WINTER – 14 EXAMINATIONS

Subject Code: 17304 **Model Answer** **Total Pages: 50**

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.

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 examiners

1) In Q. 6 C) the value of power transmitted is given is 20kN but it should be 20KW. The examiner may consider the same while assessing this question.

2) In Q. 6 e) the problem is on design of shaft diameter, but value of relationship between external diameter (D) and internal diameter(d) , value of modulus of rigidity (G) is not given in problem.

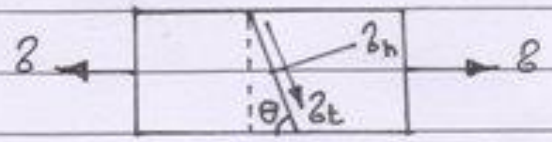
Therefore Two solutions are possible. Examiner should consider any one for giving proportionate marks

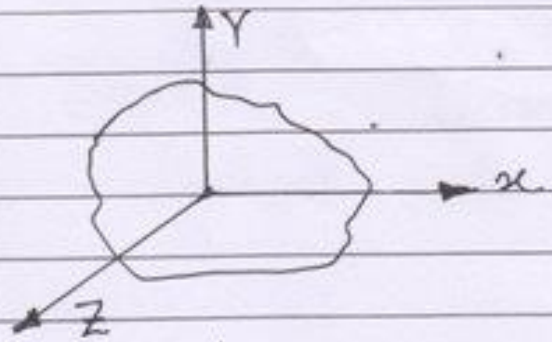
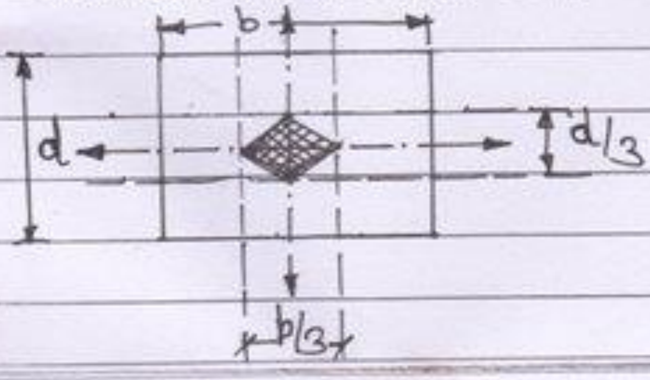
Solution 1

I) Student may assume suitable relationship between D & d with value of modulus of rigidity (G) to find external diameter D, by using strength criteria and stiffness criteria.

Solution 2

II) Student may assume only Value of modulus of rigidity (G) and find external diameter D, by using directly torsional formula.

Q.NO	SOLUTION	MARKS
Q.1 A)	Attempt any SIX of the following	2×6=12
a)	Ans: Malleability – This is the property of material which allows it to expand in all directions without rupture. –	1M
	Names : i) Steel iv) Gold –	
	(Any Two) ii) copper v) Silver –	½ M. (Any two)
	iii) Aluminium.	
b)	Ans : 	
	Equation of tangential stress on an inclined plane : $$\sigma_t = \frac{\sigma}{2}\sin 2\theta$$ –	2M
c)	Mutually Perpendicular axis theorem : It states that "the moment of inertia of a plane section about an axis perpendicular to the section and passing through the centroid is equal to the sum of moment of inertia of the plane figure about two mutually perpendicular axis passing trough the centroid.	1M

Q .NO	SOLUTION	MARKS
1 (c) cont.		
	$I_{zz} = I_{xx} + I_{yy}$ —	1M
	This theorem is also called as polar axis theorem.	
d)	Ans: Middle Third Rule with diagram.	
	 —	1m
	"Incase of rectangular section, when any external load is applied within the middle one third part of section, then no tensile stresses are produced anywhere in the section." —	1M

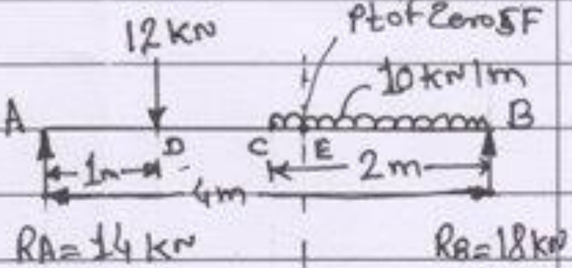
Q.NO	SOLUTION	MARKS
1) e)	four assumptions made in the theory of Pure Torsion :-	
	i) The material is homogeneous and isotropic.	Any
	ii) The twist along the shaft is uniform.	four
	iii) Radial lines remain radial even after applying torsional moment.	-2M (½ for each)
	iv) The stresses are within the elastic limit, i.e. shear stress is proportional to shear strain.	
	v) Cross-sections which are plane before applying twisting moment remain plane even after the application of twisting moment. i.e. no warping takes place.	
f)	Lateral Strain :	
	"The strain which is set in the perpendicular direction to the applied force is called as lateral strain."	— 1m
	Mathematically, it is the ratio of change in lateral dimension to the original dimension	
	$e_{lat} = \frac{\delta b}{b}$ or $\frac{\delta t}{t}$ or $\frac{\delta d}{d}$	

Q.NO	SOLUTION	MARKS
1 f) cont.	Longitudinal Strain: The strain which is set along the direction of the applied force is called as longitudinal strain.	1m
	Mathematically it is the ratio of change in length to the original length in the direction of force. $e_{long} = \frac{\delta L}{L}$	
g)	Distinguish: In a thin cylindrical shell, when subjected to an internal pressure,	
	1) The longitudinal stress is equal to half the circumferential stress.	1M.
	2) Circumferential stress acts along the circumference and longitudinal stress acts along the length of shell	1m
h)	Core of Section: It is the central limited area of section, when any external load acts within it, then no tension is produced at anywhere in the section.	1M
	* The value of diameter of core of section for circular section is $\frac{d}{4}$ and $\frac{d}{8}$ for on either side from centre of section.	1M.

Q .NO	SOLUTION	MARKS
Q.1 B)	Attempt any two of the following:	4X2=8
a)	Given : i) $A = 20 \times 20 = 400\ mm^2$	
	ii) $\sigma = 50\ mpa$	
	iii) $\delta l = 1.2\ mm$	
	iv) $L = 3m = 3000\ mm$	
	Find : i) $P = ?$	
	ii) $E = ?$	
	Sol^n:	
	$P = \sigma \times A = 50 \times 400$	
	$\therefore P = 20{,}000\ N$	
	$\boxed{P = 20\ KN}$	— 2M
	$E = \frac{\sigma}{e}$	
	$\because e = \frac{\delta l}{l} = \frac{1.2}{3000} = 4 \times 10^{-4}$	
	$\therefore E = \frac{50}{4 \times 10^{-4}} = 125000\ N/mm^2$	
	$\boxed{E = 125 \times 10^3\ N/mm^2}$	— 2M
	[Or] $\delta l = \frac{PL}{AE}$	OR
	$\therefore E = \frac{PL}{A \cdot \delta l} = \frac{20 \times 10^3 \times 3000}{400 \times 1.2} = 125 \times 10^3\ N/mm^2$	2M

Q .NO	SOLUTION	MARKS
1(B) b)		

A) Support Reactions:



i) $\Sigma fy = 0$

$\therefore R_A + R_B = 12 + (10 \times 2)$

$\therefore R_A + R_B = 32$

ii) $\Sigma M @ A = 0$

$\therefore (R_B \times 4) - (10 \times 2 \times (2 + \frac{2}{2}) - (12 \times 1) = 0$

$\therefore R_B = 18 KN$

$\therefore R_A = 32 - 18 = 14 kN.$ — 1m

B) Shear force calculation:

i) SF @ B (R) = −0 kN

ii) SF @ B (L) = −18 kN

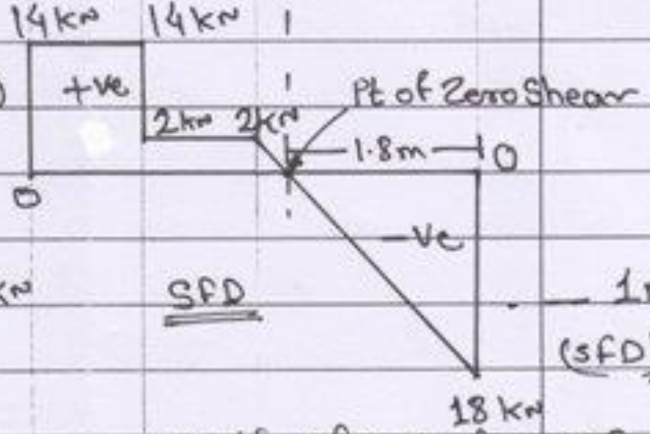
iii) SF @ C (R) = −18 + (10×2) = 2 kN.

iv) SF @ D (R) = 2 kN.

v) SF @ D (L) = 2 + 12 = 14 kN

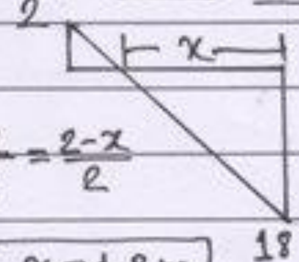
vi) SF @ A (R) = 14 kN.

vii) SF @ A (L) = 14 − 14 = 0



— 1m (SFD)

Location of Point of zero S.F.



