Exemplar examination paper

QUESTION 1

1.1 Draw a stress/strain graph of a mild-steel specimen being tested for failure when under tension. Indicate the following:

1.1.1 The proportional limit

1.1.2 The elastic limit

1.1.3 The yield point

1.1.4 The maximum load point (ultimate tensile strength)

1.1.5 The point of fracture

1.2 The mechanical properties of an aluminium alloy is analysed using a tensile testing machine as shown in Figure 1. The test piece is 13 mm in diameter and has a gauge length of 70 mm.

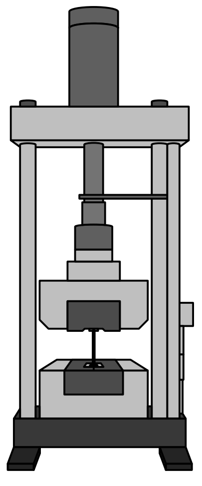


Figure 1

The following results were obtained in the test:

- Load at proportional limit = 32 kN
- Extension at l proportional limit = 0,22 mm
- Maximum load = 70 kN
- Fracturing load = 52 kN
- Extension at fracture = 8,33 mm
- Diameter at fracture = 10,45 mm

Calculate the following:

1.2.1 The stress at the proportional limit

1.2.2 Young's modulus of elasticity

1.2.3 The ultimate stress

1.2.4 The fracturing stress

1.2.5 The percentage elongation

In these calculations: M = 10^6; k = 10^3 and G = 10^9

QUESTION 2

The steel bar shown in Figure 2 consists of two sections. One section has a length of 90 mm with a diameter of 50 mm, and the other section has a diameter of 70 mm. A strain energy of 12 J is developed when a large ship piston of 2 038 kg is hung onto the steel bar. E = 215 GPa.

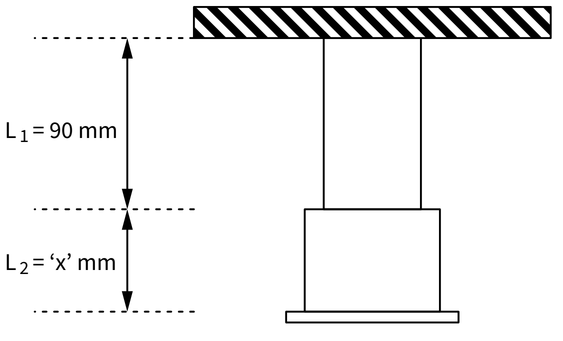


Figure 2

Refer to Figure 2 and the details given. Calculate:

1.1 The length of the 70-mm diameter section

1.2 The total change in length caused by the ship piston

1.3 The total strain in the bar

1.4 The maximum stress in the bar

QUESTION 3

3.1 The compound bar shown in Figure 3 is used in a machine frame and consists of a parallel steel bar and copper bar. The compound bar undergoes a compressive load of 65 kN and is 127 mm long. (The steel bar and copper bar are equal in length).

The steel bar is 15 mm in diameter and Young's modulus is 215 GPa.

The copper bar is 20 mm in diameter and Young's modulus is 145 GPa

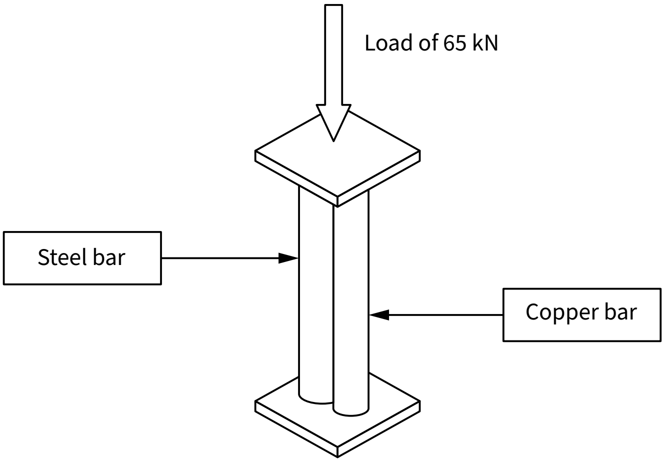


Figure 3

Calculate:

3.1.1 The stress in each material when loaded by 65 kN

3.1.2 The final length of the compound bar under the given conditions

3.2 The compound bar mentioned in Question 3.1 was left loaded throughout the night. The temperature surrounding the compound bar dropped from 35°C to –2°C.

