

CHAPTER 6 BENDING STRESSES IN BEAMS

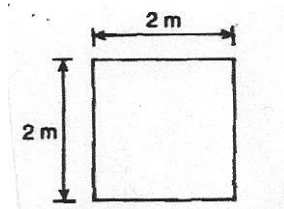
EXERCISE 29, Page 137

1. A concrete beam of uniform square cross-section, as shown below is to be lifted by its ends, so that it may be regarded as being equivalent to a horizontal beam, simply supported at its ends and subjected to a uniformly distributed load due to its self-weight. Determine the maximum permissible length of this beam, given the following:

Density of concrete = 2400 kg/m^3

Maximum permissible tensile stress in the concrete = 1 MN/m^2

$g = 9.81 \text{ m/s}^2$



$$w = \rho g A = 2400 \times 9.81 \times 4 = 94176 \quad (1)$$

$$M_{\max} = \frac{wl^2}{8}$$

from which, $w = \frac{8M_{\max}}{l^2}$ (2)

Now, $\frac{\sigma}{y} = \frac{M_{\max}}{I}$ where $I = \frac{bd^3}{12} = \frac{2 \times 2^3}{12} = 1.333 \text{ m}^4$

$$M_{\max} = \frac{\sigma \times I}{y} = \frac{1 \times 10^6 \times 1.333}{1} = 1.333 \times 10^6 \text{ N m}^2 \quad (3)$$

Substituting equation (3) into equation (2) gives:

$$w = \frac{8M_{\max}}{l^2} = \frac{8 \times 1.333 \times 10^6}{l^2} = \frac{10.664 \times 10^6}{l^2} \quad (4)$$

Equating equations (1) and (4) gives:

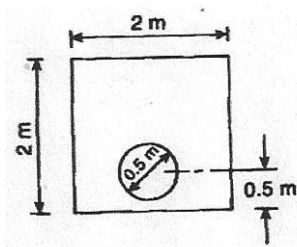
$$w = 94176 = \frac{10.664 \times 10^6}{l^2}$$

from which,
$$l^2 = \frac{10.664 \times 10^6}{94176}$$

$$l = \sqrt{\frac{10.664 \times 10^6}{94176}}$$

and **maximum permissible length of beam, $l = 10.64 \text{ m}$**

2. If the concrete beam of question 1 had a hole in the bottom of its cross-section, as shown below, what would be the maximum permissible length of the beam?



Section	a	y	ay	ay^2	i_o
1	4	1	4	4	1.333
2	-0.196	0.5	-0.098	-0.049	-3.07×10^{-3}
Σ	3.804	-	3.902	3.951	1.33

$$\bar{y} = \frac{\sum ay}{\sum a} = \frac{3.902}{3.804} = 1.026 \text{ m}$$

$$I_{xx} = \sum ay^2 + \Sigma i = 3.951 + 1.33 = 5.281 \text{ m}^4$$

$$I_{NA} = I_{xx} - (\bar{y})^2 \sum a = 5.281 - (1.026)^2 \times 3.804$$

i.e. $I_{NA} = 1.277 \text{ m}^4$

$$M_{max} = 1.2466 \times 10^6 \text{ N m}$$

$$w = \frac{8M_{max}}{l^2} = \frac{8 \times 1.2466 \times 10^6}{l^2} = \frac{9.973 \times 10^6}{l^2}$$

$$w = \rho g A = 2400 \times 9.81 \times (4 - \pi(0.5)^2 / 4) = 2400 \times 9.81 \times 3.804 = 89561.4$$