$\frac{x}{18} = \frac{2-x}{2}$

$\boxed{\therefore x = 1.8 m}$

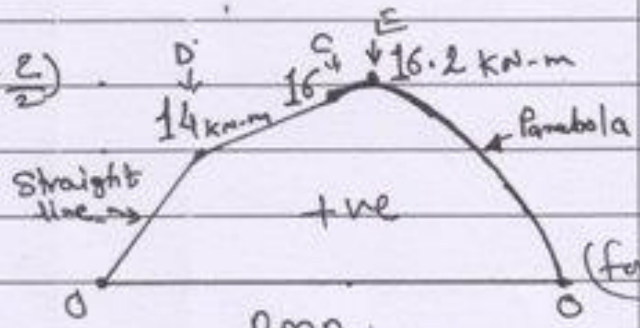
C) Bending Moment Calculation:

i) BM @ B = 0

ii) BM @ E = $(18 \times 1.8) - (10 \times 1.8 \times \frac{1.8}{2})$ = 16.2 kN-m — 1m for (B.M. calculation)

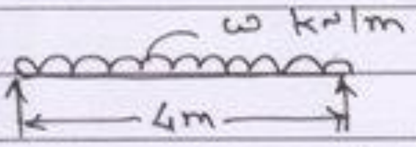
iii) BM @ C = $(18 \times 2) - (10 \times 2 \times \frac{2}{2})$ = 16 kN-m

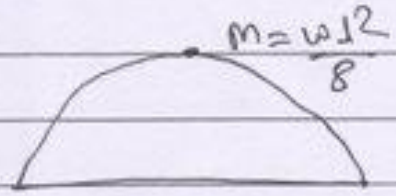
Q.NO	SOLUTION	MARKS
1 (B) b cont.	iv) BM@D= $=(18\times3)-(10\times2\times(1+\frac{2}{2})$ $=14$ kN-m	
	v) BM@A=0	1m (for BMD)



BMD

Q.NO	SOLUTION	MARKS
	c) Given:	
	i) b = 120 mm	
	ii) d = 300 mm	
	iii) L = 4m = 4000 mm	
	iv) σ_b = 120 MPa	
	Find: ω = ?	





BMD

Q.NO	SOLUTION	MARKS
	Using flexural formula let ω is udl in N/m.	
	$\frac{M}{I}=\frac{\sigma_b}{y}$	
	$\therefore M=\frac{\omega l^2}{8}=\frac{4^2\omega}{8}=2\omega$ N-m	
	$=2\omega\times10^3$ N-mm.	1/2 m
	$I=\frac{bd^3}{12}=\frac{120\times300^3}{12}=270\times10^6$ mm^4	1m

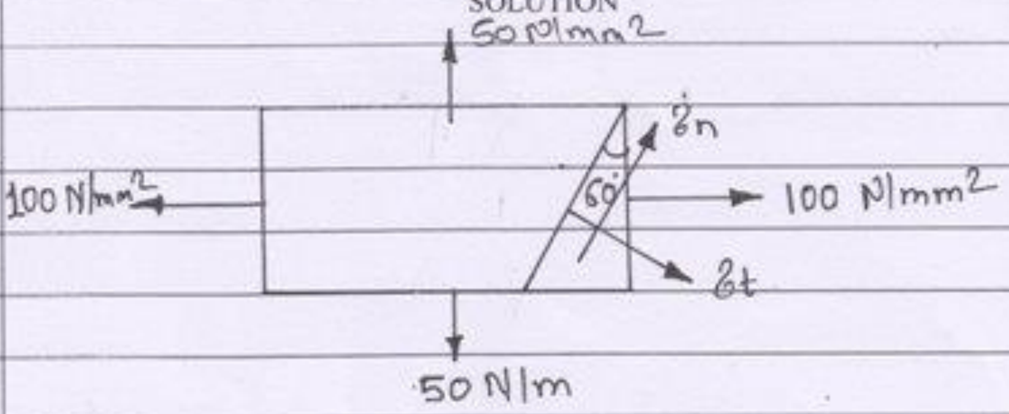
Q.NO	SOLUTION	MARKS
1 (B) C cont.	$\sigma_b = 120\ N/mm^2$	
	$y = \frac{300}{2} = 150\ mm.$ —	½m
	$\therefore \frac{2\times10^3\ \omega}{270\times10^6} = \frac{120}{150}$ —	1m
	$\therefore \omega = \frac{120\times270\times10^6}{150\times2\times10^3}$	
	$\omega = 108000\ N/m$ —	1m
	$\boxed{\therefore \omega = 108\ kN/m}$	
Q.2	Attempt any four of the following	4X4=16
a) i)	i) Composite Section: If two or more members of different materials are connected together and are subjected to the loads, then the combination is called composite section. —	1m
	ii) Modular Ratio: It is defined as the ratio of modulli of the two different materials. —	1m

Q.NO	SOLUTION	MARKS
2 a) ii)	Rankine's Formula:	
	$$P_R = \frac{\sigma_c . A}{1 + a\left[\frac{Le}{K}\right]^2}$$	1m
	∴ Symbols Used:	
	P_R = Rankine's crippling load	
	σ_c = Ultimate crushing stress for the column material.	
	A = Area of cross-section	
	$a = \frac{\sigma_c}{\pi^2 E}$ = Rankine's constant	
	Le = Effective length of column which depends upon the column end conditions.	1m
b)	Effective length of Column:	
	i) Both end hinged $Le = L$	1m
	ii) Both end fixed $Le = \frac{L}{2}$	1m
	iii) One end fixed and other end hinged. $Le = \frac{L}{\sqrt{2}}$	1m
	iv) One end fixed and other end free. $Le = 2L$	1m

Q.NO	SOLUTION	MARKS
2 c)	Given: i) $E = 2.8K$	
	Find: i) $\mu = ?$	
	ii) $\frac{E}{G} = ?$	
	Sol^n:	
	Using $E = 3K(1-2\mu)$	1m
	$2.8K = 3K(1-2\mu)$	
	$\therefore 2.8 = 3(1-2\mu)$	
	$\therefore 2.8 = 3 - 6\mu$	
	$\therefore 2.8 - 3 = -6\mu$	
	$\therefore \frac{0.2}{6} = \mu$	
	$\boxed{\therefore \mu = 0.0333}$	1M
	Now, Using $E = 2G(1+\mu)$	1m
	$\therefore \frac{E}{G} = 2(1+0.033)$	
	$\boxed{\therefore \frac{E}{G} = 2.066}$	1m

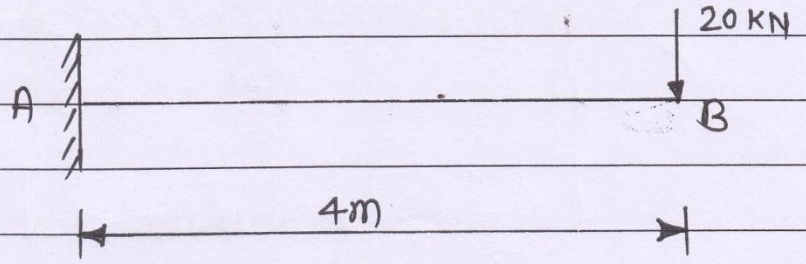
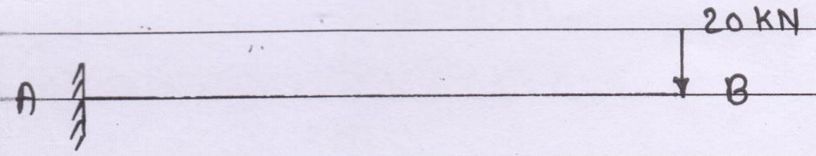
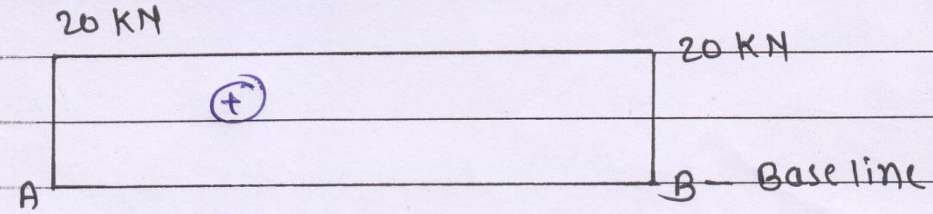
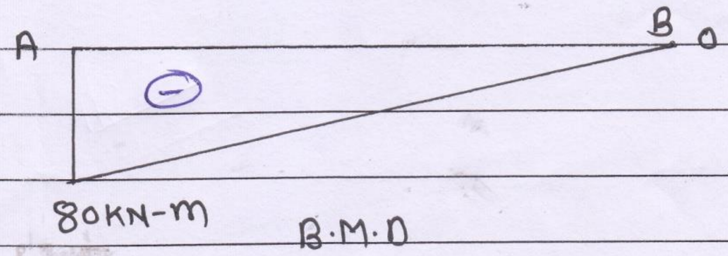
Q.NO	SOLUTION	MARKS
2 d)	Given: i) $d = 40\,mm$	
	ii) $t = 4\,mm$ $\therefore D = 40+8 = 48\,mm$	
	iii) $P = 120 \times 10^3\,N$	
	iv) $E_s = 2.1 \times 10^5\,N/mm^2$	
	v) $E_c = 0.14 \times 10^5\,N/mm^2$	
	Find:	
	i) $\sigma_c = ?$	
	ii) $\sigma_s = ?$	
	Sol^n:	
	$A_s = \frac{\pi}{4}(D^2 - d^2)$	
	$= \frac{\pi}{4}(48^2 - 40^2)$	
	$= 552.92\,mm^2$	- 1/2 m
	$A_c = \frac{\pi}{4} d^2$	
	$= \frac{\pi}{4} 40^2$	
	$= 1256.63\,mm^2$	- 1/2 m
	$\sigma_s = \frac{E_s}{E_c} \sigma_c$	- 1/2 m
	$\sigma_s = \frac{2.1 \times 10^5}{0.14 \times 10^5} \sigma_c$	

