
	S.F at B = 2 − (1×2) = 0 KN.	
	iii) B.M Calculation	
	B.M at B = 0 free end	
	BM at D = −(1×2×1) = −2 KN.M	
	BM at C = −(1×2×2) = −4 KN.m	1M
	BM at A = −(1×2×3) − (2×1) = −8 KN.m	

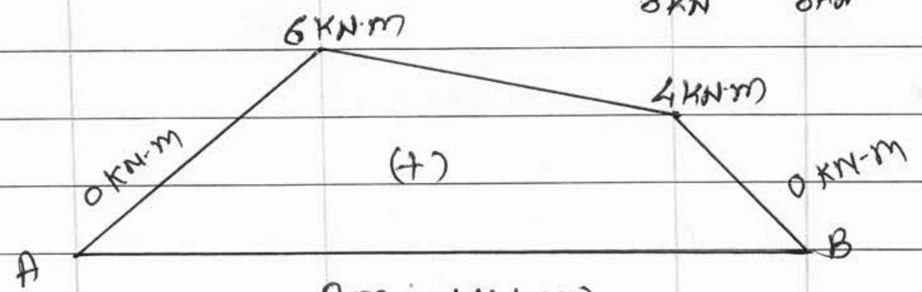
Q.NO	SOLUTION	MARKS

Q3 c)





S.F.D (KN) — ½ M



B.M.D (KN.m) — ½ M

i) Support reactions

a) $\Sigma F_y = 0$

$R_A + R_B = 5 + 7 = 12 KN.$

b) $\Sigma M @ A = 0$

$(5 \times 1.5) + (7 \times 3.5) - 4R_B = 0$

$32 = 4R_B$

$\therefore R_B = 8 KN$ — 1M

$\therefore R_A = 12 - 8 = 4 KN.$

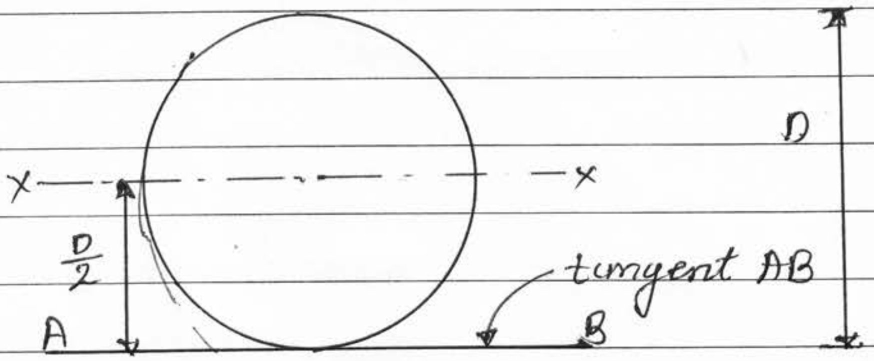
ii) S.F. Calculation

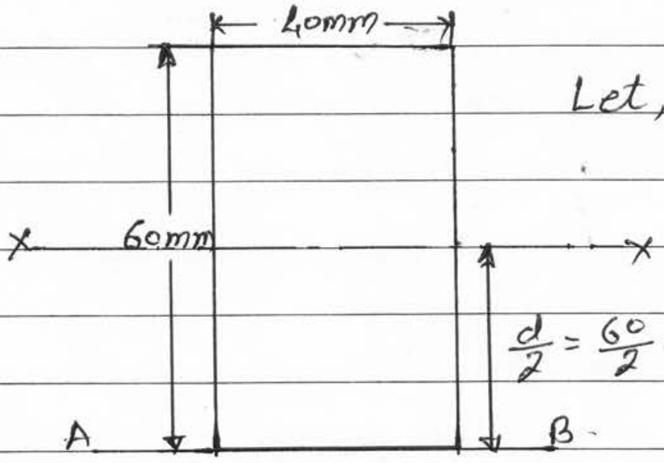
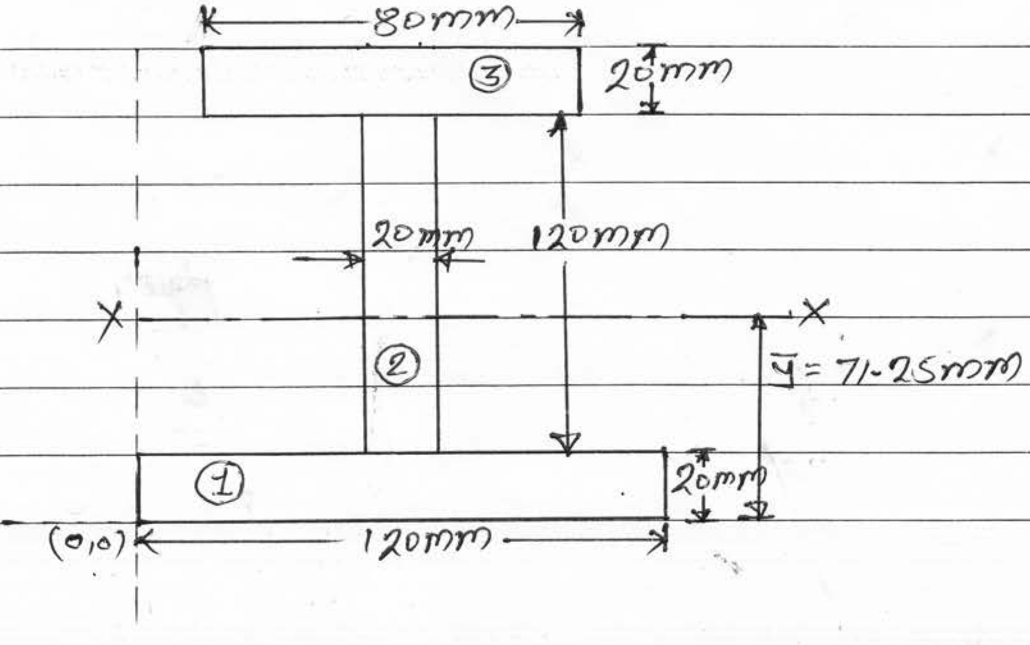
S.F at just left of A = 0