Hence,
$$89561.4 = \frac{9.973 \times 10^6}{l^2}$$

from which,
$$l^2 = \frac{9.973 \times 10^6}{89561.4}$$

$$l = \sqrt{\frac{9.973 \times 10^6}{89561.4}}$$

and **maximum permissible length of beam, $l = 10.55 \text{ m}$**

3. What would be the maximum permissible length of the beam of questions 1 and 2, if the hole were at the top?

From problem 2,

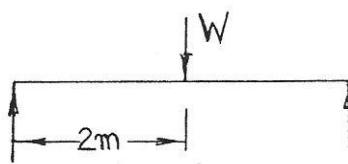
$$I_{NA} = 1.277 \text{ m}^4$$

$$M_{max} = \frac{1 \times 10^6 \times 1.277}{0.974} = 1.311 \times 10^6 \text{ N}\cdot\text{m}$$

$$w = \frac{1.051 \times 10^7}{l^2} = 89561$$

from which, **$l = 10.83 \text{ m}$**

4. A horizontal beam, of length 4 m, is simply supported at its ends and subjected to a vertically applied concentrated load of 10 kN at mid-span. Assuming that the width of the beam is constant and equal to 0.03 m, and neglecting the self-weight of the beam, determine an equation for the depth of the beam, so that the beam will be of uniform strength. The maximum permissible stress in the beam is 100 MN/m^2 .



$$M_{max} = \frac{W}{2} \times x = 5x$$

4

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

i.e.
$$\sigma = \frac{My}{I} = \frac{5x \left(\frac{d}{2} \right)}{\frac{0.03d^3}{12}}$$

i.e.
$$\sigma = \frac{1000x}{d^2}$$

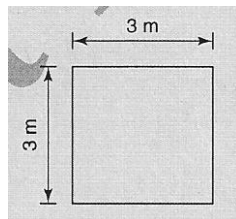
Hence,
$$d^2 = \frac{1000x}{\sigma} = \frac{1000 \times 1000}{100 \times 10^6} x$$

from which,
$$d = \sqrt{0.01x} = 0.1\sqrt{x} \text{ or } 0.1x^{\frac{1}{2}} \text{ from 0 to 2 m}$$

5. A concrete beam of uniform square cross-section, as shown below, is to be lifted by its ends, so that it may be regarded as being equivalent to a horizontal beam, simply supported at its ends and subjected to a uniformly distributed load due to its self-weight. Determine the maximum permissible length of this beam, given the following:

Density of concrete = 2400 kg/m^3 $g = 9.81 \text{ m/s}^2$

Maximum permissible tensile stress in the concrete = 1 MN/m^2



$$w = \rho g A = 2400 \times 9.81 \times 9 = 211896 \quad (1)$$

$$M_{max} = \frac{wl^2}{8} 5$$

from which,
$$w = \frac{8M_{max}}{l^2} \quad (2)$$

Now, $\frac{\sigma}{y} = \frac{M_{\max}}{I}$ where $I = \frac{bd^3}{12} = \frac{3 \times 3^3}{12} = 6.75 \text{ m}^4$

$$M_{\max} = \frac{\sigma \times I}{y} = \frac{1 \times 10^6 \times 6.75}{1.5} = 4.5 \times 10^6 \text{ N m} \quad (3)$$

Substituting equation (3) into equation (2) gives:

$$w = \frac{8M_{\max}}{l^2} = \frac{8 \times 4.5 \times 10^6}{l^2} = \frac{36 \times 10^6}{l^2} \quad (4)$$

Equating equations (1) and (4) gives:

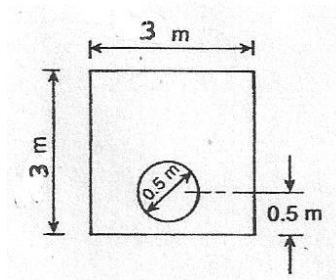
$$w = 211896 = \frac{36 \times 10^6}{l^2}$$

from which, $l^2 = \frac{36 \times 10^6}{211896}$

$$l = \sqrt{\frac{36 \times 10^6}{211896}}$$

and **maximum permissible length of beam, $l = 13.03 \text{ m}$**

6. If the concrete beam of Problem 5 has a hole in the bottom of its cross-section, as shown below, what would be the maximum permissible length of the beam?