Q.NO	SOLUTION	MARKS
2 d cont.	$\boxed{f_s = 15 f_c}$ —	½ m
	~~$P = f_s f_s + f_c$~~	
	$P = f_s A_s + f_c A_c$ —	½ m
	$120\times10^3 = 15 f_c \times 552.92 + f_c \times 1256.63$	
	$120\times10^3 = 9550.43\ f_c$	
	$\therefore f_c = \dfrac{120\times10^3}{9550.43}$	
	$\boxed{f_c = 12.56\ N/mm^2}$ —	1 m
	$\therefore f_s = 15 f_c = 15\times 12.56$	
	$\therefore \boxed{f_s = 188.47\ N/mm^2}$ —	½ m
e)	Given : i) $f_x = 100\ N/mm^2$ (Tensile)	
	ii) $f_y = 50\ N/mm^2$ (Tensile)	
	iii) $\theta = 60°$	
	Find : i) f_n = normal stresses on inclined plane	
	ii) f_t = Tangential stress on inclined plane.	
	Soln : i) Normal stress on inclined plane	
	$f_n = \dfrac{f_x + f_y}{2} + \dfrac{f_x - f_y}{2}\cos 2\theta$ —	1m

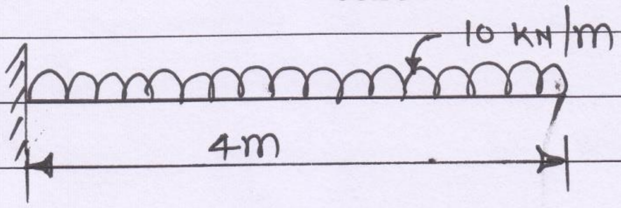
Q .NO	SOLUTION	MARKS
2 e cont.		
	$\therefore \sigma_n = \frac{100+50}{2} + \frac{100-50}{2}\cos 2\times 60^\circ$	
	$= 75 - 12.5$	
	$\boxed{\sigma_n = 62.5\ N/mm^2}$	1M
	$\sigma_t = \frac{\sigma_x - \sigma_y}{2}\sin 2\theta$	1 m
	$= \frac{100-50}{2}\sin 2\times 60^\circ$	
	$\boxed{\sigma_t = 21.65\ N/mm^2}$	1m

Q.NO	SOLUTION	MARKS
2 f)	Given: i) $d = 1m = 1000\ mm$	
	ii) $t = 10\ mm$	
	iii) $h = 200\ m = 200 \times 10^3\ mm$	
	iv) $\gamma_w = 10 \times 10^3\ N/m^3$	
	find: i) Hoop Stress $(\sigma_c) = ?$	
	ii) Longitudinal stress $(\sigma_L) = ?$	
	Sol^n: i) Maximum water Pressure	
	$P = \gamma_w \times h = \frac{10 \times 10^3 \times 200 \times 10^3}{(10^3)^3}$	
	$= \frac{2000 \times 10^3}{10^6}$	
	$P = 2\ N/mm^2$ —	1 m
	Now,	
	$\sigma_c = \text{Hoop Stress} = \frac{Pd}{2t}$ —	$\frac{1}{2}$ m
	$= \frac{2 \times 1000}{2 \times 10}$	
	$\boxed{\sigma_c = 100\ N/mm^2}$ —	1 m
	$\sigma_L = \frac{1}{2}\sigma_c = \frac{Pd}{4t}$ —	$\frac{1}{2}$ m
	$= \frac{1}{2} \times 100$	

$\boxed{\sigma_L = 50\ N/mm^2}$ — 1 m

Q .NO	SOLUTION	MARKS
Q-3 (a)	i) 	
	Shea force calculation	
	i) S.f at B = 20 KN	
	ii) S.f at A = 20 KN	1/2 M
	Bending moment calculation	
	i) B.M at B = 0 KN-m	
	ii) B.M at A = -20 X 4 = -80 KN-m	1/2 M
		
		1/2 M
	S.F.D	
		1/2 M
	B.M.D	

Q .NO	SOLUTION	MARKS
Q.3 a. Cont..	ii)	



i) S.f calculation

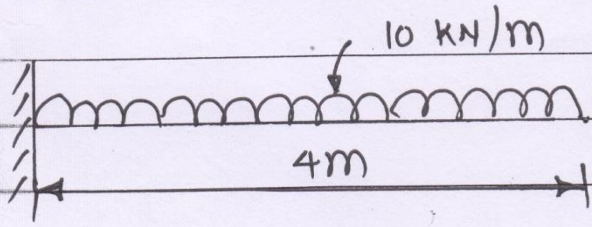
S.f at B = 0

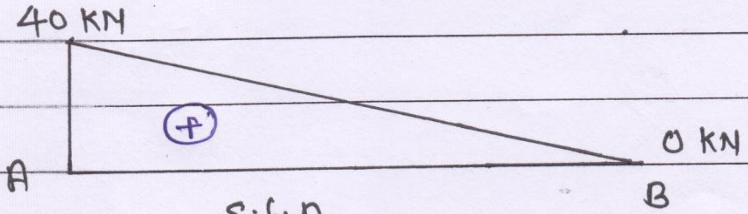
S.f at A = 10×4 = 40 KN — ½ M

ii) B.M. calculation

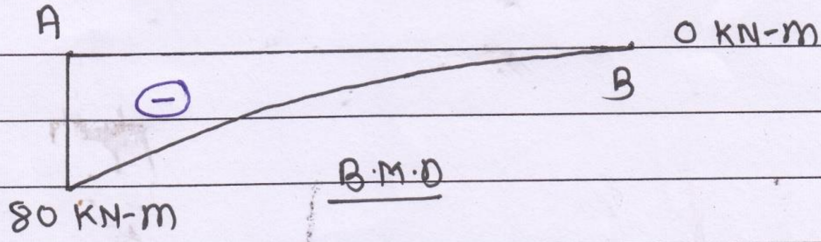
B.M at B = 0 KN-m

B.M at A = $-(10\times4)\times\frac{4}{2} = -80$ KN-m — ½ M

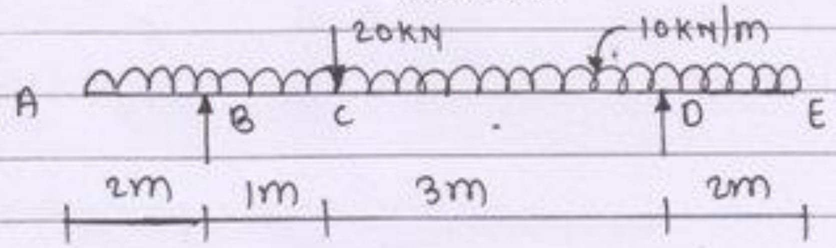




S.f.D — ½ M



B.M.D — ½ M

Q.NO	SOLUTION	MARKS
Q3 b)		

i) To find reaction (support reaction)

$\Sigma Fy = 0$

$R_A + R_B = 20 + 10 \times 8$

$R_A + R_B = 100$ —— (1)

$\Sigma M_A = 0$

$-R_B \times 4 + 10 \times 8 \times \frac{4}{2} + 20 \times 1 = 0$

$-R_B \times 4 + 80 \times 2 + 20 = 0$

$-4R_B + 160 + 20 = 0$

$R_B = \frac{180}{4}$

$\boxed{R_B = 45\ KN}$ $\therefore \boxed{R_A = 55\ KN}$

ii) S.F. calculation

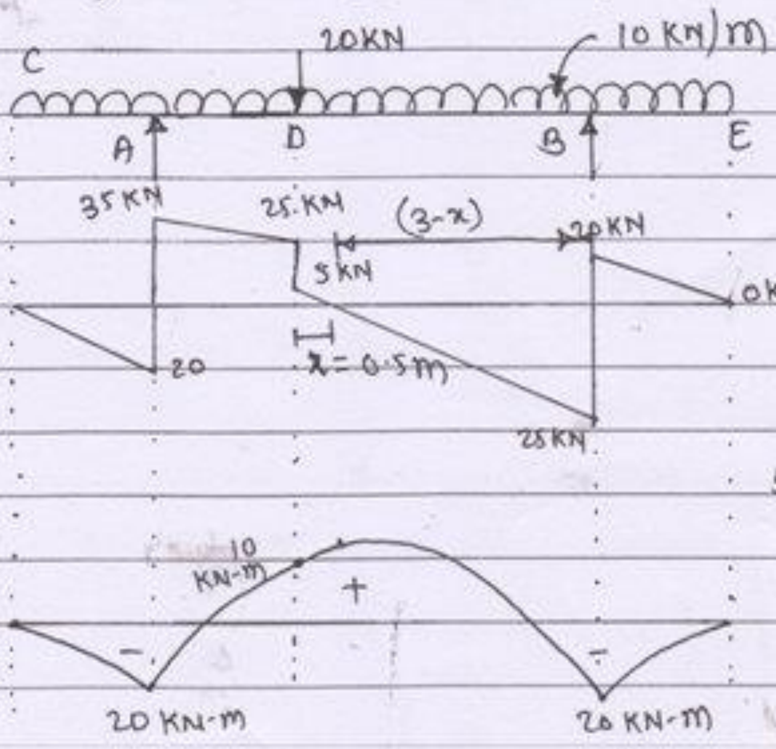
a) S.f at c = 0

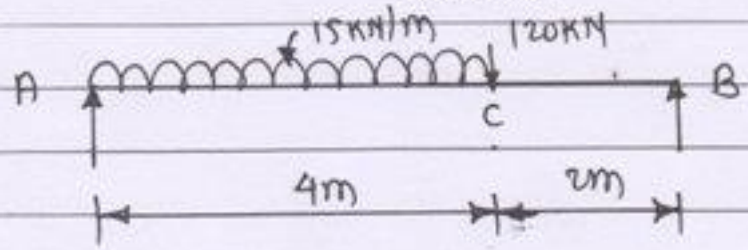
b) S.f at $A_{(L)} = -10 \times 2 = -20 KN$

c) S.f at $A_{(R)} = -20 + 55 = 35 KN$

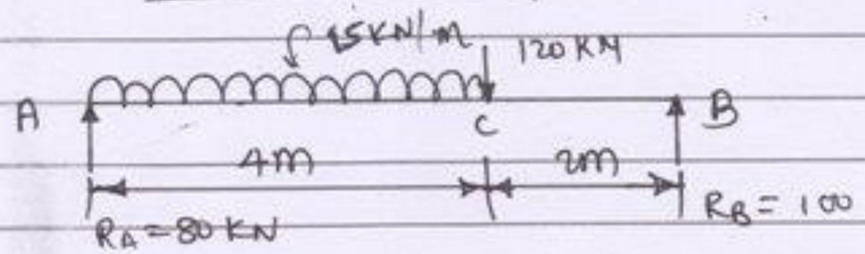
d) S.f at $D_{(L)} = 35 - 10 \times 1 = 25 KN$

