Q.6 i. How will you justify that Rankine's formula is applicable for all length of column ranging from short to long column? **4**

ii. A bar of length 4m when used as a simply supported beam and subjected to a uniformly distributed load of 30KN/m over the whole span deflects 15 mm at the centre. Determine the crippling loads when it is used as a column with following end conditions : (a) Both ends pin jointed (b) Both ends fixed **6**

OR iii. A hollow cylinder cast iron column is 4m long with both ends fixed. Determine the minimum diameter of the column, if it has to carry a safe load of 250 KN with a factor of safety of 5. Take the internal diameter as 0.8 times the external diameter. Take Rankine constant as 1/1600 and σc =550 MPa. **6**

******

Total No. of Questions: 6 *Total No. of Printed Pages:4*

Enrollment No.....................................

Faculty of Engineering

End Sem (Odd) Examination Dec-2017

AU3CO02 / FT3CO02 / ME3CO02

Strength of Materials

Programme: B.Tech. Branch/Specialisation: AU/FT/ME

Duration: 3 Hrs. **Maximum Marks: 60**

Note: All questions are compulsory. Internal choices, if any, are indicated. Answers of Q.1 (MCQs) should be written in full instead of only a, b, c or d.

Q.1 i. The ratio of lateral strain to linear strain is known as **1**
(a) Modulus of elasticity (b) Modulus of rigidity
(c) Elastic limit (d) Poisson's ratio

ii. The temperature stress developed in a bar depends upon **1**
(a) Coefficient of linear expansion
(b) Change of temperature
(c) Young's modulus
(d) All of these

iii. For an element under a biaxial state of stress $\sigma_x = -\sigma_y$ in the plane x-y, the radius of Mohr's Circle is **1**
(a) $2\sigma_x$ (b) $2\sigma_y$ (c) $3\sigma_x$ (d) σ_x

iv. The young's modulus E, the shear modulus G and the poisson's ratio μ are related by **1**
(a) E=2G (1-μ) (b) E=2G (1+2μ)
(c) E=2G (1-2μ) (d) E=2G (1+μ)

v. The deflection at the free end of a cantilever of length L carrying a point load W at its free end is **1**
(a) WL/2EI (b) WL2/2EI (c) WL3/2EI (d) WL3/3EI

vi. The strength of beam mainly depends on **1**
(a) Bending Moment (b) Centre of gravity
(c) Weight (d) Section modulus

vii. If two shafts of same length, one of which is hollow, transmit equal torque and have equal maximum stress, then they should have equal **1**

(a) Diameter (b) Angle of twist

(c) Polar moment of inertia (d) Polar modulus of section

viii. A circular shaft of length L subjected to a torque T, G is rigidity modulus and J is polar moment of inertia, then the total angle of twist is given by **1**

(a) TJ/GL (b) GJ/TL (c) TG/JL (d) TL/GJ

ix. The ratio of equivalent length of a column, having one end fixed and the other hinged, to its length is **1**

(a) 2 (b) $\sqrt{2}$ (c) ½ (d) $1/\sqrt{2}$

x. In the Rankine formula, the material constant for mild steel is **1**

(a) 1/1200 (b) 1/1600 (c) 1/5000 (d) 1/7500

Q.2 Attempt any two:

i. Describe various mechanical properties of materials. **5**

ii. Explain the term: Strain, shear strain, modulus of elasticity, resilience and modulus of rigidity. **5**

iii. Establish the relationship among elastic constants. **5**

Q.3 i. Explain the term principle plane and principle stresses. **4**

ii. An element in a stressed material has tensile stress of 500 MPa and a compressive stress of 350 MPa acting on two mutually perpendicular planes and equal shear stresses of 100 MPa on these planes. Find principal stresses and position of the principal planes. Find also maximum shearing stress. **6**

OR iii. Draw Mohr's stress circle for direct stresses of 65 MPa (Tensile) and 35 MPa (compressive) and estimate the magnitude and direction of the resultant stresses on planes making angles of 20^{o} and 65^{o} with the plane of the first principal stress. Find also the normal and tangential stresses on these planes. **6**

Q.4 i. Derive the relation for a circular shaft when subjected to simple bending as **5**

$M/I = \sigma_b/y = E/R$, where M= Bending Moment, I=Moment of inertia, σ_b =bending stress, y= distance of upper fiber from neutral axis, E= modulus of elasticity, R=shaft radius

ii. A 250 mm x 150 mm rectangular beam is subjected to maximum bending moment of 750 KN-m. Find maximum stresses in beam. If modulus of elasticity for beam material is 200GN/m2, find out the radius of curvature for that portion of the beam where the bending is maximum. **5**