S.F at just right of A = RA = 4 KN

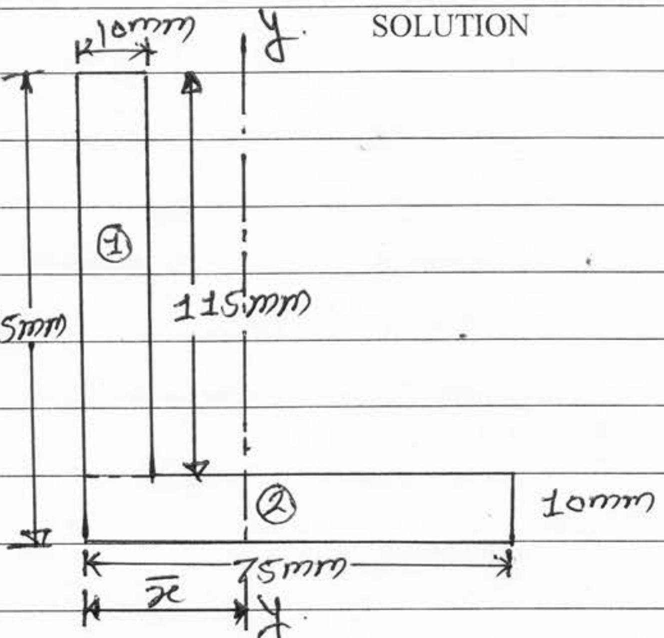
S.F at just left of C = 4 KN

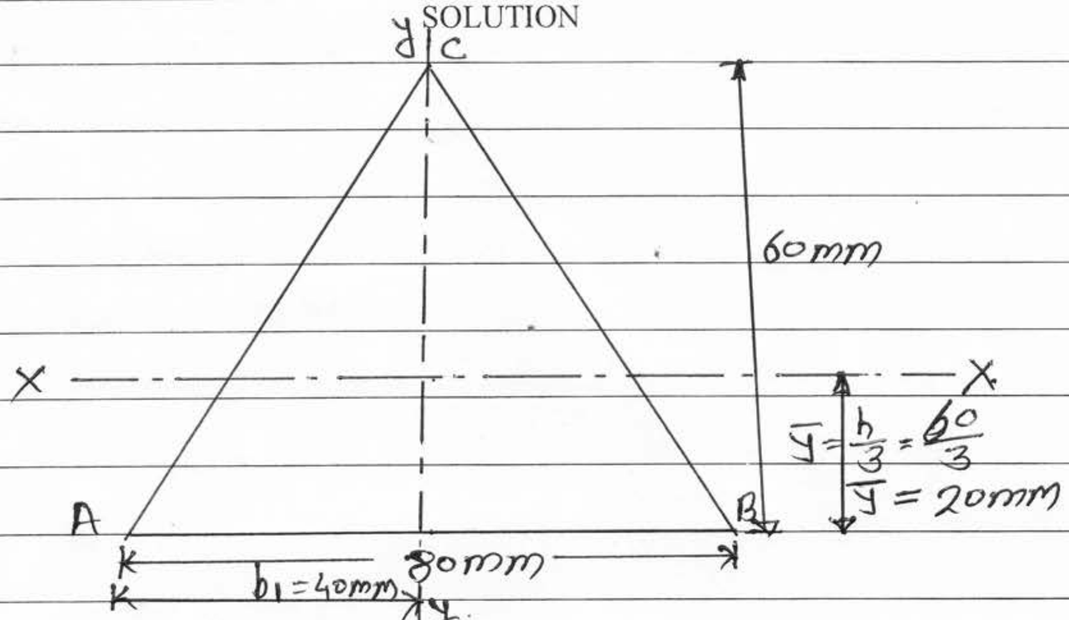
S.F at just right of C = 4 − 5 = −1 KN.