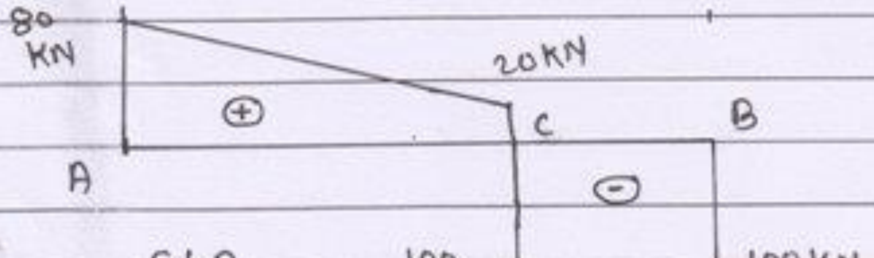
e) S.f at $D_{(R)} = 25 - 20 = 5 KN$ 01M

Q .NO	SOLUTION	MARKS
Q.3 b. Cont.	f) S.F. at $B(L) = 5 - 10\times3 = -25$ KN	
	g) S.F at $B(R) = -25 + 45 = 20$ KN	
	i) S.F at $E = 20 - 10\times2 = 0$ KN	
	iii) B.M. calculation	
	a) B.M at C = 0 KN·m	
	b) B.M at $A = -10\times2\times1 = -20$ KN·m	
	c) B.M at $D = -10\times3\times1.5 + 55\times1$	
	$= 10$ KN·m	
	d) B.M at $B = -10\times6\times3 + 55\times4 - 20\times3$	
	$= -20$ KN-m	
	e) B.M at E = 0 KN-m	01M
		
	iv) point of zero shear	01M
	$\frac{5}{x} = \frac{25}{(3-x)}$	
	$5(3-x) = 25x$	
	$15 - 5x = 25x$	
	$15 = 30x$	
	$\therefore \boxed{x = 0.5}$	01M

Q.NO	SOLUTION	MARKS
Q3 c)		
	i> To find reaction (support reaction)	
	$\Sigma M_A = 0$	
	$R_B \times 6 - 120 \times 4 - 15 \times 4 \times 4/2 = 0$	
	$R_B \times 6 - 480 - 120 = 0$	
	$6R_B - 600 = 0$	
	$\boxed{R_B = 100 \text{ KN}}$	
	$\Sigma F_y = 0$	
	$R_A + R_B = 120 + 60$	
	$R_A + R_B = 180$ put $R_B = 100$ KN	
	$\therefore \boxed{R_A = 80 \text{ KN}}$	
	ii> S.F calculation	
	a) S.F at A = 80 KN	
	b) S.F at C_L = 80 − 15×4 = 20 KN	
	c) S.F at C_R = 80 − 15×4 − 120 = −100 KN	
	d) S.F at B = −100 KN.	01M

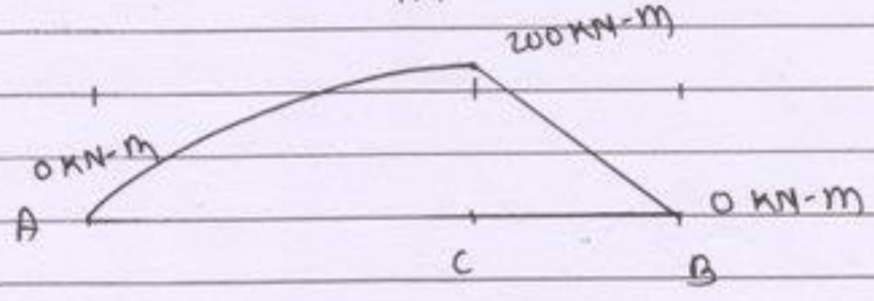
Q.NO	SOLUTION	MARKS
Q.3. C Cont^{d}--	iii) B.M calculation	
	a) M_A & $M_B = 0$ kN-m	
	b) $M_C = 80 \times 4 - 15 \times 4 \times 4/2$	
	$M_C = 320 - 120$	
	$\boxed{M_C = 200 \text{ kN-m}}$	01M





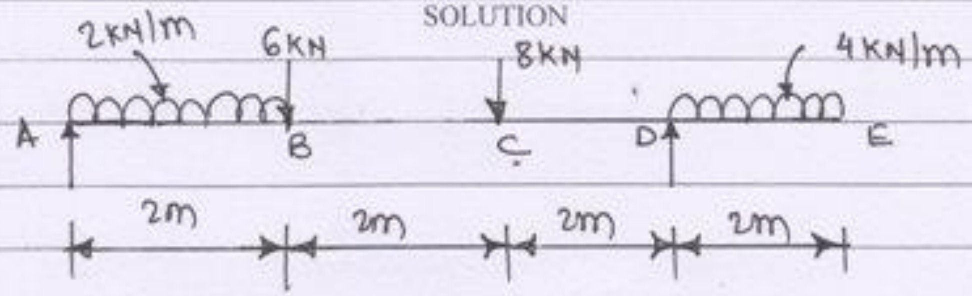
S.F.D

01M

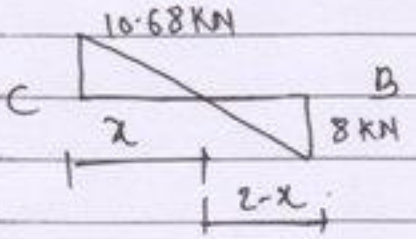


B.M.D

01M

Q.NO	SOLUTION	MARKS
d)		
	i) To find support reaction	
	$\Sigma fy = 0$	
	$R_A + R_D - 4 - 6 - 8 - 8 = 0$	
	$R_A + R_D = 26$ —— (1)	
	$\Sigma M_A = 0$	
	$-6R_D + 4\times2\times7 + 8\times4 + 6\times2 + 2\times2 = 0$	
	$R_D = 17.33$ KN	
	$\therefore R_A = 26 - 17.33$	
	$R_A = 8.67$ KN	
	ii) S.F calculation	
	a) S.f at A = 8.67 KN	
	b) S.f at $B_{(L)}$ = 8.67 − 2×2 = 4.67 KN	
	c) S.f at $B_{(R)}$ = 4.67 − 6 = −1.33	
	d) S.f at $C_{(L)}$ = −1.33 − 8 = −9.33 KN	
	e) S.f at $D_{(L)}$ = −9.33 + 17.33 = 8 KN	
	f) S.f at E = 0 KN	01 M

Q.NO	SOLUTION	MARKS
Q.3 d. Cont..	iii) B.M calculation	
	a) B.M at A = 0 KN.m	
	b) B.M at B = $8.67 \times 2 - 2 \times 2 \times 1 = 13.34$ KN.m	
	c) B.M at C = $8.67 \times 4 - 2 \times 2 \times 3 - 6 \times 2 = 10.68$ KN.m	
	d) B.M at D = $-4 \times 2 \times 1 = -8$ KN.m	
	e) B.M at E = 0 KN.m	01 M
	iv) point of contraflexure	



let x be the point of contraflexure

$$\frac{x}{10.68} = \frac{2-x}{8}$$

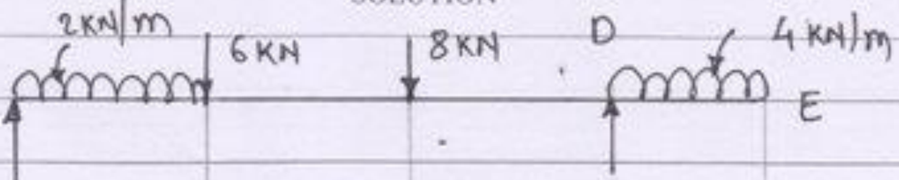
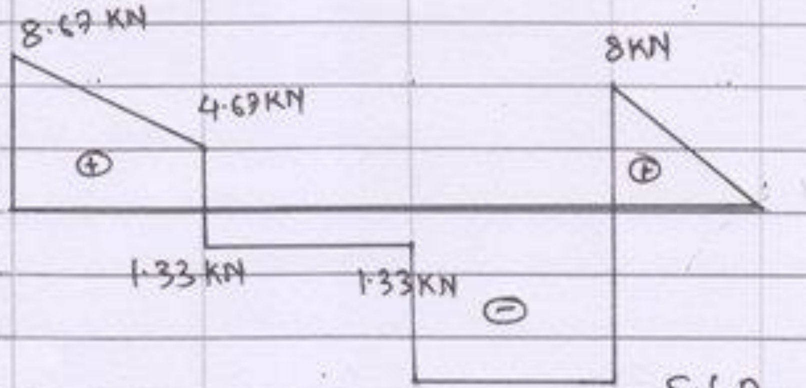
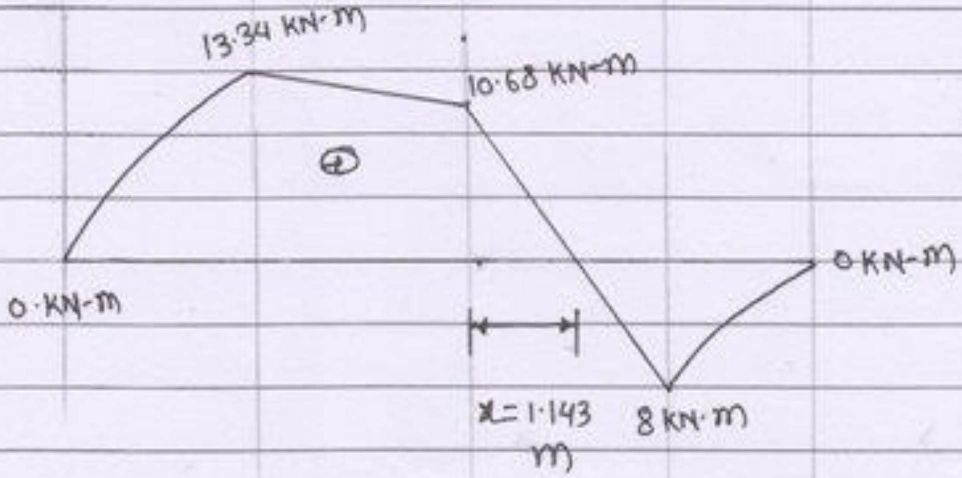
$$8x = 10.68(2-x)$$