OR iii. A cantilever 2 m long is of rectangular section 100 mm wide and 200 mm deep. It carries a uniformly distributed load of 2 KN per unit meter length for a length of 1.25 m from fixed end a point load of 0.8 KN at the free end. Find the deflection at the free end. Take E=10GN/m2. **5**

Q.5 i. Derive the relationship for a circular shaft when subjected to torsion as given below: **5**

$T/J = G\Theta/L = \tau/R$ Where T= Torque, J= polar moment of inertia, G= Modulus of rigidity, Θ=angle of twist, L= Length of shaft, τ = shear stress and R= Shaft radius

ii. A hollow shaft having an inside diameter 60% of its outer diameter is to replace a solid shaft transmitting the same power at the same speed. Calculate the percentage saving in material, if the material to be used is also the same. **5**

OR iii. A hollow shaft is to transmit 300 KW at 80 rpm. If the shear stress is not to exceed 60MPa and internal diameter is 0.6 of the external diameter, find the external and internal diameters assuming that the maximum torque is 1.4 times the mean. **5**

AU3CO02 / FT3CO02 / ME3CO02 Strength of Materials

Marking Scheme

Q.1	i.	(d) Poisson's ratio	**1**
	ii.	(d) All of these	**1**
	iii.	(d) σ_x	**1**
	iv.	(d) E=2G (1+μ)	**1**
	v.	(d) WL3/3EI	**1**
	vi.	(d) Section modulus	**1**
	vii.	(d) Polar modulus of section	**1**
	viii.	(d) TL/GJ	**1**
	ix.	(d) $1/\sqrt{2}$	**1**
	x.	(d) 1/7500	**1**
Q.2		Attempt any two:	
	i.	Each property – 1mark * 5 = 5 marks	**5**
	ii.	Each Explanation – 1mark * 5 = 5 marks	**5**
	iii.	Derivation 5 marks	**5**
Q.3	i.	Principle plane - 2 marks	**4**
		Principle stresses – 2 marks	
	ii.	Principal stress – 2 marks	**6**
		Position of the principal planes – 2 marks	
		Maximum shearing stress – 2 marks	
OR	iii.	Magnitude and direction of the resultant stresses- 2 marks	**6**
		Normal stress – 2 marks	
		Tangential stress – 2 marks	
Q.4		Attempt any two:	
	i.	Derivation 5 marks	**5**
	ii.	Radius of curvature – 2.5 marks	**5**
		Maximum Stress – 2.5 marks	
	iii.	Deflection – 5 marks	**5**
Q.5	i.	Derivation 5 marks	**5**
	ii.	Percentage saving – 5 marks	**5**
OR	iii.	External & Internal Diameter – 5 marks	**5**
Q.6	i.	Explanation – 4 marks	**4**
	ii.	(a) Both ends pin jointed - 3 marks	**6**
		(b) Both ends fixed- 3 marks	
OR	iii.	Diameter 6 marks	**6**

solution.

Rajshree PAGE NO.: DATE: 1

Strength of Materials

Q.1 (i) (d) Poisson's ratio

(ii) (d) All of these

(iii) (d) σ_x

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

(v) (d) $WL^3/3EI$

(vi) (d) Section modulus

(vii) (d) Polar modulus of section

(viii) (d) TL/GJ

(ix) (d) $1/\sqrt{2}$

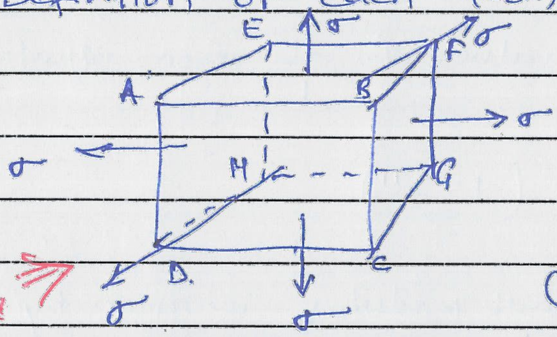
(x) (d) $1/7500$

Q.2

(i) For each mechanical properties (name & description) = 1 mark

Q2 (ii) Definition of each term = 1 mark.