Section	a	y	ay	ay^2	i_o
1	9	1.5	13.5	20.25	1.442
2	-0.196	0.5	-0.098	-0.049	-3.07×10^{-3}
Σ	8.804	-	13.402	20.201	1.44

$$\bar{y} = \frac{\sum ay}{\sum a} = \frac{13.402}{8.804} = \mathbf{1.522 \text{ m}}$$

$$I_{xx} = \sum ay^2 + \sum i = 20.201 + 1.44 = 21.641 \text{ m}^4$$

$$I_{NA} = I_{xx} - (\bar{y})^2 \sum a = 21.641 - (1.522)^2 \times 8.804$$

i.e. $I_{NA} = \mathbf{3.016 \text{ m}^4}$

$$M_{max} = \frac{wl^2}{8}$$

from which, $w = \frac{8M_{max}}{l^2}$

Now, $\frac{\sigma}{y} = \frac{M_{max}}{I}$

and $M_{max} = \frac{\sigma \times I}{y} = \frac{1 \times 10^6 \times 3.016}{1.522} = 1.98 \times 10^6 \text{ N m}$

But $w = \frac{8M_{max}}{l^2} = \frac{8 \times 1.98 \times 10^6}{l^2} = \frac{15.84 \times 10^6}{l^2}$ (1)

Also, $w = \rho ga = 2400 \times 9.81 \times 8.804 = 207281$ (2)

Equating equations (1) and (2) gives:

$$\frac{15.84 \times 10^6}{l^2} = 207281$$

from which, $l = \sqrt{\frac{15.84 \times 10^6}{207281}} = 8.74 \text{ m}$

i.e. **the maximum permissible length of the beam = 8.74 m**

7. What would be the maximum permissible length of the beam in problem 5, if the hole were at the top?

From Problem 6, $I_{NA} = \mathbf{3.016 \text{ m}^4}$

$$\bar{y} = 3 - 1.522 = \mathbf{1.478 \text{ m}}$$

$$M = \frac{\sigma \times I}{y} = \frac{1 \times 10^6 \times 3.016}{1.478} = 2.04 \times 10^6 \text{ N m}$$

$$w = \frac{8M}{l^2} = \frac{8 \times 2.04 \times 10^6}{l^2} = \frac{16.325 \times 10^6}{l^2} \quad (1)$$

$$\text{From Problem 6, } w = 207281 \quad (2)$$

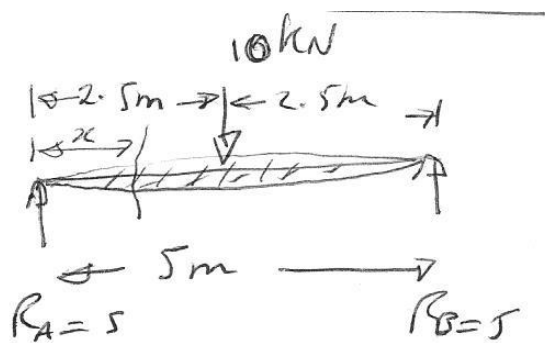
Equating equations (1) and (2) gives:

$$\frac{16.325 \times 10^6}{l^2} = 207281$$

$$\text{from which, } l = \sqrt{\frac{16.325 \times 10^6}{207281}} = 8.875 \text{ m}$$

i.e. **the maximum permissible length of the beam = 8.875 m**

8. The horizontal beam, of length 5 m, is simply supported at its ends and subjected to a vertically applied concentrated load of 10 kN at mid-span. Assuming that the width of the beam is constant and equal to 0.04 m, and neglecting the self-weight of the beam, determine an equation for the depth of the beam, so that the beam will be of uniform strength. The maximum permissible stress in the beam is 100 MN/m^2 .



$$\text{At } x, \quad M = 5x \quad (1)$$

$$d = \text{depth of beam} = 2y$$

$$\frac{\sigma}{y} = \frac{M}{I} \quad \text{i.e.} \quad \frac{100 \times 10^6}{y} = \frac{5 \times 10^3 x}{0.04 \times \frac{(2y)^3}{12}}$$

from which,

$$\frac{y^3}{y} = \frac{5 \times 10^3 x}{100 \times 10^6 \times 0.04 \times \frac{8}{12}}$$

i.e.