$$8x = 21.36 - 10.68x$$

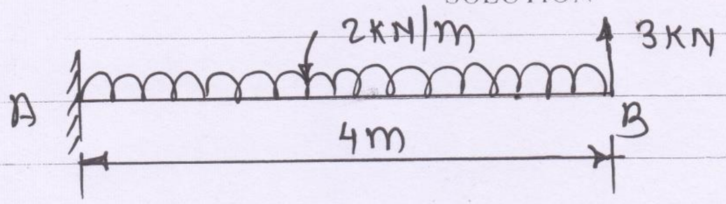
$$18.68x = 21.36$$

$$x = \frac{21.36}{18.68}$$

$$\therefore \boxed{x = 1.143\text{ m}}$$

Q.NO	SOLUTION	MARKS
Q.3.d Cont..		
	 S.F.D	01 M
	 B.M.D	01 M

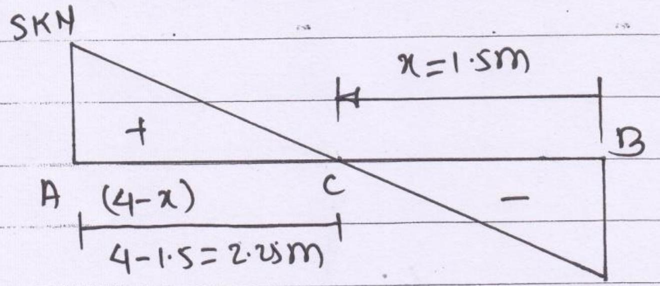
Q.NO	SOLUTION	MARKS
Q-3 (e)		



i) S.F. calculation

a) S.F at B = −3 KN

b) S.F at A = −3 + (2×4) = −3+8 = 5 KN — ½M



1M for S.F.D

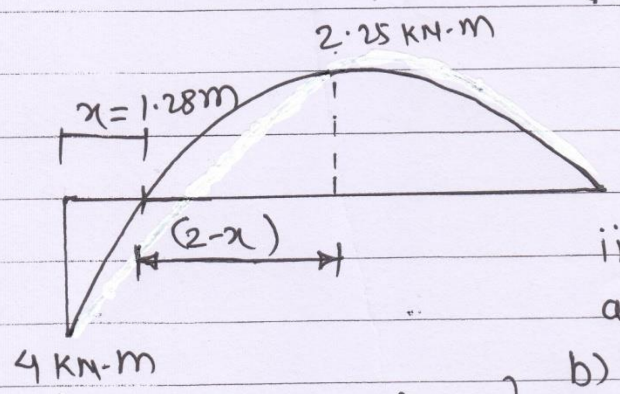
* Location of zero shear force

$\frac{3}{x} = \frac{5}{4-x}$

$3(4-x) = 5x$

$12 - 3x = 5x$

$\boxed{x = 1.5m}$ — ½M for Point of zero shear



ii) B.M. calculation

a) B.M at B = 0 KN·m — 1M for B.M.D

b) B.M at C = Max. B.M

$= (3\times1.5) - (2\times1.5)\frac{1.5}{2}$

$= \underline{2.25\ KN\text{-}m}$ → ½M (Max^m. B.M.)

c) B.M at A

$= 3\times4 - 2\times4\times2$

$= 12 - 16$

$= -4\ KN\text{-}m$

* Let x be the distance of P.C. from L.H.S. point of contraflexure

$\frac{2.25}{2-x} = \frac{4}{x}$

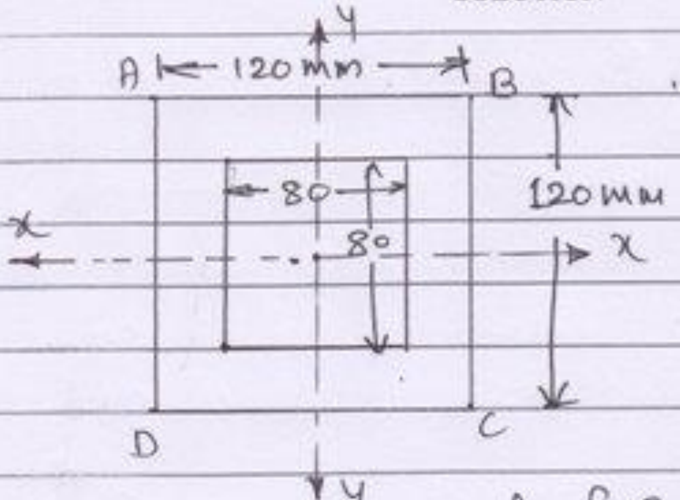
$2.25x = 4(2-x)$

$2.25x = 8 - 4x$

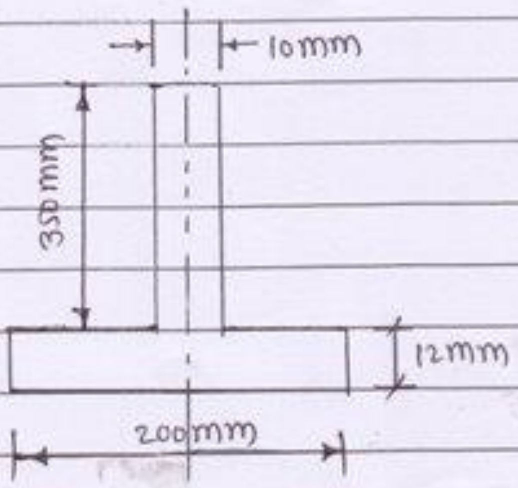
$2.25x + 4x = 8$

$\therefore x = \frac{8}{6.25}$

$\boxed{x = 1.28m}$ — ½M for Point of contraflexure

Q.NO.	SOLUTION	MARKS
Q.3F		
	finding moment of Inertia @ centroidal axis	
	i) $I_G = I_{xx} = I_{yy}$	
	$I_G = \frac{1}{12}[BD^3 - bd^3]$	01M
	$= \frac{1}{12}[120 \times 120^3 - 80 \times 80^3]$	
	$= \frac{1}{12}[207.36 \times 10^6 - 4.096 \times 10^6]$	
	$\boxed{I_G = 13.867 \times 10^6 \ mm^4}$	1M
	ii) $h = \frac{120}{2} = 60 \ mm$	
	iii) using parallel axis theorem	
	$I_{AB} = I_G + Ah^2$	

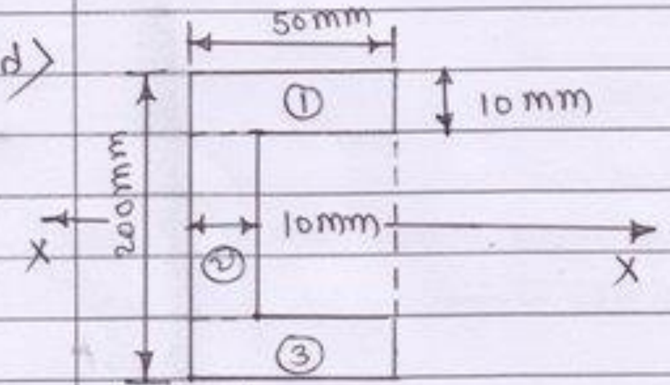
Q.NO	SOLUTION	MARKS
Q.3.F. Cont..	$\therefore I_G = I_{xx} = I_{yy} = I$	
	$\therefore \boxed{I_G = 13.867 \times 10^6 \; mm^4}$	
	iv) $A = [(120 \times 120) - (80 \times 80)]$	
	$A = 8000 \; mm^2$	
	v) $I_{AB} = I_G + Ah^2$	1M
	$= 13.867 \times 10^6 + 8000 \times 60^2$	
	$\boxed{I_{AB} = 42.667 \times 10^6 \; mm^4}$	1M

Q.NO	SOLUTION	MARKS
Q-4		
(a)	i) Moment of inertia (I)	
	Moment of inertia of section is defined as the product of area of a section and the square of the distance between the centroid of section and reference axis.	2 M
	ii) Radius of Gyration (K)	
	It is defined as the distance at which the area 'A' is supposed to be concentrated to give the same moment of inertia	2 M
	$I = AK^2$	
	$K = \sqrt{\frac{I}{A}}$ where K is Radius of gyration	
b)		

Q.NO	SOLUTION	MARKS
	Find area of each figure	
Q.4.b. Cont.	i) $A_1 = 350 \times 10 = 3500\ mm^2$	
	$A_2 = 200 \times 12 = 2400\ mm^2$	
	Total Area $= A_1 + A_2$	
	$= 3500 + 2400$	
	$= 5900\ mm^2$	
	ii) To find $\bar{x}$ & $\bar{y}$	
	Given Section is symmetrical @ yy axis	
	$\therefore \bar{x} = \frac{200}{2} = 100\ mm$	1M
	iii) $\bar{y}$ To find $\bar{y}$	
	$y_1 = 12 + \frac{350}{2} = 187\ mm$	
	$y_2 = \frac{12}{2} = 6\ mm$	
	$\therefore \bar{y} = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2}$	
	$\bar{y} = \frac{3500 \times 187 + 2400 \times 6}{3500 + 2400}$	
	$\bar{y} = \frac{654500 + 14400}{5900}$ $\boxed{\bar{y} = 113.37\ mm}$	1M