Q.2(iii)



1 marks

$v = L^3$

(1) strain of AB due to stress on face AEHD (Tensile) & BFGC $= \frac{\sigma}{E}$

(2) strain of AB due to stresses on the faces AEFB & DHGC This is compressive lateral strain and is $= -\frac{\mu\sigma}{E}$

(3) strain of AB due to stresses on faces ABCD & EFGH This is also compressive lateral strain and is equal to $-\mu\sigma/E$

L = length of cube

dL = change in length of cube

E = Youngs modulus

σ = Tensile stress

μ = poisson's ratio

Hence the total strain of AB is given by

$$\frac{dL}{L} = \frac{\sigma}{E} - \frac{\mu\sigma}{E} - \frac{\mu\sigma}{E} = \frac{\sigma}{E}(1-2\mu) \quad \text{--- (i)}$$

now original volume of cube $V = L^3$ (ii)
if dL is the change in length then dV is the change in volume

Differentiating equation (ii) with respect to L

$$dV = 3L^2 \times dL \quad \text{--- (iii)}$$

Dividing equation (iii) by equation (ii) we get

1.5 marks

$$\frac{dV}{V} = \frac{3L^2 \times dL}{L^3} = \frac{3dL}{L}$$

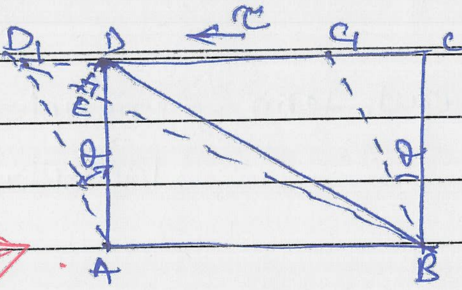
Substituting the value of $\frac{dL}{L}$ from equation we get

$$\frac{dV}{V} = \frac{3\sigma}{E}(1-2\mu)$$

We know that bulk modulus is given by

$$K = \frac{\sigma}{(dV/V)} = \frac{\sigma}{\frac{3\sigma}{E}(1-2\mu)}$$

$$\boxed{E = 3K(1-2\mu)} \qquad \boxed{\mu = \frac{3K-E}{6K}}$$



μ = poisson's ratio

E = young's modulus for the material

1 mark

Now tensile strain in diagonal BD due to tensile stress τ along BD

$$= \frac{\text{Tensile stress along BD}}{E} = \frac{\tau}{E}$$

Tensile strain in diagonal BD due to compressive stress τ along AC

$$= \frac{\mu \times \tau}{E}$$

$\therefore$ Total tensile strain along diagonal BD

$$= \frac{\tau}{E} + \frac{\mu\tau}{E} = \frac{\tau}{E}(1+\mu)$$

1.5 marks

Similarly total strain in the diagonal AC will be compressive and will be given by

$$= \frac{\tau}{E}(1+\mu)$$

We know that Tensile strain in diagonal BD is given by

$$= \frac{1}{2}\,\text{shear strain} = \frac{1}{2} \times \frac{\text{shear stress}}{C}$$

$$= \frac{1}{2}\frac{\tau}{C}$$

Equating the Two tensile strain along diagonal BD we get $\tau/E(1+\mu) = \frac{1}{2}\frac{\tau}{C} \rightarrow \boxed{E = 2C(1+\mu)}$

Q.3. (i) Explanation of each term principle plane = 2 marks
principle stresses = 2 marks

Q.3. (ii) given

$\sigma_x = 500\ MN/m^2$ (tensile)

$\sigma_y = 350\ MN/m^2$ (compress)

$\tau_{xy} = 100\ MN/m^2$ (shear)

Principal stresses

σ_1, σ_2

1 marks ⇒ $\sigma = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$

$= \frac{500 + (-350)}{2} \pm \sqrt{\left[\frac{500 - (-350)}{2}\right]^2 + 100^2}$

$= 75 \pm 436.6$

2 marks ⇒ $\boxed{\sigma_1 = 511.6\ MN/m^2 \text{ (tensile)}}$ Ans.

$\boxed{\sigma_2 = -361.6\ MN/m^2 \text{ (compressive)}}$ Ans.

Position of principle planes θ_1, θ_2

1 marks ⇒ $\boxed{\tan 2\theta = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}} = \frac{2 \times 100}{500 - (-350)} = 0.2353$

$2\theta = 13°14'$ or $193°14'$

1 marks ⇒ $\boxed{\theta_1 = 6°37'}$ Ans $\boxed{\theta_2 = 96°37'}$ Ans.