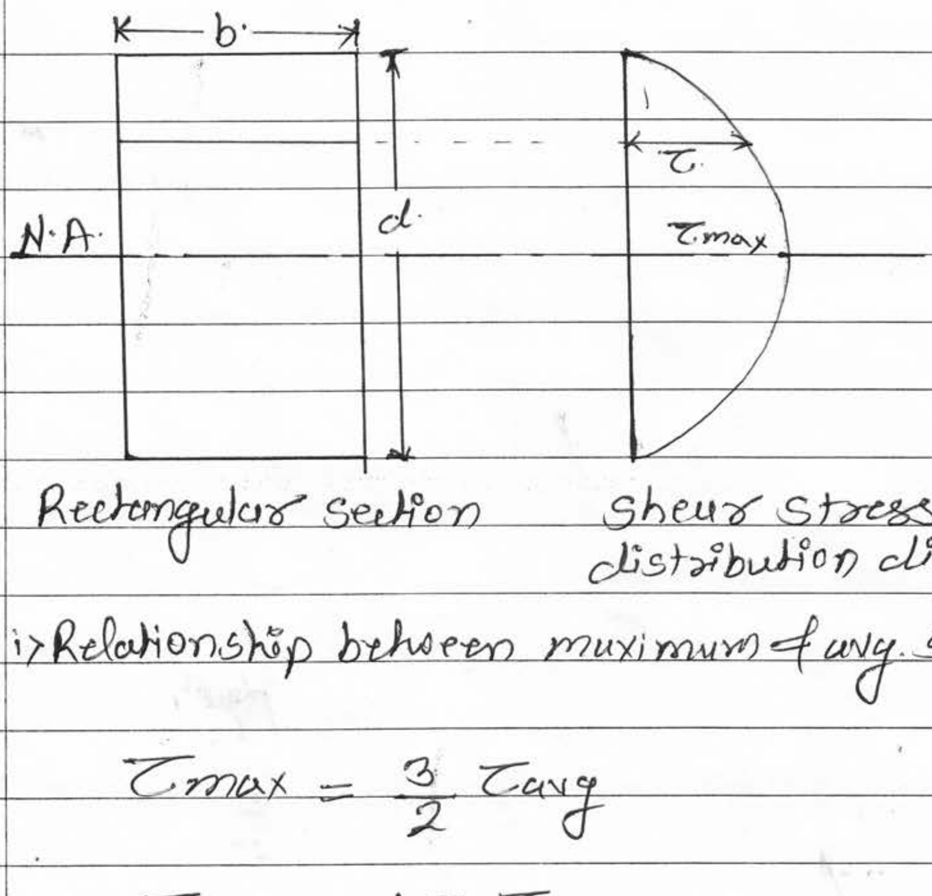
Q .NO	SOLUTION	MARKS
Q3e) Cont...	S.F. at just left of D = −1 KN.m	
	S.F at just right of D = −1−7 = −8 KN	1M
	S.F at just left of B = −8 KN.	
	S.F at just right of B = −8+R_B = 0 KN.	
	iii) B.M. Calculation.	
	B.M at A = B.M at B = 0 ---- simple support	
	B.M at C = $R_A \times 1.5 = 4\times1.5 = 6$ KN.m	1M
	B.M at D = $R_A \times 3.5 - (5\times2) = 4\times3.5 - 10 = 4$ KN.m.	
Q3f)		1M
	Given - M.I$_{AB}$ = 6.283×10^5 mm^4 —— (i)	
	Using parallel axis theorem M.I$_{AB}$ is given by	
	$M.I_{AB} = \underline{I_G + Ah^2} = \left[\frac{\pi}{64}D^4 + \frac{\pi}{4}D^2\times\left(\frac{D}{2}\right)^2\right]$	1M
	$M.I_{AB} = \frac{\pi}{64}D^4 + \frac{\pi}{16}D^4 = 0.2454D^4$ —— (ii)	1M
	Equating eq^n(i) & (ii)	
	$6.283\times10^5 = 0.2454D^4$	
	$D^4 = 2.56\times10^6$	
	$D = (2.56\times10^6)^{1/4}$	
	$D = 40$ mm	1M
	Diameter of disc is 40mm.	

Q .NO	SOLUTION	MARKS
Q4 a)	 Let, $b = 40mm$ $d = 60mm$	1M
	M.I. about AB By parallel axis theorem. $I_{AB} = I_G + Ah^2$	1M
	$= \frac{bd^3}{12} + bd \cdot \left(\frac{d}{2}\right)^2$	
	$= \frac{40 \times 60^3}{12} + 40 \times 60 \times \left(\frac{60}{2}\right)^2$	1M
	$= 720 \times 10^3 + 2.16 \times 10^6$	
	$I_{AB} = 2.88 \times 10^6 \, mm^4$	1M
	M.I. of solid rectangular section about its smaller side is $2.88 \times 10^6 \, mm^4$	
Q4 b)		

Q .NO	SOLUTION	MARKS
Q4 b) Contd...	i) Position of x-x axis ($\bar{Y}$)	
	$a_1 = 120 \times 20 = 2400\,mm^2$; $a_2 = 120 \times 20 = 2400\,mm^2$; $a_3 = 80 \times 20 = 1600\,mm^2$	
	$x_1 = 60\,mm$; $x_2 = 60\,mm$; $x_3 = 60\,mm$	
	$y_1 = \frac{20}{2} = 10\,mm$; $y_2 = 20 + \frac{120}{2} = 80\,mm$; $y_3 = 20 + 120 + \frac{20}{2} = 150\,mm$	
	$\therefore \bar{Y} = \frac{a_1y_1 + a_2y_2 + a_3y_3}{a_1 + a_2 + a_3}$	
	$= \frac{(2400 \times 10) + (2400 \times 80) + (1600 \times 150)}{2400 + 2400 + 1600}$	
	$\bar{Y} = 71.25\,mm$ from bottom.	1M
	ii) M.I. about x-x by parallel axis theorem	
	$Ixx = Ixx_1 + Ixx_2 + Ixx_3$	
	$Ixx = \left[IG_1 + A_1h_1^2\right] + \left[IG_2 + A_2h_2^2\right] + \left[IG_3 + A_3h_3^2\right]$	1M
	$Ixx_1 = \frac{120 \times 20^3}{12} + 2400(71.25 - 10)^2 = 9.08 \times 10^6\,mm^4$	½M
	$Ixx_2 = \frac{20 \times 120^3}{12} + 2400(71.25 - 80)^2 = 3.06 \times 10^6\,mm^4$	½M
	$Ixx_3 = \frac{80 \times 20^3}{12} + 1600(71.25 - 150)^2 = 9.97 \times 10^6\,mm^4$	½M
	$\therefore Ixx = 9.08 \times 10^6 + 3.06 \times 10^6 + 9.97 \times 10^6$	
	$Ixx = 22.11 \times 10^6\,mm^4$	
	$\therefore$ M.I. about x-x axis is $22.11 \times 10^6\,mm^4$	½M