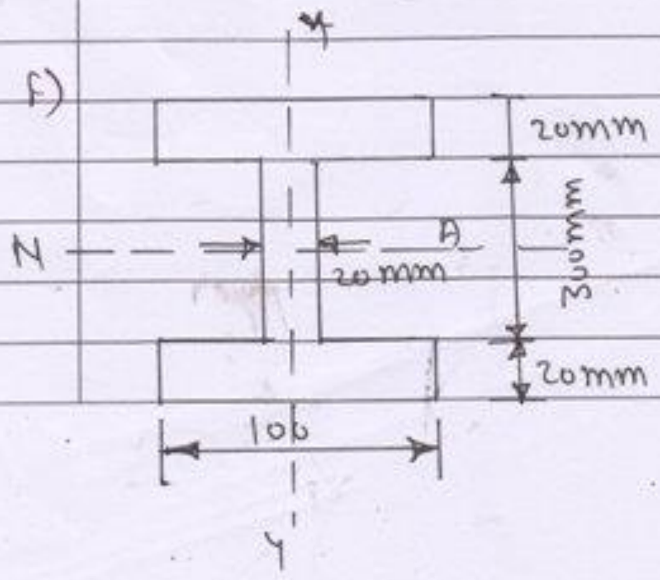
Q.NO	SOLUTION	MARKS
Q.4.b Cont.	To find Ixx	
	$I_{xx} = I_{x_1x_1} + I_{x_2x_2}$.	
	$I_{xx} = \left[I_{G_1} + A_1h_1^2\right] + \left[I_{G_2} + A_2h_2^2\right]$	
	$= \left[\frac{10 \times 350^3}{12} + 3500(187-113.37)^2\right] +$	
	$\left[\frac{200 \times 12^3}{12} + 2400(113.37-6)^2\right]$	
	$I_{xx} = 82.40 \times 10^6 \ mm^4$	2M.

Q .NO	SOLUTION	MARKS
Q.4.c)		
	i> To find M.I w.r.t diameter	
	Moment of Inertia @ centroidal axis	
	$\therefore I_G = I_{xx} = I_{yy}$	
	$I_G = \frac{\pi}{64}(D^4 - d^4)$	
	$= \frac{\pi}{64}(220^4 - 110^4)$	
	$= 107803272 \ mm^4$	
	$\boxed{I_G = 10.78 \times 10^7 \ mm^4}$	01 M
	ii> $h = D/2 = \frac{220}{2} = 110mm$	½ M
	iii> $A = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}(220^2 - 110^2)$	½ M
	$A = 28509.9532 \ mm^2 = 28.51 \times 10^3 \ mm^2$	
	iv) apply parallel axis theorem	
	$I_{tangent} = I_G + Ah^2$	
	$= 107803272 + 28509.9532 \times 110^2$	
	$= 452773706 \ mm^4$	
	$= 45.27 \times 10^7 \ mm^4$	01 M

Q.NO	SOLUTION	MARKS
Q.4.c. Cont..	v) polar moment of inertia	
	$I_P = I_{xx} + I_{yy}$ $\therefore I_G = I_{xx} = I_{yy}$	
	$\therefore I_{pp} = I_{xx} + I_{yy}$	
	$I_P = 107803272 + 107803272$	
	$=$	
	$I_{Polar} = 215.60 \times 10^6\ mm^4$	01M
d)		
	(1) finding Area.	
	$A_1 = A_3 = 50 \times 10 = 500 mm^2$	
	$A_2 = (200-10-10) \times 10 = 180 \times 10 = 1800 mm^2$	
	$A = A_1 + A_2 + A_3 = 500 + 1800 + 500 = 2800\ mm^2$	
	(2) Distance of the centroid from the left face	
	$X_1 = X_3 = \frac{50}{2} = 25 mm$	
	$X_2 = \frac{10}{2} = 5 mm$	

Q.NO	SOLUTION	MARKS
Q.4.d. Cont-	Dist^n of the vertical centroidal axis from the left face	
	$\bar{x} = \dfrac{A_1x_1 + A_2x_2 + A_3x_3}{A_1 + A_2 + A_3}$	
	$= \dfrac{500\times25 + 1800\times5 + 500\times25}{2800}$	
	$= 12.14\,mm$	01M
	$\therefore I_{xx} =$ M.I of ABCD − M.I of PQRS	
	$= \dfrac{50\times200^3}{12} - \dfrac{(50-10)\times180^3}{12}$	
	$= 13.89\times10^6\,mm^4$	01M
	To find I_{yy}	
	$I_{yy} = I_{yy_1} + I_{yy_2} + I_{yy_3}$	
	$I_{yy_1} = I_{G_1} + A_1h_1^2$	
	$I_{G_1} = \dfrac{10\times50^3}{12} = 104166.67\,mm^4$	
	$h_1 = \dfrac{50}{2} - \bar{x} = 25 - 12.4 = 12.6\,mm$	
	$I_{yy_1} = 104166.67 + 500\times(12.6)^2 = 183546.67\,mm^4$	01M

Q.NO	SOLUTION	MARKS
Q.4.d. Cont.	$I_{yy_2} = I_{G_2} + A_2 h_2^2$	
	$I_{G_2} = \frac{180 \times 10^3}{12} = 15000 \text{ mm}^4$	
	$h_2 = 12.14 - \frac{10}{2} = 7.14 \text{ mm}$	
	$I_{yy_2} = 15000 + 1800 \times 7.14^2$	
	$= 106763.28 \text{ mm}^4$	
	$I_{yy_1} = I_{yy_3} = 183546.67 \text{ mm}^4$	
	$I_{yy} = I_{yy_1} + I_{yy_2} + I_{yy_3}$	
	$= 183546.67 + 106763.28 + 183546.67$	
	$\boxed{I_{yy} = 47.38 \times 10^4 \text{ mm}^4}$	01M

Q.NO	SOLUTION	MARKS
Q.4.e)	State four assumption made in pure bending	
	i) The material of the beam is homogeneous and isotropic	4 M (Any four)
	ii) Transverse section of the beam which is plane before bending will remain plane after bending	
	iii) The beam is stressed well up to proportional limit such that it must obey's Hook's law	
	iv) The value of young's modulus is same in tension & in compression	
	v) The elastic limit is not exceeded.	
	vi) The beam initially straight & unstressed.	
	vii) Each longitudinal fiber is free to expand or contract independently from every other layer	
	viii) The resultant force across transverse section of beam is zero	
	ix) The deformation of the section due to shear force is neglected.	
f)		

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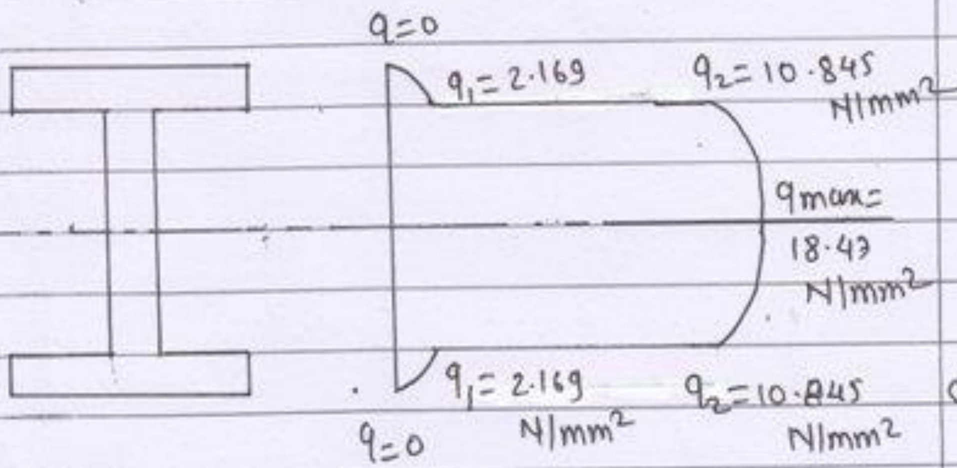
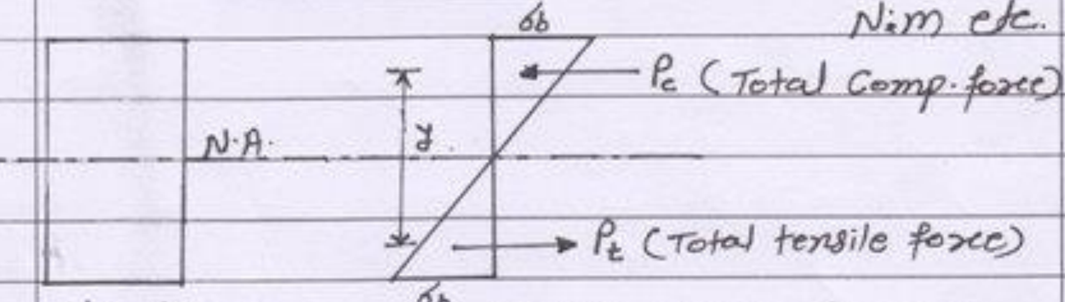
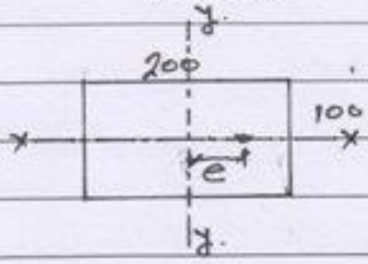
Q NO	SOLUTION	MARKS
Q-4 (f) cont.	a) q = shear stress at the extreme layer = 0	
	b) q_1 = shear stress at the junction of flange and web	
	$I = \frac{1}{12}(BH^3 - bh^3) = \frac{1}{12}(100\times340^3 - 80\times300^3)$	
	$I = 1.47\times10^3\ mm^4$	
	i) shear stress at junction in flange	
	$q_1 = \frac{FA\bar{y}}{IB} = \frac{100\times10^3\times100\times20\times(150+\frac{20}{2})}{1.47\times10^8\times100}$	
	$q_1 = 2.169\ N/mm^2$	01 M
	ii) shear stress at junction (in web)	
	$\therefore$ q_1 suddenly increases to q_2	
	$q_2 = \frac{B}{t}\times q_1 = \frac{100}{20}\times2.169 = 10.845\ N/mm^2$	01 M
	iii) $q_{max} = \frac{FA\bar{y}}{I\cdot B}$ (for additional part)	
	$\therefore A\bar{y} = A_1\bar{y}_1 + A_2\bar{y}_2$	
	$A\bar{y} = 100\times20\times160 + 150\times20\times75$	
	$A\bar{y} = 545\times10^3\ mm^3$	½ M
	$\therefore q_{max} = \frac{100\times10^3\times545\times10^3}{1.47\times10^8\times20}$	
	$q_{max} = 18.53\ N/mm^2$	½ M