Max shear stress $\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{511.6 - (-361.6)}{2}$

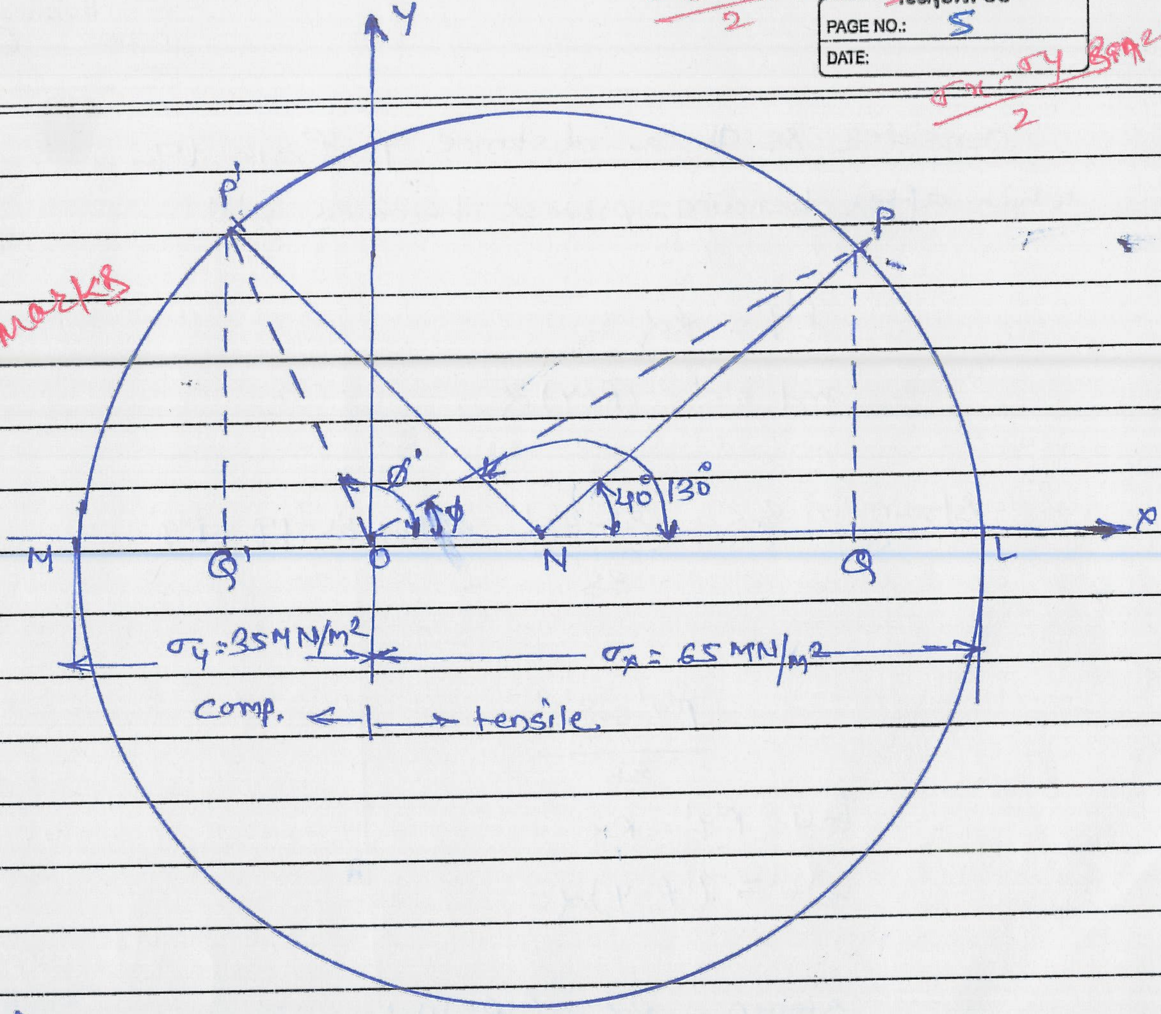
1 marks. ⇒ $\boxed{\tau_{max} = 436.6\ MN/m^2}$ Ans.

$\frac{\sigma_x+\sigma_y}{2} + \frac{\sigma_x-\sigma_y}{2}\cos 2\theta$ ..