Q .NO	SOLUTION	MARKS
Q4 c)		
	i) Position of y-y axis $(\bar{x})$	
	$a_1 = 115 \times 10 = 1150\ mm^2$ $\quad a_2 = 75 \times 10 = 750\ mm^2$	
	$x_1 = \frac{10}{2} = 5\ mm$ $\quad x_2 = \frac{75}{2} = 37.5\ mm$	
	$\bar{x} = \frac{a_1 x_1 + a_2 x_2}{a_1 + a_2} = \frac{(1150 \times 5) + (750 \times 37.5)}{1150 + 750}$	
	$\bar{x} = 17.828\ mm$	1M
	ii) M.I. about y-y is given by parallel axis theorem	
	$I_{yy} = I_{yy_1} + I_{yy_2}$	1M
	$I_{yy_1} = I_{G_1} + A_1 h_1^2 = \left[\frac{d b^3}{12} + bd(\bar{x} - x_1)^2\right]_1$	
	$I_{yy_1} = \frac{115 \times 10^3}{12} + 1150(17.828 - 5)^2 = 198.82 \times 10^3\ mm^4$	½M
	$I_{yy_2} = I_{G_2} + A_2 h_2^2 = \frac{10 \times 75^3}{12} + 750(17.828 - 37.5)^2$	
	$I_{yy_2} = 641.80 \times 10^3\ mm^4$	½M
	$\therefore I_{yy} = 840.62 \times 10^3\ mm^4$	1M

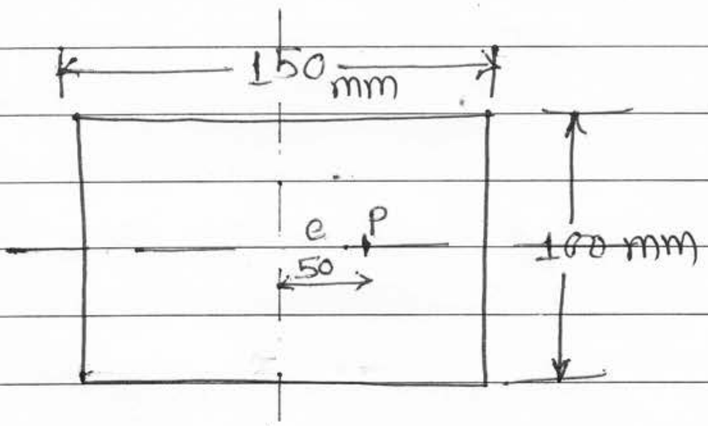
Q .NO	SOLUTION	MARKS
Q4 d)		
	i) M.I. about the C.G. of section	
	$I_{xx} = \frac{bh^3}{36}$	½ M
	$I_{xx} = \frac{80\times60^3}{36} = 480\times10^3\ mm^4$	½ M
	$I_{yy} = \frac{hb_1^3}{12}\times2 = \frac{2\times60\times40^3}{12} = 640\times10^3\ mm^4$	1 M
	ii) M.I. about the base of triangle.	
	I_{AB} = By parallel axis theorem	
	$= I_{G_1} + Ah^2 = \frac{bh^3}{36} + \frac{1}{2}\times b\times h\times\left(\frac{h}{3}\right)^2$	
	$I_{AB} = \frac{bh^3}{36} + \frac{bh^3}{18} = \frac{bh^3}{12}$	1 M
	$\therefore I_{AB} = \frac{80\times60^3}{12} = \underline{1.44\times10^6\ mm^4}$	1 M
	OR alternate solution	
	ii) $I_{AB} = \frac{bh^3}{12} = \frac{80\times60^3}{12} = \underline{1.44\times10^6\ mm^4}$	2 M

Q .NO	SOLUTION	MARKS
Q4 e)	i) Bending eqn. $\boxed{\frac{M}{I} = \frac{\sigma_b}{y} = \frac{E}{R}}$	2M
	ii) Moment of resistance (M.R) The resistance offered by the moment of couple due to two equal & opposite forces to the bending moment M due to external loads is called as moment of resistance. moment of resistance is the internal moment setup in the material of the beam.	2M
Q4 f)		2M
	i) Relationship between maximum & avg. shear stress $\tau_{max} = \frac{3}{2}\tau_{avg}$	2M
	$\tau_{max} = 1.5\,\tau_{avg}$.	