$$y^2 = 1.875 \times 10^{-3} x$$

and

$$y = \sqrt{1.875 \times 10^{-3} x} = 0.0433 x^{0.5}$$

Hence, **depth of beam, $d = 2y = 0.087 x^{0.5}$**

EXERCISE 30, Page 141

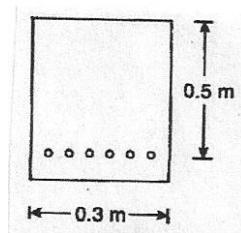
1. The cross-section of a reinforced concrete beam is as shown below. Determine the maximum bending moment that this beam can sustain, assuming that the steel reinforcement is on the tensile side and that the following apply:

Maximum permissible compressive stress in concrete = 10 MN/m^2

Maximum permissible tensile stress in steel = 200 MN/m^2

Modular ratio = 15 Diameter of a steel rod = 2 cm

n = number of steel rods = 6



$$A_s = 1.885 \times 10^{-3} \text{ m}^2$$

From equation (6.12) in the textbook,

$$\begin{aligned} H &= \sqrt{(mA_s / B)^2 + 2mDA_s / B} - mA_s / B \\ &= \sqrt{(15 \times 1.885 \times 10^{-3} / 0.3)^2 + 2 \times 15 \times 0.5 \times 1.885 \times 10^{-3} / 0.3} - 15 \times 1.885 \times 10^{-3} / 0.3 \\ &= \sqrt{8.883 \times 10^{-3} + 0.09425} - 0.09425 \end{aligned}$$

i.e. $H = 0.227 \text{ m}$

From equation (6.13) in the textbook,

$$\sigma_s = \frac{M}{A_s [(D - H) + 2H / 3]} = \frac{M}{A_s [(D - H / 3)]}$$

i.e. $200 \times 10^6 = \frac{M}{1.885 \times 10^{-3} [(0.5 - 0.227 / 3)]}$

from which, $M = 200 \times 10^6 \times 1.885 \times 10^{-3} [(0.5 - 0.227 / 3)]$

i.e. $M = 0.16 \text{ MN m}$

From equation (6.14) in the textbook,

$$\sigma_c = \frac{2M}{BH(D - H/3)}$$

i.e. $10 \times 10^6 = \frac{2M}{0.3 \times 0.227(0.5 - 0.227/3)} = \frac{2M}{0.0289}$

from which, $M = 10 \times 10^6 \times \frac{0.0289}{2}$

i.e. $M = 0.145 \text{ MN m}$

i.e. **the maximum bending moment, M (permissible) = 0.145 MN m**

2. The cross-section of a reinforced concrete beam is as shown below. Determine the maximum bending moment that this beam can sustain, assuming that the steel reinforcement is on the tensile side and that the following apply:

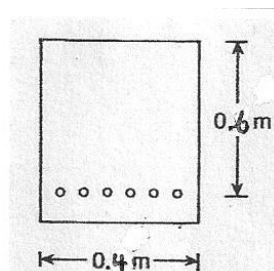
Maximum permissible compressive stress in concrete = 10 MN/m^2

Maximum permissible tensile stress in steel = 200 MN/m^2

Modular ratio = 14

Diameter of a steel rod = 2 cm

n = number of steel rods



From problem 1, $A_s = 1.885 \times 10^{-3} \text{ m}^2$

From equation (6.12) in the textbook,

$$H = \sqrt{(mA_s / B)^2 + 2mDA_s / B} - mA_s / B$$

$$= \sqrt{\left(14 \times 1.885 \times 10^{-3} / 0.4\right)^2 + 2 \times 14 \times 0.6 \times 1.885 \times 10^{-3} / 0.4} - 14 \times 1.885 \times 10^{-3} / 0.4$$

$$= \sqrt{4.353 \times 10^{-3} + 0.07917} - 0.066 = 0.289 - 0.066$$

i.e. **$H = 0.223 \text{ m}$**

From equation (6.13) in the textbook,

$$\sigma_s = \frac{M}{A_s [(D-H) + 2H/3]} = \frac{M}{A_s [(D-H/3)]}$$

from which, $M = 200 \times 10^6 \times 1.885 \times 10^{-3} [(0.6 - 0.223/3)]$

i.e. **$M = 0.198 \text{ MN m}$**

From equation (6.14) in the textbook,

$$\sigma_c = \frac{2M}{BH(D-H/3)}$$

i.e. $10 \times 10^6 = \frac{2M}{0.4 \times 0.223(0.6 - 0.223/3)} = \frac{2M}{0.0469}$