Q .NO	SOLUTION	MARKS
Q.4.f. Cont.	$q_{max} = 18.49 \ N/mm^2$	
		01 M

Q.NO	SOLUTION	MARKS
Q5 a)	i) Moment of Resistance :-(MR)	
	The resistance offered by the moment of Couple due to two equal and opposite forces to the bending moment (M) indused due to external forces is called as moment of resistance. It is given by product of section modulus and allowable bending stress.	02
	$\boxed{M.R = Z \times \sigma_b}$ S.I. unit N.mm; N.m etc.	
		
	c/s of beam Bending stress diagram	
	ii) Neutral axis (N.A)	
	When the beam is subjected to pure bending there will be always one layer which will not be subjected to either Compression or tension such a layer is called as neutral layer. The line of intersection of neutral layer and cross section of the beam is called as neutral axis.	02

Q .NO	SOLUTION	MARKS
Q5 b)	Given	
	b - 200mm	
	d - 100mm	
	P - 60 KN	
	e - 40mm	
	σmax - ?	
	σmin - ?	
	 	
	1) σmax = Direct stress (σ_0) + Bending stress (σ_b)	
	$\sigma max = \frac{P}{A} + \frac{M}{Z_{yy}}$	01 M
	$\sigma max = \frac{P}{A} + \frac{P.e}{Z_{yy}}$ $\quad Z_{yy} = \frac{db^2}{6}$	
	$Z_{yy} = \frac{100\times200^2}{6}$	01 M for Z
	$\sigma max = \frac{60\times10^3}{200\times100} + \frac{60\times10^3\times40}{\frac{100\times200^2}{6}}$	
	$\therefore \boxed{\sigma max = 3 + 3.6 = 6.6 \text{ MPa}}$ ... (Comp)	01 M
	2) σmin = Direct stress (σ_0) - Bending stress (σ_b)	
	$= 3 - 3.6$	
	$\boxed{\sigma min = -0.6 \text{ MPa}}$ .... -ve sign indicate tensile stress.	01 M

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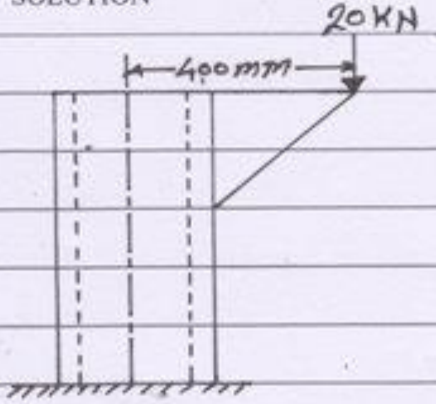
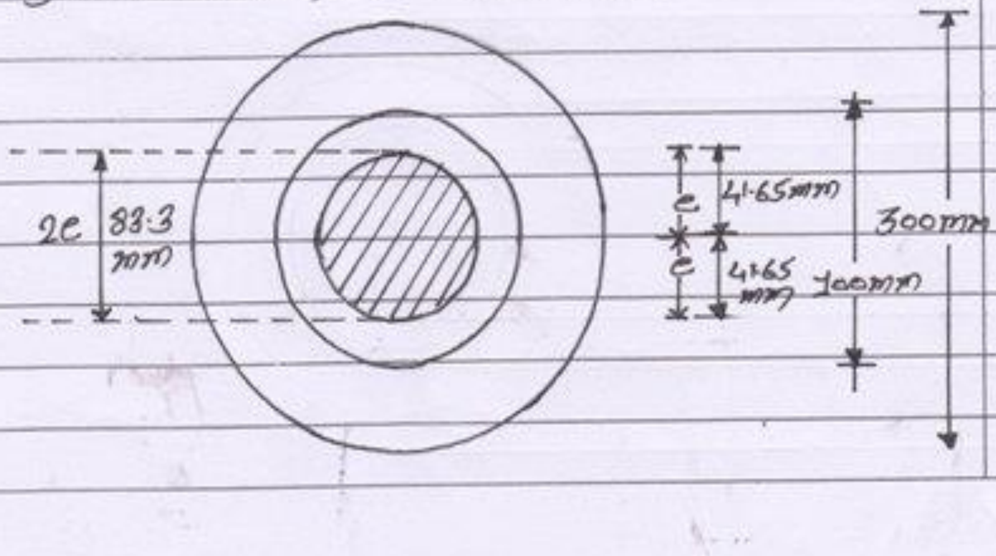
Q.NO	SOLUTION	MARKS
Q5 c)	Given	
	$D - 250\ mm$	
	$d - 200\ mm$	
	$P - 20\ KN$	
	$e - 400\ mm$	
	$\sigma_{max} - ?$	
	$\sigma_{min} - ?$	
		
	1) σ_{max} = Direct stress(σ_0) + Bending stress(σ_b)	
	$\sigma_{max} = \frac{P}{A} + \frac{M}{Z}$	01 M
	$M = P \times e = 20 \times 10^3 \times 400 = 8 \times 10^6\ N\cdot mm$	
	$Z = \frac{\pi}{32D}(D^4 - d^4) = 905.66 \times 10^3\ mm^3$	01 M
	$A = \frac{\pi}{4}(D^2 - d^2) = 17671.45\ mm^2$	
	$\therefore \sigma_{max} = \frac{20 \times 10^3}{17671.45} + \frac{8 \times 10^6}{905.66 \times 10^3}$	
	$= 1.13 + 8.83$	
	$\boxed{\sigma_{max} = 9.96\ N/mm^2}$ ...(Comp)	01 M
	2) σ_{min} = Direct stress (σ_0) − Bending stress(σ_b)	
	$= 1.13 - 8.83$	
	$\boxed{\sigma_{min} = -7.70\ N/mm^2}$ ... −ve sign indicate tensile stress.	01 M

Q .NO	SOLUTION	MARKS
Q5 d)	Given, $P = 4kN$; $e = 200\,mm$; $b = 60\,mm$; $t = 20\,mm$	
	1) $\sigma_{max} = \sigma_0 + \sigma_b = \frac{P}{A} + \frac{M}{Z}$	01 M
	$\sigma_{max} = \frac{P}{A} + \frac{P.e}{Z}$ $\quad Z = \frac{tb^2}{6}$	01 (for Z)
	$= \frac{4\times10^3}{60\times20} + \frac{4\times10^3\times200}{\frac{20\times60^2}{6}}$	
	$\sigma_{max} = 3.33 + 66.67$	
	$\therefore \boxed{\sigma_{max} = 70\ N/mm^2}$ ....(Comp)	01 M
	2) $\sigma_{min} = \sigma_0 - \sigma_b$	
	$= 3.33 - 66.67$	
	$\boxed{\sigma_{min} = -63.34\ N/mm^2}$ ....(Tensile)	01 M
Q5 e)	Given, $P = 80\,kN$; $b - 120\,mm$; $t - 40\,mm$	
	$e = b/3 = 120/3 = 40\,mm$.	
	1) $\sigma_{max} = \sigma_0 + \sigma_b$	
	$= \frac{P}{A} + \frac{M}{Z}$	01 M
	$\sigma_{max} = \frac{P}{A} + \frac{P.e}{Z}$	

Q.NO	SOLUTION	MARKS
Q5c) Cont...	$Z = \frac{tb^2}{6} = \frac{40\times120^2}{6} = 96\times10^3 \, mm^3$	01 M
	$\therefore \sigma max = \frac{80\times10^3}{120\times40} + \frac{80\times10^3\times40}{96\times10^3}$	
	$= 16.67 + 33.33$	
	$\therefore \boxed{\sigma max = 50 \ N/mm^2}$ ...(Comp)	01 M
	$\sigma min = \sigma_0 - \sigma_b$	
	$= 16.67 - 33.33$	
	$\boxed{\sigma min = -16.66 \ N/mm^2}$ ....-ve sign indicate tensile stress.	01 M
Q5f)	Given	
	$D = 100 \, mm \, ; \, d = 100 \, mm.$	
		01 M

Q.NO	SOLUTION	MARKS
Q5 f) Cont...	i) Limit of eccentricity (e).	
	$e \leq \frac{Z}{A}$	01M
	$Z = \frac{\pi}{32D}(D^4 - d^4) = \frac{\pi}{32 \times 300}(300^4 - 100^4)$	
	$Z = 2.617 \times 10^6\ mm^3$	
	$A = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}(300^2 - 100^2)$	
	$A = 62.83 \times 10^3\ mm^2$	
	$\therefore e \leq \frac{2.617 \times 10^6}{62.83 \times 10^3} \leq 41.65\ mm$	01M
	$\therefore \boxed{e = 41.65\ mm}$	1/2 M
	$\therefore \boxed{2e = 83.30\ mm}$	1/2 M
	For hollow circular section having D=300mm and d=100mm the core of section is circular of Diameter 2e i.e. 83.30 mm.	