Q .NO	SOLUTION	MARKS
5-a)	Given:- for rectangular beam	
	$b = 100mm$, $d = 150mm$	
	$L = 2m$, σ_b = Maximum bending stress $= 28 N/mm^2$	
	τ_{max} = shear stress $= 2 N/mm^2$	
	To find:- Intensity of 'udl' i.e. Maximum load supported by beam in N/m.	
	Soln:- $\frac{M}{I} = \frac{\sigma_b}{y}$	½M
	M = Maximum bending moment	
	$= \frac{wL^2}{8}$ $\longrightarrow$ Assuming beam as simply supported beam	
	$M = \frac{w \times (2)^2}{8} = 0.5w \, Nm$	
	$\boxed{M = 0.5w \times 10^3 \, N\text{-}mm}$	½M
	$I = \frac{bd^3}{12} = \frac{100 \times (150)^3}{12} = 28.125 \times 10^6 \, mm^4$	½M
	$y = d/2 = \frac{150}{2} = 75mm.$	½M
	$\therefore \frac{M}{I} = \frac{\sigma_b}{y}$	
	$\frac{0.5w \times 10^3}{28.125 \times 10^6} = \frac{28}{75}$	01M
	$w = \frac{28 \times 28.125 \times 10^6}{0.5 \times 10^3 \times 75}$	
	$w = 21000 \, N/m$	
	$\boxed{w = 21 kN/m}$ $\longrightarrow$ Ans. (udl)	
	$\boxed{W = 21 \times 2 = 42 kN}$ $\longrightarrow$ (Point load)	01M

Q .NO	SOLUTION	MARKS
5-b	Given:- d = diameter of shaft	
	i.e. circular section	
	d = 80mm.	
	To find:- limit of eccentricity 'e'	
	Solution:- We know that	
	$\sigma_0 = \sigma_b$	1/2M
	$\frac{P}{A} = \frac{M}{Z}$	1/2M
	$\frac{\cancel{P}}{A} = \frac{\cancel{P}e}{Z}$	
	$\frac{1}{A} = \frac{e}{Z}$	
	$e = \frac{Z}{A}$	1/2M
	$e = \frac{\frac{\pi}{32} \times d^3}{\pi/4 \times d^2}$	1/2M
	$= \frac{\cancel{\pi}}{\cancel{32}8} \times \frac{d^{\cancel{3}}}{1} \times \frac{\cancel{4}}{\cancel{\pi}} \times \frac{1}{d^{\cancel{2}}}$	
	$e = \frac{d}{8}$	01M
	$e = \frac{80}{8}$	
	$\boxed{e = 10mm}$ → Ans.	01M

Q .NO	SOLUTION	MARKS
5-C	Given:- for a rectangular column	



b = width of rectangular plate = 150mm

d = thickness of column = 100mm

P = 150×10^3 N, load

e = eccentricity = 50mm

To find : (i) Maximum stress intensity (σ_{max})

(ii) Minimum stress intensity (σ_{min})

Sol^n:- We know that,

$\sigma_{max} = \sigma_0 + \sigma_b$ — ½M

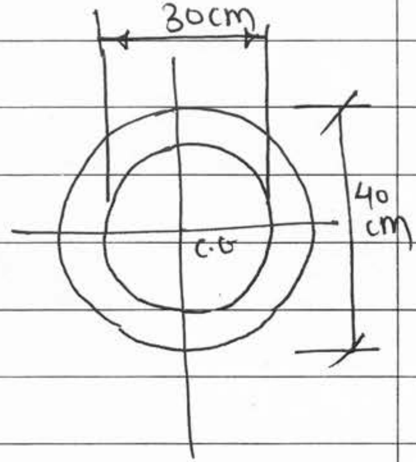
$\sigma_{min} = \sigma_0 - \sigma_b$ — ½M

$$\sigma_0 = \frac{P}{A} = \frac{150 \times 10^3}{100 \times 150}$$

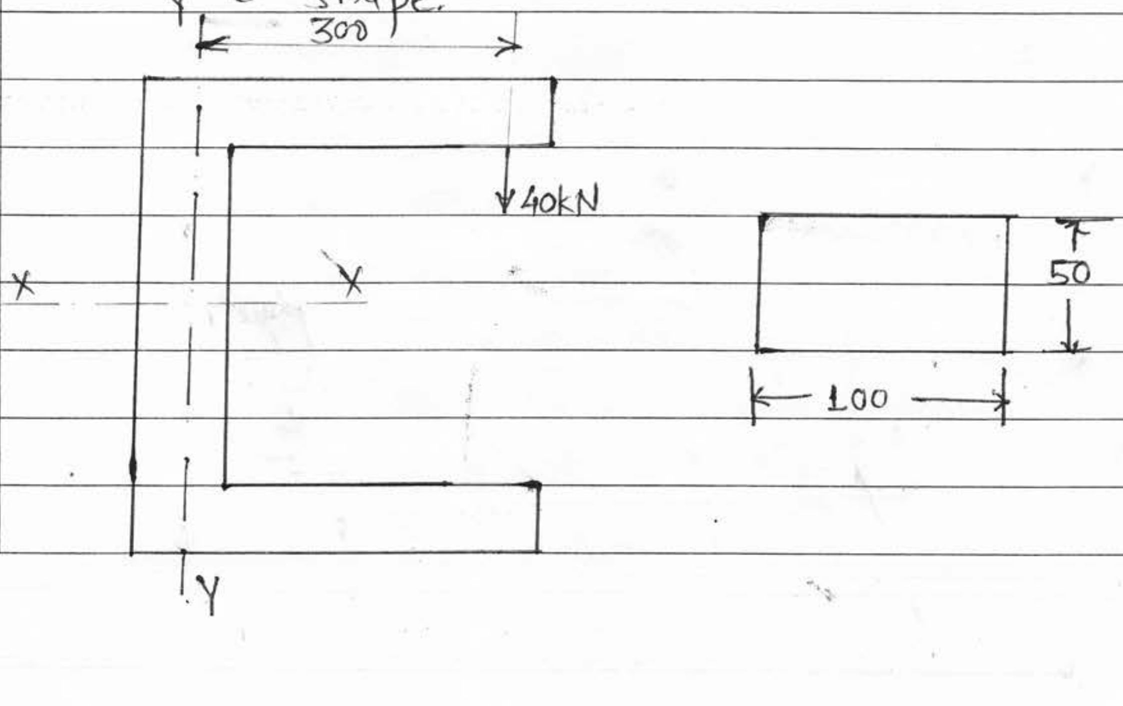
$$= \frac{150 \times 10^3}{150 \times 100}$$