$\frac{\sigma_x-\sigma_y}{2}\sin 2\theta$

Q.3(iii)

3 marks



from mohr's circle

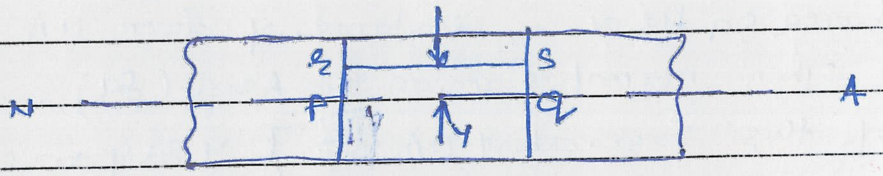
first plane (case 1)	second plane (case 2)
$\sigma_n = OQ = 53.3\ MN/m^2$ (tensile)	$\sigma_n = OQ' = 17.1\ MN/m^2$
$\tau = PQ = 32.1\ MN/m^2$ (shear)	$\tau = P'Q' = 38.3\ MN/m^2$
$\sigma_R = OP = 62.2\ MN/m^2$	$\sigma_R = OP' = 41.9\ MN/m^2$
$\phi = 31°$	$\phi = 114°$

Ans.

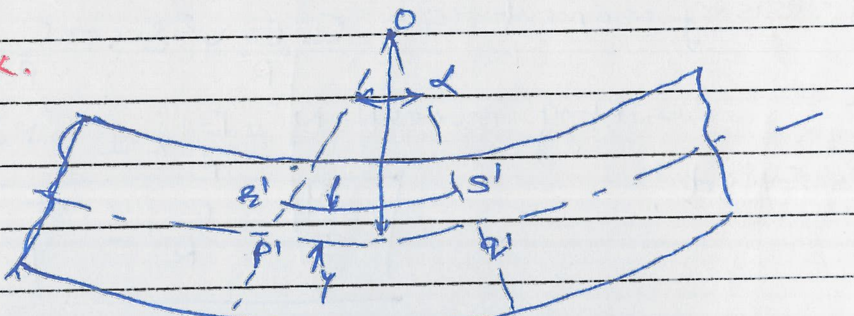
1.5 marks

1.5 marks

Q.4 (i)



1 mark



Consider rs at a distance y from pq which after bending process becomes r's'

$$p'q' = R\alpha$$

and $r's' = (R-y)\alpha$

Strain in rs $= \dfrac{rs - r's'}{rs}$ but $rs = pq = p'q'$

$$= \frac{p'q' - r's'}{rs}$$

but $p'q' = R\alpha$

$r's' = (R-y)\alpha$

$$\text{strain} = \frac{R\alpha - (R-y)\alpha}{R\alpha} = \frac{y}{R}$$

$$\text{strain} = \frac{\sigma}{E}$$

$$\frac{\sigma}{E} = \frac{y}{R} \Rightarrow \boxed{\sigma/y = E/R}$$ ⇒ 1.5 marks.

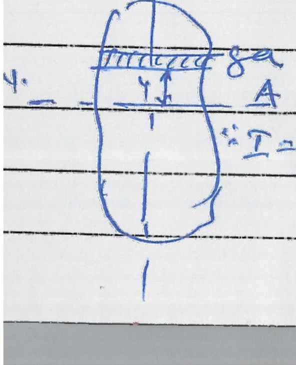
Let a strip of area δa lie at a distance y from N.A

Then normal force on this Area $(\delta a) = \dfrac{E}{R} y \delta a$

1 mark.

Moment of this force about N.A is $= \dfrac{E}{R} y \delta a\, y$ or $\dfrac{E}{R} y^2 \delta a$

∴ total resisting moment is $= \Sigma \dfrac{E}{R} y^2 \delta a$ or $\dfrac{E}{R} \Sigma y^2 \delta a$

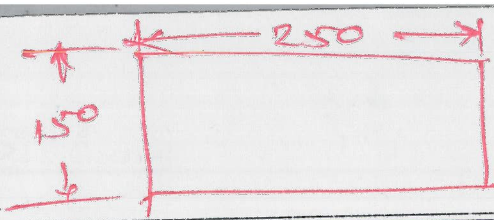


Resisting moment $M = \dfrac{E}{R} \times I \; \{\because I = \Sigma y^2 \delta a\}$

$\because I = \Sigma y^2 \delta a$.