from which, $M = 10 \times 10^6 \times \frac{0.0469}{2}$

i.e. **$M = 0.235 \text{ MN m}$**

i.e. the maximum bending moment, M (permissible) = 0.198 MN m

EXERCISE 31, Page 145

1. (a) A wooden beam of rectangular section is 12 cm depth and 6 cm width. Determine the moment of resistance of this section, given the following: $E_{wood} = 1.4 \times 10^{10} \text{ N/m}^2$ and $\sigma_{wood} = 20 \text{ MPa}$

(b) What percentage increase will there be in the moment of resistance of this beam section if it is reinforced by a 6 mm thick galvanised steel plate attached to the top and bottom surfaces of the beam, one plate at the bottom and the other plate at the top. Assume the following:

$$E_{steel} = 2 \times 10^{11} \text{ N/m}^2 \text{ and } \sigma_{steel} = 150 \text{ MPa}$$

$$(a) \quad I = \frac{6 \times 10^{-2} (12 \times 10^{-2})^3}{12} = 8.64 \times 10^{-6} \text{ m}^4$$

$$\bar{y} = 6 \times 10^{-2} \text{ m}$$

$$\frac{\sigma}{y} = \frac{M}{I} \quad \text{i.e.} \quad M = \frac{\sigma I}{y} = \frac{20 \times 10^6 \times 8.64 \times 10^{-6}}{6 \times 10^{-2}}$$

$$\text{i.e. } M = 2880 \text{ N m}$$

$$(b) \quad R_s = R_w \quad \text{or} \quad \frac{\sigma_s}{E_s y_s} = \frac{\sigma_w}{E_w y_w}$$

$$\begin{aligned} \text{from which,} \quad \sigma_s &= \frac{E_s y_s \sigma_w}{E_w y_w} = \frac{2 \times 10^{11} \times 5.3 \times 10^{-2} \sigma_w}{1.4 \times 10^{10} \times 6 \times 10^{-2}} \\ &= 12.62 \sigma_w \end{aligned}$$

$$\text{Therefore,} \quad 150 \equiv 12.62 \times 20 \equiv 252.4$$

Hence, 150 MN/m^2 is taken, so that σ_s is design criterion

$$\sigma_s = 150 \text{ MPa} \text{ and } \sigma_w = 11.89 \text{ MPa}$$

$$M_w = 2880 \times \frac{11.89}{20} = 1711.6 \text{ N m}$$

$$I_s = 6 \times 10^{-2} \times 6 \times 10^{-3} \times (6.3 \times 10^{-2})^2 \times 2$$

$$= 2.858 \times 10^{-6} \text{ m}^4$$

$$M_s = \frac{150 \times 10^6 \times 2.858 \times 10^{-6}}{6.3 \times 10^{-2}} = 6804 \text{ N m}$$

Percentage increase in bending resistance

$$= \left(\frac{6804 - 2880}{2880} \right) \times 100\%$$

$$= \mathbf{136.3\%}$$

EXERCISE 32, Page 149

1. A short steel column, of circular cross-section, has an external diameter of 0.4 m and a wall thickness of 0.1 m and carries a compressive but axially applied eccentric load. Two linear strain gauges, which are mounted longitudinally at opposite sides on the external surface of the column but in the plane of the load, record strains of 50×10^{-6} and -200×10^{-6} . Determine the magnitude and eccentricity of the axial load. Assume that $E = 2 \times 10^{11} \text{ N/m}^2$.

$$\varepsilon_1 = \varepsilon_d - \varepsilon_b \quad (1)$$

$$\varepsilon_2 = \varepsilon_d + \varepsilon_b \quad (2)$$

Adding equations (1) and (2) gives:

$$\varepsilon = 2 \varepsilon_d = 50 \times 10^{-6} - 200 \times 10^{-6}$$

from which, $\varepsilon_d = -75 \times 10^{-6}$

Hence, $\sigma_d = \varepsilon_d \times E = -75 \times 10^{-6} \times 2 \times 10^{11} = -15 \text{ MN/m}^2$