$$\boxed{\sigma_0 = 10 N/mm^2}$$ — ½M

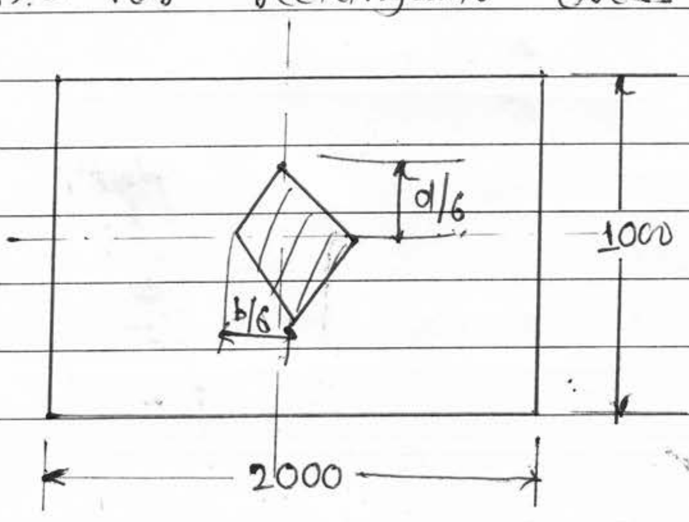
Q .NO	SOLUTION	MARKS
	$M = M_{yy} = Pe$	
	$= 150\times10^3\times50$	
	$\boxed{M = 7.5\times10^6\ N\text{-}mm}$	½M
	$Z = Z_{yy}$	
	$= \dfrac{db^2}{6}$	
	$= \dfrac{100\times(150)^2}{6}$	
	$\boxed{Z = 375\times10^3\ mm^3}$	½M
	$\sigma_b = \dfrac{M}{Z} = \dfrac{M_{yy}}{Z_{yy}}$	
	$= \dfrac{7.5\times10^6}{375\times10^3}$	
	$\boxed{\sigma_b = 20\ N/mm^2}$	½M
	$\therefore\ \sigma_{max} = \sigma_0 + \sigma_b$	
	$= 10+20$	
	$\boxed{\sigma_{max} = 30\ N/mm^2}$ $\longrightarrow$ compressive Nature.	½M
	$\sigma_{min} = \sigma_0 - \sigma_b$	
	$= 10-20$	
	$\boxed{\sigma_{min} = -10\ N/mm^2}$ i.e. tensile nature	½M

Q .NO	SOLUTION	MARKS
5-d)	Given:- for circular column	
	D = External diameter = 40 cm = 400 mm	
	d = Internal diameter = 30 cm = 300 mm	
	P = 150×10^3 N = load	
		
	To find:- (i) σ_{max}	
	(ii) σ_{min}	
	soln:- We know that	
	$\sigma_{max} = \sigma_0 + \sigma_b$	
	$\sigma_{min} = \sigma_0 - \sigma_b$	
	$\sigma_0 = \frac{P}{A} = \frac{150\times10^3}{\frac{\pi}{4}\times(400^2-300^2)}$	½M
	$\boxed{\sigma_0 = 2.7283\ N/mm^2}$	½M
	$\sigma_b = \frac{M}{Z} = \frac{M}{I/y}$	½M
	$= \frac{My}{I}$	
	$= \frac{P\times e\times D/2}{\frac{\pi}{64}\times(D^4-d^4)}$	½M
	$= \frac{150\times10^3\times 200\times(400/2)}{\frac{\pi}{64}\times(D^4-d^4)}$	½M

Q .NO	SOLUTION	MARKS
	$\sigma_b = \dfrac{150\times10^3\times200\times200}{859.029\times10^6}$	
	$\boxed{\sigma_b = 6.9846\ N/mm^2}$.	1/2 M
	$\sigma_{max} = \sigma_0 + \sigma_b$	
	$= 2.728 + 6.984$	
	$\boxed{\sigma_{max} = 9.7126\ N/mm^2}$ → compressive in Nature	1/2 M
	$\sigma_{min} = \sigma_0 - \sigma_b$	
	$= 2.728 - 6.984$	
	$\boxed{\sigma_{min} = -4.256\ N/mm^2}$ → Tensile in Nature.	1/2 M
5-e)	Given:- for a rectangular rod bent into 'C' shape.	