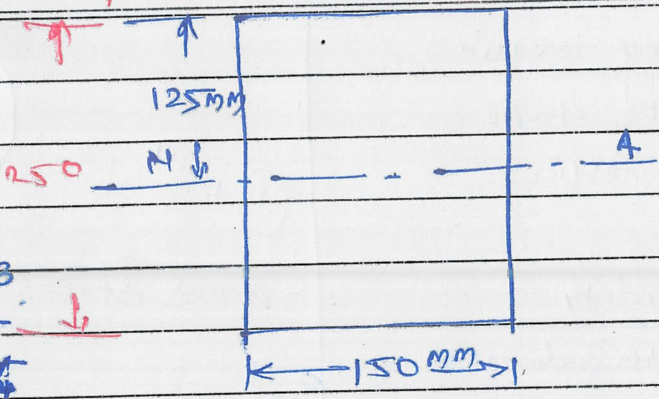
$$\boxed{\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}}$$ ⇒ 1.5 marks.

$R = 20m$.
$\sigma = 800\ N/mm^2$



wise versa. may be considered

Q.4 (ii)



Width $b = 150mm = 0.15m$
depth $d = 250 = 0.25m$
$M = 750\ kNm$
$E = 200 GN/m^2$

~~250×150~~

$\frac{.25 \times .15^3}{12}$

.703×10⁻⁴

56250

(a) Maximum stress in beam

Moment of inertia $\Rightarrow I = \frac{bd^3}{12} = \frac{0.15 \times 0.25^3}{12}$

$\boxed{I = 0.0001953\, m^4}$

$y = \frac{d}{2} = \frac{0.25}{2} = 0.125m$

1 Mark

$\boxed{\frac{M}{I} = \frac{\sigma}{y}}$ $\sigma = \frac{M \cdot y}{I}$

$= 750 \times 10^3 \times 75$

$\sigma = 4.8 \times 10^8\ N/m^2$ or

1.5 marks $\boxed{\sigma = 480\ MN/m^2}$ Ans

(b) Radius of curvature R

$\boxed{\frac{M}{I} = \frac{E}{R}}$ — 1 mark.

$R = \frac{EI}{M}$

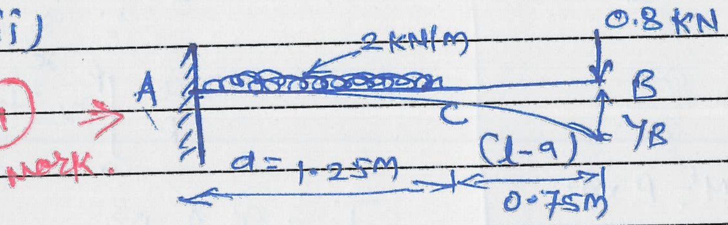
$\boxed{R = 52.08m}$ Ans. 1.5 marks

~~(c) 62.5 mm from top, M/I = y/x = 60~~

~~280 N/mm² Ans~~

Q.4 (iii)

1 mark.



Deflection of the free end B y_B = downward

= Deflection at B due to uniformly distributed load + deflection at B due to point load at B

1 mark $= \left[\frac{wa^4}{8EI} + \frac{wa^3}{6EI}(l-a)\right] + \frac{Wl^3}{3EI}$

length of cantilever $l = 2m$

Cross section $b = 100mm = 0.1m$

$d = 200mm = 0.2m$

1 mark $\Rightarrow$ $\boxed{I = \frac{bd^3}{12} = 66.66 \times 10^{-6} m^4}$

$w = 2kN/m$ $E = 10 GN/m^2$

$= 4.848 \times 10^{-3} m = 4.848\ mm$

$\boxed{y_B = 4.848mm}$ 2 marks.

Ans

Q.5 (i) T = Maximum twisting torque

D = Diameter of the shaft

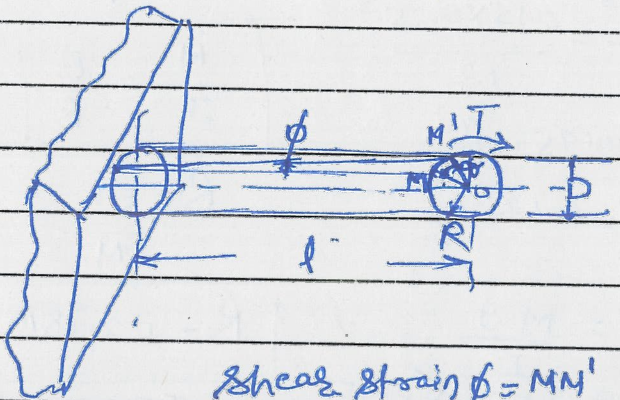
I_p = polar moment of inertia

τ = shear stress

C = modulus of Rigidity

θ = The angle of Twist (radians)

l = length of the shaft



Shear strain $\phi = \frac{MM'}{l}$

1 mark.