Q.NO	SOLUTION	MARKS
Q6) a)	Given $D - 80mm$, for hollow $D = 1.5d$; $d = \frac{2}{3}D$	
	1) Torque from solid shaft	
	$T_{solid} = \frac{\pi}{16}(D)^3 \cdot \tau = \frac{\pi}{16}(80)^3 \cdot \tau$	
	$T_{solid} = 100.53 \times 10^3 \ \tau \ \cdots\cdots (i)$	01M
	2) Torque from hallow shaft	
	$T_h = \frac{\pi}{16D}(D^4 - d^4) \cdot \tau \qquad \cdots\cdots d = \frac{2}{3}D$	
	$= \frac{\pi}{16D}\left[D^4 - (\frac{2}{3}D)^4\right] \cdot \tau$	
	$= \frac{\pi}{16} \times 0.802 \ D^3 \cdot \tau$	
	$T_h = 0.1574 \ D^3 \cdot \tau \ \cdots\cdots (ii)$	01 M
	3) Equating eqn (i) & (ii)	
	$100.53 \times 10^3 \ \tau = 0.1574 \ D^3 \cdot \tau$	
	$\therefore \boxed{D = 86.11 \ mm}$	1/2 M
	$\therefore d = \frac{2}{3} D \qquad \boxed{d = 57.40 \ mm}$	1/2 M

Q.NO	SOLUTION	MARKS
Q6 a) Cont....	4) Percentage saving in the material	
	$= \frac{A_s - A_h}{A_s} \times 100$	
	$= \frac{\left[\frac{\pi}{4}(80)^2 - \frac{\pi}{4}(86.11^2 - 57.4^2)\right]}{\frac{\pi}{4}(80)^2} \times 100$	
	$\boxed{\% \text{ saving} = 35.64\%}$	01 M
Q6 b)	Given, $L - 3m$, $d - 75\ mm$, $F = 2\ KN$, $R = 0.6m$	
	$G = 90\ GN/m^2 = 90 \times 10^3\ N/mm^2$	
	1) Using Torsional formula	
	$\frac{T}{I_p} = \frac{G\theta}{L}$	01 M
	$\therefore\ \theta = \frac{TL}{I_p \cdot G}$	
	$T = F \times R = 2 \times 0.6 = 1.2\ KN \cdot m = 1.2 \times 10^6\ N \cdot mm$	01 M
	$I_p = \frac{\pi}{32}(d)^4 = \frac{\pi}{32}(75)^4 = 3.106 \times 10^6\ mm^4$	01 M
	$\therefore\ \theta = \frac{1.2 \times 10^6 \times 3000}{3.106 \times 10^6 \times 90 \times 10^3}$	
	$\boxed{\theta = 0.01287\ rad}$ OR $\boxed{\theta = 0.737^\circ}$	01 M

Q.NO	SOLUTION	MARKS
Q6 c)	Given. Power $P = 20\,KW$; $N = 2$ Revolution/sec	
	$\tau = 40\,MN/m^2 = 40\,N/mm^2$; $T_{max} = 1.4\,T_{mean}$	
	1) Power Transmitted by shaft	
	$P = 2\pi N T_{mean}$	
	$20\times10^3 = 2\times\pi\times2\,T_{mean}$	
	$\therefore T_{mean} = 1.59\times10^3\,N{\cdot}m$	
	$T_{mean} = 1.59\times10^6\,N{\cdot}mm$	01 M
	$T_{max} = 1.4\times1.59\times10^6$	
	$T_{max} = 2.226\times10^6\,N{\cdot}mm$	01 M
	2) Using Torsional formula	
	$\frac{T}{I_P} = \frac{\tau}{R}$	01 M
	$I_P = \frac{\pi}{32}D^4$; $R = D/2$	
	$\frac{2.226\times10^6}{\frac{\pi}{32}D^4} = \frac{40}{D/2}$	
	$\frac{32\times2.226\times10^6}{\pi\times2\times40} = D^3$	
	$\therefore \boxed{D = 65.68\,mm}$	01 M

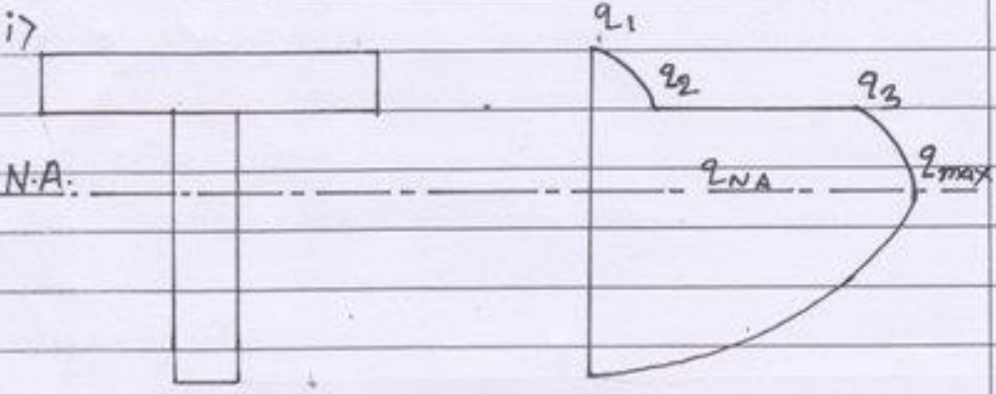
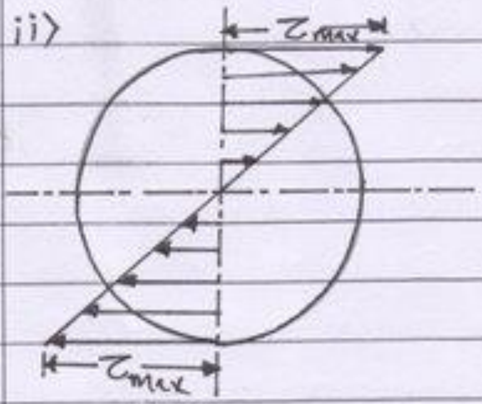
* Note:- The value of Power is Printed in Q.Paper as 20 KN but it is taken as 20 KW in above problem. examiner should consider the same

Q.NO	SOLUTION	MARKS
Q-6 (d)	given $D = 100mm$, $\theta = 2.75^\circ = 0.04799$ rad	
	$L = 6m$ $G = 80\ kN/mm^2$	
	1) using Torsional formula	
	$\frac{T}{I_p} = \frac{G\theta}{L}$	1M
	$T = \frac{G \cdot \theta \cdot I_p}{L}$	
	$I_p = \frac{\pi}{32}(D^4) = \frac{\pi}{32} \times 100^4 = 9.817 \times 10^6\ mm^4$	1M
	$T = \frac{80 \times 10^3 \times 0.04799 \times 9.817 \times 10^6}{6000}$	
	$\boxed{T = 6.28 \times 10^6\ N \cdot mm}$	2M

Q.NO	SOLUTION	MARKS
	solution ①	
Q-6 (e)	Two : solutions are Possible in this Problem.	
*	In this problem relationship between external diameter with internal diameter is not given	
	*So student can assume the same. *	
	• assume $G = 80$ Gpa & $d = 0.75D$	
	solution ①	
	$\tau = 63$ Mpa	
	$R = D/2$	
	$T = 62\times10^6$ N·mm & $J = \frac{\pi}{32}(D^4 - d^4)$	
	$\therefore J = \frac{\pi}{32}((D^4 - (0.75D)^4)$	
	$\therefore \boxed{J = 0.0671029\,D^4}$	½ M
	i) Diameter based on strength criteria	
	$\therefore \frac{\tau}{R} = \frac{T}{J}$	½ M
	$\frac{63}{D/2} = \frac{62\times10^6}{0.0671029\,D^4}$	
	$\therefore 4.2279\,D^4 = 0.5D \times 62\times10^6$	
	$\therefore D^3 = \frac{31\times10^6}{4.228}$	
	$\therefore \boxed{D = 194.27 \text{ mm}}$	1 M

Q.NO	SOLUTION	MARKS
	ii) Diameter based on stiffness criteria	
	$\frac{T}{J} = \frac{G\theta}{L}$	$\frac{1}{2}$M
	$\frac{62\times10^6}{0.06711029\,D^4} = \frac{80\times10^3 \times 0.024434}{3000}$	
	$62\times10^6 \times 3000 = 0.06711029\,D^4 \times 80\times10^3 \times 0.024434$	
	$\therefore 62\times10^6 \times 3000 = 131.181\ D^4$	
	$\therefore D^4 = 1417888261$	
	$\therefore \boxed{D = 194.048\ mm}$	01
	from above two criteria max. diameter = 194.27mm	$\frac{1}{2}$M
Q-6 (e)	~~other~~ alternate solution-2	
	a) maximum Torque = 62 KN.m	
	b) shear stress = 63 Mpa	
	c) Length of shaft = 3m	
	d) $\theta^\circ = 1.4^\circ$	
	e) assuming G = 80 Gpa	
	f) R = D/2	

Q.NO	SOLUTION	MARKS
	External diameter of shaft	
	$\frac{\tau_{max}}{R} = \frac{G \cdot \theta}{L}$	1M
	$\frac{63}{D/2} = \frac{80 \times 10^3 \times 0.024434}{3000}$	
	$63 \times 3000 = 0.5D \times 80 \times 10^3 \times 0.024434$	
	$189000 = 977.36\ D$	
	$\therefore \boxed{D = 193.38\ mm}$	3M.

Q.NO	SOLUTION	MARKS
Q6 f)	i)  T-Section Shear stress distribution diagram	02M
	ii)  Circular shaft τ_{max} → Intensity of shear stress. at outer fibre.	02M