Now,
$$W = -15 \times \pi \left(\frac{0.4^2 - 0.2^2}{4} \right) = -1.414 \text{ MN}$$

$$\varepsilon_2 - \varepsilon_1 = 2\varepsilon_b = 250 \times 10^{-6}$$

from which, $\varepsilon_b = 125 \times 10^{-6}$

and $\sigma_b = \pm 25 \text{ MN/m}^2$

Now,
$$\frac{\sigma}{y} = \frac{M}{I}$$

from which,
$$M = \frac{\sigma I}{y} = \frac{25}{0.2} \times \frac{\pi(0.4^2 - 0.2^2)}{64} = 0.1473 \text{ MN m}$$

i.e. $0.1473 = W\Delta = 1.414\Delta$

i.e. **eccentricity of the axial load, $\Delta = 0.1473/1.414 = 0.104 \text{ m}$**

2. Determine the maximum tensile and compressive stresses in the clamp shown.

The diagram illustrates a C-clamp and its cross-section. The top part shows the C-clamp with a 1 kN force applied to the handle. A vertical dashed line labeled 'A-A' indicates the section line. The distance from the handle to the center of the C-shape is 12 cm. The bottom part shows the cross-section 'Section through AA', which is an L-shape. The vertical leg has a height of 3 cm and a thickness of 0.5 cm. The horizontal leg has a width of 2 cm and a thickness of 0.5 cm.

Section	a	y	ay	ay^2	i_o
1	1.5	2	3	6	1.125
2	1.0	0.25	0.25	0.0625	0.021
Σ	2.5	—	3.25	6.0625	1.146

$$\bar{y} = \frac{3.25}{2.5} = 1.3 \text{ cm} = 1.3 \times 10^{-3} \text{ m}$$

$$A = 2.5 \text{ cm}^2 = 2.5 \times 10^{-4} \text{ m}^2$$

$$I_{XX} = 6.063 + 1.15 = 7.213 \text{ cm}^4$$

$$I_{NA} = 2.983 \text{ cm}^4 = 2.983 \times 10^{-8} \text{ m}^4$$

$$M = 1 \text{ kN} \times 0.133 = \mathbf{0.133 \text{ kN m}}$$

$$\sigma_d = \frac{1 \text{ kN}}{2.5 \times 10^{-4}} \cdot 11 = \mathbf{4 \text{ MN/m}^2}$$

$$\sigma_{\text{bottom}} = \frac{M \bar{y}}{I} = \frac{0.133 \times 10^3 \times 1.3 \times 10^{-2}}{2.983 \times 10^{-8}} + 4 \cdot 12$$

i.e. $\sigma_{\text{bottom}} = \mathbf{61.96 \text{ MN/m}^2}$

$$\sigma_{\text{top}} = \frac{-0.133 \times 10^3 \times 0.022}{2.983 \times 10^{-8}} + 4 \cdot \frac{-0.133 \times 10^3 \times 0.022}{2.983 \times 10^{-8}} + 4 \cdot 13$$

i.e. $\sigma_{\text{top}} = \mathbf{-94.1 \text{ MN/m}^2}$

i.e. $\sigma_{\text{top}} = -94.1 \text{ MN/m}^2$

3. A short steel column, of circular cross-section, has an external diameter of 0.5 m and a wall thickness of 0.1 m and carries a compressive but axially applied eccentric load. Two linear strain gauges, which are mounted longitudinally at opposite sides on the external surface of the column but in the plane of the load, record strains of 60×10^{-6} and -300×10^{-6} . Determine the magnitude and eccentricity of the axial load. Assume that $E = 2 \times 10^{11} \text{ N/m}^2$.

$$\varepsilon_1 = \varepsilon_d - \varepsilon_b \quad (1)$$

$$\varepsilon_2 = \varepsilon_d + \varepsilon_b \quad (2)$$

Adding equations (1) and (2) gives:

$$\varepsilon = 2 \varepsilon_d = 60 \times 10^{-6} - 300 \times 10^{-6}$$

from which, $\varepsilon_d = -120 \times 10^{-6}$

Hence, $\sigma_d = \varepsilon_d \times E = -120 \times 10^{-6} \times 2 \times 10^{11} = -24 \text{ MN/m}^2$