Q.NO	SOLUTION	MARKS
5-e.	$b = 100\,mm$	
Continues	$d = 50\,mm$	
	$P = 40\,kN = 40\times10^3\,N$	
	$e = 300\,mm$	
	To find:- Resultant along X-X.	
	solution:- $\sigma_{max} = \sigma_0 + \sigma_b$	
	$\sigma_{min} = \sigma_0 - \sigma_b$	
	$\sigma_0 = \frac{P}{A} = \frac{40\times10^3}{(100\times50)}$	
	$\boxed{\sigma_0 = 8\,N/mm^2}$	½M
	$M = Pe$	
	$= 40\times10^3\times300$	
	$\boxed{M = 12\times10^6\,mm^3}$	½M
	$y = \frac{100}{2} = 50\,mm$	
	$I = \frac{db^3}{12} = \frac{50\times(100)^3}{12}$	½M
	$\boxed{I = 4.166\times10^6\,mm^4}$	½M
	$\sigma_b = \frac{My}{I} = \frac{12\times10^6\times50}{4.166\times10^6}$	½M
	$\boxed{\sigma_0 = 144\,N/mm^2}$	½M

Q .NO	SOLUTION	MARKS
	$\sigma_{max} = \sigma_0 + \sigma_b$	
	$= 8 + 144$	
	$= 152$ MPa	
	$\boxed{\sigma_{max} = 152 \text{ MPa}} \longrightarrow$ 'Tension'	½ M
	$\sigma_{min} = \sigma_0 - \sigma_b$	
	$= 8 - 144$	
	$\sigma_{min} = -136$	
	$\boxed{\sigma_{min} = -136 \text{ MPa}} \longrightarrow$ compression	½ M
	As rod is bent into 'c' shape, it is tension member so tension is considered as +ve and compression is taken as -ve.	
	Resultant stresses developed at section x-x.	
	$\sigma_{max} = 152$ MPa	
	$\sigma_{min} = 136$ MPa	
5-f)	Given:- for rectangular cross section	
		01 M

Q .NO	SOLUTION	MARKS
	To find:- Limit of eccentricity	
	solution:- Case-I : load along x-axis	
	$\sigma_0 = \sigma_b$	
	$\frac{P}{bd} = \frac{P \times e}{db^2/6}$	½M
	$\frac{P}{bd} = \frac{6Pe}{db^2}$	
	$\frac{\cancel{P}}{\cancel{bd}} = \frac{6\cancel{P}e}{\cancel{d}b^{\cancel{2}}}$	
	$1 = \frac{6e}{b}$	
	$e = b/6$	½M
	$= 1000/6$	
	$\boxed{e = 166.66\ mm}$ → along x-axis	½M
	Case-II :- load along y-axis	
	$\sigma_0 = \sigma_b$	
	$\frac{P}{bd} = \frac{Pe}{bd^2/6}$	½M
	$\frac{P}{bd} = \frac{6Pe}{bd^2}$	
	$\frac{\cancel{P}}{\cancel{bd}} = \frac{6\cancel{P}e}{\cancel{b}d^{\cancel{2}}}$	
	$1 = \frac{6e}{d}$ $\therefore e = d/6$	½M
	$\boxed{e = 2000/6 = 333.33\ mm}$ → Along y axis	½M

Q.NO	SOLUTION	MARKS
6-a)	Assumptions of Pure torsion are,	
	1) The shaft material is homogenous & isotropic	(1M for each any four)
	2) The shaft is straight having uniform cross-section	
	3) The shaft is acted upon by pure torsion	
	4) shear stress is directly proportional to shear strain.	(01x4)
	5) section plane before twisting moment will remain plane even after application of twisting moment.	
6-b)	Given :- for a shaft, used to transmit power	
	$P = 20kW = 20\times10^3 W$	
	$N = 150$ rpm	
	T_{max} = Maximum torque = 40% of T_{ave}	
	$= 0.4 + T_{ave}$	
	$\boxed{T_{max} = 1.4\ T_{ave}}$	½M
	$\tau = 50MPa = 50N/mm^2$	
	To find :- Diameter of shaft	
	Solution :- $P = \frac{2\pi N T_{ave}}{60}$	½M
	$20\times10^3 = \frac{2\pi \times 150 \times T_{ave}}{60}$	
	$T_{ave} = 1.273\times10^3$ N-m	
	$\boxed{T_{ave} = 1.273\times10^6 Nmm}$	½M

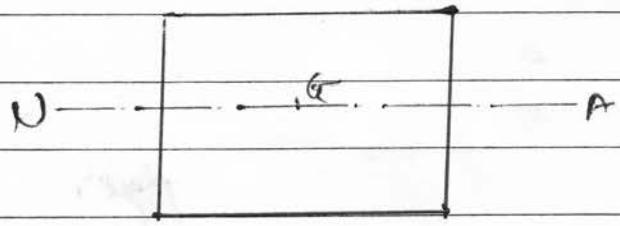
Q .NO	SOLUTION	MARKS
	$T_{max} = 1.4\, T_{avg}$	
	$T_{max} = 1.4 \times 1.273\times10^6$	
	$T_{max} = 1.782 \times 10^6\, Nm$	01 M
	$1.782\times10^3 = \pi/16 \times \tau \times D^3$	1/2 M
	$= \pi/16 \times 50 \times D^3$	
	$\boxed{D = 56.63\, mm} \longrightarrow$ Ans	01 M
Q-6 c)	Given:- for a shaft	
	$d = 40\, mm$ = diameter of shaft	
	$N = 200 rpm$	
	τ = shear stress = 85 MPa	
	$= 85\, N/mm^2$	
	To find :- Power transmitted by shaft	
	Solution :- $P = \frac{2\pi N T}{60}$	1/2 M
	$T = \pi/16 \times \tau \times (d)^3$	1/2 M
	$= \pi/16 \times 85 \times (40)^3$	
	$= 1.068\times10^6\, N\text{-}mm$	
	$\boxed{T = 1.068\times10^3\, Nm}$	01 M
	$P = \frac{2\pi \times 200 \times 1.068\times10^3}{60}$	01 M
	$\boxed{P = 22.37\times10^3\, W \quad P = 22.37\, kW} \longrightarrow$ Ans	01 M