Refer to your calculations in Question 2.1 and calculate the following:

3.2.1 The resultant stress developed in each material when considering the 65 kN load and the change in temperature.

3.2.2 The final length of the compound bar under both of the conditions mentioned.

QUESTION 4

A steel boiler drum with a wall thickness of 18 mm is designed to withstand an internal pressure of 3 MPa. The drum is joined circumferentially and longitudinally by rivets, each with a joint efficiency of 52% and 85% respectively. E = 200 GPa and Poisson's ratio is 0,3. The allowable stress in the steel material must not exceed 150 MPa.

4.1 Calculate the allowable internal diameter for the boiler drum. Also motivate why you have chosen that specific internal diameter.

4.2 Calculate the following in the cylinder:

4.2.1 The longitudinal strain

4.2.2 The circumferential strain

4.2.3 The change in volume if the length of the boiler is 3 m.

4.3 The stresses acting at a point in the drum can be represented by the common perpendicular tensile stresses: on the Y-face 150 MPa and on the X-face 122,6 MPa in the same plane.

Use Mohr's circle and determine the normal stresses on the *x*- and *y*-faces on a plane inclined at 65° to the *xx*-axis.

QUESTION 5

Figure 4 shows a built-up beam consisting of a channel and a parallel flange I-section, and acting as a simply supported beam. The length of the beam is 1,2 m with a uniformly distributed load of 25 kNm applied over the full span of the beam. A point load of 17 kN is also applied at the midpoint of the beam. Ignore the weight of the beam in your calculations.

- Channel: $300 \times 100 \times 46{,}2$ kg/m
- I-section: $254 \times 146 \times 43{,}2$ kg/m

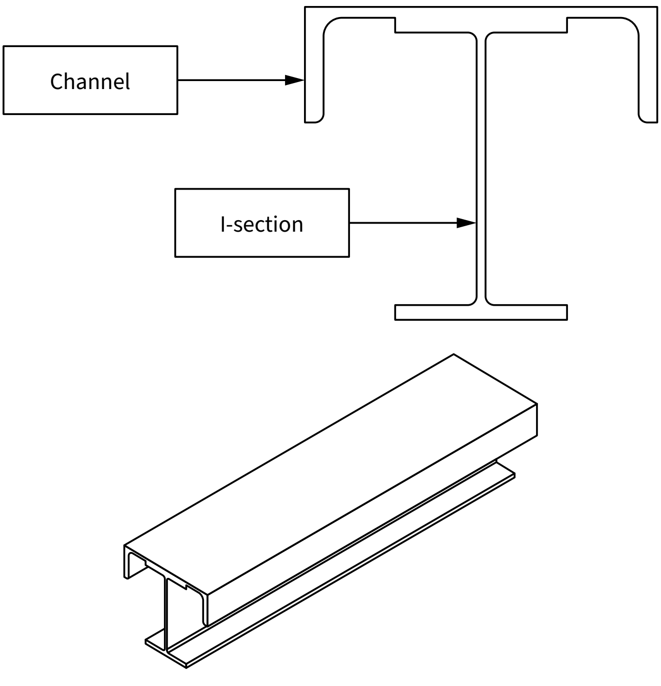


Figure 4

Refer to the given data and Figure 4 to calculate the following:

5.1 The bending moment subjected to the built-up beam

5.2 The position of the *xx*-axis

5.3 The bending resistance of the *xx*-axis (2nd moment of area)

5.4 The maximum and minimum bending stress about the *xx*-axis

QUESTION 6

6.1 A solid shaft of 1,55 m is used as a tractor propeller (prop) shaft. The shaft twists through 1,8° while rotating at 900 rpm. The diameter of the shaft is 60 mm and the modulus of rigidity is 85 GPa.