$$\phi = \frac{\tau}{C}$$

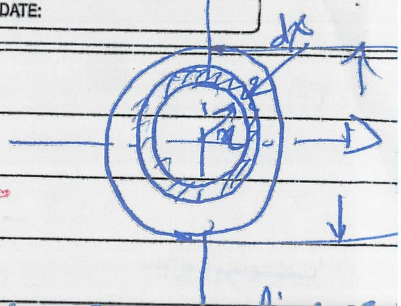
$$\frac{MM'}{l} = \frac{\tau}{C}$$

$\because MM' = R \times \theta$

$$\frac{R\theta}{l} = \frac{\tau}{C}$$

$$\boxed{\frac{\tau}{R} = \frac{C\theta}{l}} \quad \text{--- (1)}$$

1.5 marks



1 mark

Shear stress at radius x be τ_x on element of ring of dx

Turning force on the elementry ring $= \tau_x \times 2\pi x\,dx$

Turning moment due to this turning force

$$dT = \tau_x \, 2\pi x \cdot dx \times x$$

To get Total turning moment integrating both side we get

$$\int dT = \int_0^R \tau_x \, 2\pi x\,dx\,x$$

$\because \frac{\tau_x}{x} = \frac{\tau}{R}$

$$T = 2\pi \frac{\tau}{R} \int_0^R x^3\,dx$$

$$T = \tau \frac{\pi}{16} D^3$$

$$T = \frac{\tau}{R} \times I_p \quad \left\{ \because I_p = \frac{\pi D^4}{32} \right\}$$

$$\boxed{\frac{T}{I_p} = \frac{\tau}{R}} \quad \text{--- (2)}$$

1.5 marks

from (1) & (2)

$$\boxed{\frac{T}{I_p} = \frac{C\theta}{l} = \frac{\tau}{R}}$$ Ans.

Q.5 (iii) ★★★

Given $P = 300\,kW = 300 \times 10^3\,W$

$N = 80\ rpm$

$\tau = 6\ N/mm^2$

Internal dia $D_i = 0.6$ External dia

$= 0.6\,D_o$

Max. Torque $T_{max} = 1.4$ mean torque

$= 1.4\,T$

$$\boxed{P = \frac{2\pi N T}{60}}$$ (1) mark

$$T = \frac{60 \times P}{2\pi N} = \frac{60 \times 300 \times 10^3}{2\pi \times 80}$$

$T = 35809.8\ N\text{-}m$ (1) mark

$\boxed{T_{max} = 1.4\,T} = 50133.7\ N\text{-}m$

$= 50133700\ N\text{-}mm$

$$\boxed{T_{max} = \frac{\pi}{16} \times \tau \left[\frac{D_o^4 - D_i^4}{D_o}\right]}$$

$$50133700 = \frac{\pi}{16} \times 60 \left[\frac{D_o^4 - (0.6\,D_o)^4}{D_o}\right]$$

(1) mark

$$= \frac{\pi}{16} \times 60 \left[\frac{D_o^4 - 0.1296\,D_o^4}{D_o}\right]$$

$$= \frac{\pi}{16} \times 60 \times 0.8704\,D_o^3$$

$\boxed{D_o = 170\ mm.}$ Ans. (1) mark.

$D_i = 0.6\,D_o = 0.6 \times 170$

$\boxed{D_i = 102\ mm.}$ Ans. (1) mark.

Q.5 (ii) ★★

D_o = outer dia

D_i = inside dia = 60% of D_o

$D_i = 0.6\,D_o$

D = Dia of the solid shaft

P = Power transmitted by hollow shaft or by solid shaft

N = speed of shaft

τ = Max. shear stress

(1) mark.

$$P = \frac{2\pi N T}{60}$$

$$T = \frac{60 \times P}{2\pi N}$$

$\therefore$ P & N is same for both shaft so torque will be same (1) mark.

T for solid shaft $= \frac{\pi}{16} \tau D^3$

T for hollow shaft $= \frac{\pi}{16} \tau \left[\frac{D_o^4 - (0.6\,D_o)^4}{D_o}\right]$

(1) mark.

$$= \frac{\pi}{16} \tau\, 0.8704\,D_o^3$$

equating above we get

$\boxed{D = 0.9548\,D_o}$ (1) mark.

Area of solid shaft $= \frac{\pi}{4} D^2 = 0.716\,D_o^2$

Area of hollow shaft $= \frac{\pi}{4}\left[D_o^2 - D_i^2\right] = 0.502\,D_o^2$

Saving in material = Saving in area

$$= \frac{\text{Area of solid shaft} - \text{Area of hollow shaft}}{\text{Area of solid shaft}}$$

(1) mark.