Now, $W = -24 \times \pi \left(\frac{0.5^2 - 0.3^2}{4} \right) = -3.016 \text{ MN}$

$$\varepsilon_2 - \varepsilon_1 = 2\varepsilon_b = 360 \times 10^{-6}$$

from which, $\varepsilon_b = 180 \times 10^{-6}$

and $\sigma_b = \varepsilon_b \times E = 180 \times 10^{-6} \times 2 \times 10^{11} = \pm 36 \text{ MN/m}^2$

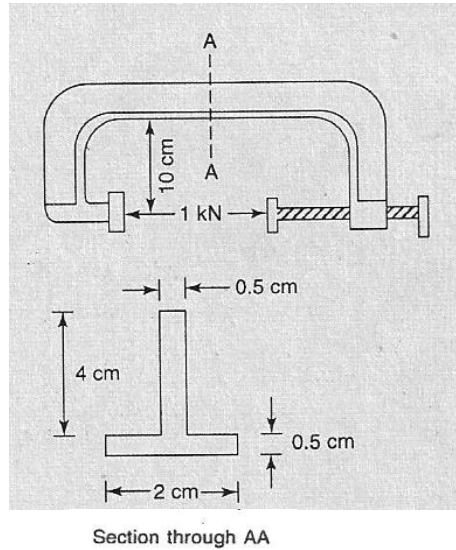
Now, $\frac{\sigma}{y} = \frac{M}{I}$

from which, $M = \frac{\sigma I}{y} = \frac{36}{0.2} \times \frac{\pi(0.5^2 - 0.3^2)}{64} = 1.4137 \text{ MN m}$

i.e. $1.4137 = WA = 3.016A$

i.e. **eccentricity of the axial load, $A = 1.4137/3.016 = 0.469 \text{ m}$**

4. Determine the maximum tensile and compressive stresses in the clamp shown.



Section	a	y	ay	ay^2	i_o
1	2×10^{-4}	2.5×10^{-2}	5×10^{-6}	1.25×10^{-7}	$\frac{0.5 \times 10^{-2} \times (4 \times 10^{-2})^3}{12} = 2.67 \times 10^{-8}$
2	1×10^{-4}	0.25×10^{-2}	2.5×10^{-7}	6.25×10^{-10}	$\frac{(0.5 \times 10^{-2})^3 \times 2 \times 10^{-2}}{12} = 2.08 \times 10^{-10}$
Σ	3×10^{-4}	—	5.25×10^{-6}	1.256×10^{-7}	2.69×10^{-8}

$$\bar{y} = \frac{\sum ay}{\sum a} = \frac{5.25 \times 10^{-6}}{3 \times 10^{-4}} = 0.0175 \text{ m}$$

$$I_{XX} = \sum ay^2 + \sum i_o = 1.256 \times 10^{-7} + 2.69 \times 10^{-8} = 1.525 \times 10^{-7} \text{ m}^4$$

$$I_{NA} = I_{XX} - (\bar{y})^2 \sum a = 1.525 \times 10^{-7} - (0.0175)^2 \times 3 \times 10^{-4}$$

$$= 6.063 \times 10^{-8} \text{ m}^4$$

$$M = 1 \times 10^3 \times (10 \times 10^{-2} + 0.0175) = \mathbf{117.5 \text{ N m}}$$

$$\sigma_{top} = \frac{-117.5 \times (4.5 \times 10^{-2} - 0.0175)}{6.063 \times 10^{-8}} + \frac{1 \times 10^3}{3 \times 10^{-4}}$$

$$= -53.32 \text{ MPa} + 3.33 \text{ MPa} = \mathbf{-50 \text{ MPa}}$$

i.e. $\sigma_{top} = -50 \text{ MPa}$ compressive

$$\sigma_{\text{bottom}} = \frac{117.5 \times 0.0175}{6.063 \times 10^{-8}} + 3.33$$

$$= 33.91 + 3.3316$$

i.e. $\sigma_{\text{bottom}} = \mathbf{37.24 \text{ MPa}}$ tensile