Q .NO	SOLUTION	MARKS
6-d)	Given:- for a shaft	
	P = Power transmitted = 150kW	
	$P = 150\times10^3$ W	
	N = 200rpm	
	τ = shear stress = 80N/mm^2	
	θ = Angle of twist = 1.5^0	
	$= \frac{1.5\times\pi}{180} = 0.02167$ radians.	
	L = Length of shaft = 4m	
	= 4000mm	
	G = Modulus of rigidity	
	$= 0.8\times10^5$ N/mm^2	
	To find :- Diameter of shaft	
	solution :- (1) On the basis of strength	
	$T = \pi/16 \times \tau \times D^3$	½M
	$P = \frac{2\pi N T}{60}$	½M
	$150\times10^3 = \frac{2\pi\times200\times T}{60}$	
	$T = 7.16\times10^3$ Nm	½M
	$\boxed{T = 7.16\times10^6 \text{ Nmm}}$	
	$7.16\times10^6 = \pi/16\times80\times D^3$	½M
	$D = \frac{(7.16\times10^6)}{(\pi/16\times80)} = 76.9669$	½M

$\boxed{D = 76.97 \text{ mm}}$

Q .NO	SOLUTION	MARKS
	② On the basis of angle of twist i.e. stiffness	
	$\frac{T}{J} = \frac{G\theta}{L}$	½M
	$\frac{T}{\pi/32 \times D^4} = \frac{G\theta}{L}$	
	$\frac{7.16\times10^6}{\frac{\pi}{32}\times D^4} = \frac{0.8\times10^5\times0.0261}{4000}$	
	$D^4 = \frac{7.16\times10^6\times32\times4000}{0.8\times10^3\times0.0261\times\pi}$	½M
	$= \frac{9.1648\times10^{11}}{6.5596\times10^3}$	
	$D^4 = 139.71\times10^6$	
	$\boxed{D = 108.72\,mm}$	½M
	larger of above two values, for diameter is taken as suitable diameter	
	$\boxed{\therefore D = 108.72\,mm} \longrightarrow$ Ans.	

Q.NO	SOLUTION	MARKS
6-e)	Given:- D = External diameter = 400 mm	
	d = Internal diameter = 200 mm	
	T = Twisting moment = 4650 Nm	
	$= 4650\times10^3$ N-mm.	
	G = Modulus of rigidity $= 82\times10^3$ N/mm²	
	$L = 20D$	
	$= 20\times400 = 8000$ mm.	
	To find ① Maximum intensity of stress	
	ⓘⓘ Angle of twist	
	Solution:- ⓘ Maximum intensity of stress	
	$\frac{T}{J} = \frac{\tau_{max}}{R}$	½M
	$J = \frac{\pi}{32}\times(D^4-d^4)$	
	$= \frac{\pi}{32}\times(400^4-200^4)$	
	$\boxed{J = 2.3561\times10^9 \text{ mm}^4}$ → Polar M.I.	½M
	$R = D/2 = \frac{400}{2} = 200$ mm	½M
	$\frac{4650\times10^3}{2.3561\times10^9} = \frac{\tau_{max}}{200}$	
	$\tau_{max} = \frac{4650\times10^3\times200}{2.3561\times10^9}$	
	$\boxed{\tau_{max} = 0.3947 \text{ N/mm}^2}$	½M

Q .NO	SOLUTION	MARKS
	(ii) Angle of twist	
	$\frac{T}{J} = \frac{G\theta}{L}$	½M
	$\frac{4650\times10^{3}}{2.3561\times10^{9}} = \frac{82\times10^{3}\times\theta}{8000}$	
	$\theta = \frac{4650\times10^{3}\times8000}{2.3561\times10^{9}}$	½M
	$= 1.9254\times10^{-4}$	
	$\boxed{\theta = 1.9254\times10^{-4} \text{ radians}}$	
	$= 1.9254\times\frac{180}{\pi}$	
	$\boxed{\theta = 0.011^{\circ}}$	01M
6-f-i)	Neutral Axis	
	- When beam is subjected to pure bending there is a layer which will ~~not~~ neither subjected to tension nor compression, such a layer is called neutral layer or neutral axis (N-A)	
		
	- Neutral Axis always passes through centroid or C.G.	02M

Q .NO	SOLUTION	MARKS
6f-ii)	Comparision between solid shaft & hollow shaft	

Sr	Parameter	solid shaft	Hollow shaft	MARKS
1	Polar MI	$J = \frac{\pi}{32} \times (D)^4$	$\frac{\pi}{32} \times \frac{(D^4-d^4)}{D}$	(01M for any Two)
2	Polar modulus	$Z = \frac{\pi}{16} \times D^3$	$\frac{\pi}{16} \times (D^4-d^4)$	
3	Torque Transmitted	$T = \frac{\pi}{16} \times \tau \times D^3$	$T = \frac{\pi}{16} \times \tau \times \left(\frac{D^4-d^4}{D}\right)$	(01x02)
4	stiffness	solid shaft has less strength & stiffness than a hollow shaft	Hollow shaft has greater strength & stiffness than a solid shaft	