$= 0.2988$ $\boxed{\text{in } \% = 29.88}$

Ans

Q.6 (i) Rankine formula

$$\frac{1}{P} = \frac{1}{P_C} = \frac{1}{P_E}$$

P = Crippling load by Rankine formula

(1) marks.

P_c = Crushing load $= \sigma_c \times A$

σ_c = Ultimate crushing stress

A = Area of cross section

P_E = Crippling load by Euler's formula

$= \frac{\pi^2 EI}{L_e^2}$ in which L_e = Effective length

(a) If the column is a short which means the value of Le is small, then the value of P_E will be large Hence the $\frac{1}{P_E}$ will be small enough and is negligible as compared to the value of $\frac{1}{P_C}$

$$\frac{1}{P} \rightarrow \frac{1}{P_C}$$

or $P \rightarrow P_C$

(1.5 marks.)

hence the crippling load by Rankine's formula for a short column is approximately equal to crushing load

(b) If the column is long which means the value of Le is large. Then the value of PE will be small and the value of $\frac{1}{P_E}$ will be large enough compared with $\frac{1}{P_C}$ hence the value of $\frac{1}{P_C}$ may be neglected

$$\frac{1}{P} = \frac{1}{P_E} \qquad P \rightarrow P_E$$

hence the Rankine formula for $\frac{1}{P} = \frac{1}{P_C} + \frac{1}{P_E}$ gives satisfactory results for all length of column.

(1.5 marks.)

(9) Both end fixed. (1)

$P_e = \frac{\pi^2 EI}{L_e^2} = \quad l_e = l/2 = 16452\,KN.$ (1)

Q.6(ii) given $l = 4m = 4000\,mm$

Uniformly D load $\omega = 30\,KN/m = 30{,}000\,N/m$

$= 30\,N/mm$

Deflection at the centre $\delta = 15\,mm$

$\delta = \frac{5}{384} \times \frac{\omega \times L^4}{EI}$ --- (1) mark.

$15 = \frac{5}{384} \times \frac{30 \times 4000^4}{EI}$

$\boxed{EI = \frac{2}{3} \times 10^{13}\,N\,mm^2}$ (1) mark.

(a) ~~Crippling load when the beam is used as a column with one end fixed and other end hinged~~ $\cancel{P = \frac{2\pi^2 EI}{l^2}}$ ~~(1) mark.~~

$\boxed{\cancel{P = 8224.5\,KN.}}$ ~~(1) mark~~

(b) Crippling load when both the ends are pin-Jointed

$P = \frac{\pi^2 \times EI}{l^2}$ -- (1) mark.

$= \frac{\pi^2 \times \frac{2}{3} \times 10^{13}}{4000^2} \Rightarrow \boxed{P = 4112.25\,KN}$ (1) mark Ans

Q.6(iii) $l = 4m = 4000\,mm$

end condition = Both ends fixed

$L_e = \frac{l}{2} = \frac{4000}{2} = 2000\,mm$

Safe load = 250 KN

fos = 5

let External Dia = D

Internal Dia = 0.8 D

Crushing stress $\sigma_c = 550\,N/mm^2$

$a = \frac{1}{1600}$

fos = $\frac{\text{Crippling load}}{\text{Safe load.}}$

Crippling load = 5 × 250

(1) $\boxed{P_c = 1250\,KN}$ Mark.

$A = \frac{\pi}{4}\left[D^2 - (0.8D)^2\right] = \pi \times 0.09 D^2$ (1) mark.

$I = \frac{\pi}{64}\left[D^4 - (0.8D)^4\right] = 0.009225\pi D^4$ (1) mark.

$\because I = AK^2$

$K = \sqrt{I/A} \doteq 0.32 D$

$P = \frac{\sigma_c A}{1 + a\left(\frac{L_e}{K}\right)^2}$ (1) mark.

$1250000 = \frac{550\pi \times 0.09 D^2}{1 + \frac{1}{1600}\left(\frac{2000}{0.32 D}\right)^2}$

$D^4 - 8038 D^2 - 196239700 = 0$

$D^2 = 185925\,mm^2$ (1) mark

$\boxed{\text{External } D = 136.3\,mm.}$ Ans.

$\boxed{\text{Internal} = 0.8 \times 136.3 = 109\,mm.}$ (1) mark. Ans.