Calculate:

6.1.1 The maximum shear stress in the shaft

6.1.2 The power transmitted by the shaft

6.2 The tractor had undergone minor modifications to increase the transmitted power by 20%. The solid shaft is replaced by a lighter, hollow shaft of the same material, with a diameter ratio of 2:1.

Calculate the suitable diameters of the hollow shaft.

QUESTION 7

Indicate whether the following statements regarding mechanical testing and properties of materials are TRUE or FALSE. Choose the answer and write only 'True" or "False" next to the question number (7.1–7.5) in your ANSWER BOOK.

7.1 Strain is the ratio with which the length changes compared to its original length.

7.2 Hardness is the resistance that the surface of the material offers to indentation.

7.3 The Rockwell hardness test includes a hardened steel ball which is pressed into the surface of a material under a certain force.

7.4 Creep is when a material under stress deforms over time.

7.5 Young's modulus is also known as the modulus of rigidity.

QUESTION 8

FIGURE 5 below is a column made up of FOUR angle irons welded together. The column is used to carry the weight of shipping components at the dock. The column is 3 m in length with one end fixed and one end free.

E = 200 GPa for all members of the column.

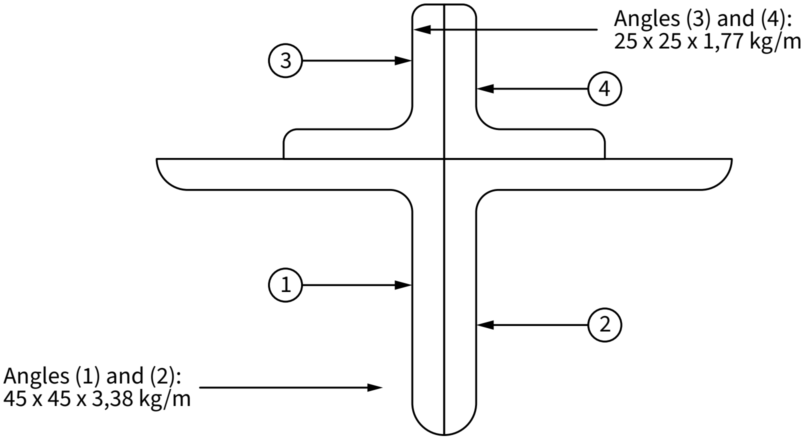


Figure 5

Position of neutral axis about the *xx*-axis	39,354 mm
Position of neutral axis about the *yy*-axis	45 mm
Position of neutral axis about the *uu*-axis and *vv*-axis	29,943 mm

Calculate the maximum buckling load that the column will be able to handle by using the Euler equation and the above tabulated data.

QUESTION 9

Graphically determine the magnitude and type of force acting in the following members of the simply supported cantilever frame shown in Figure 6.

Members:

- The reaction at the fixed support
- AF
- EF
- GH

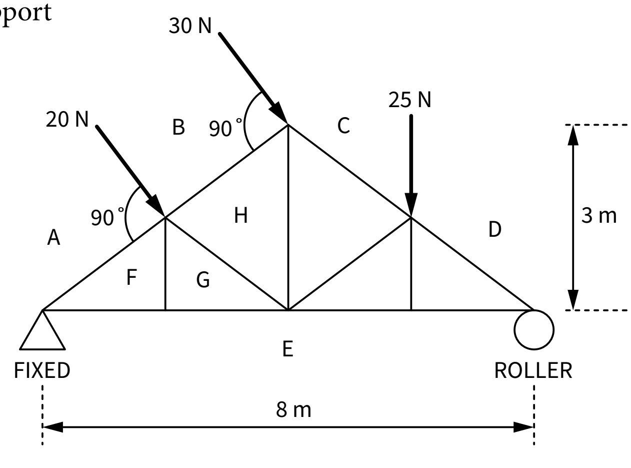
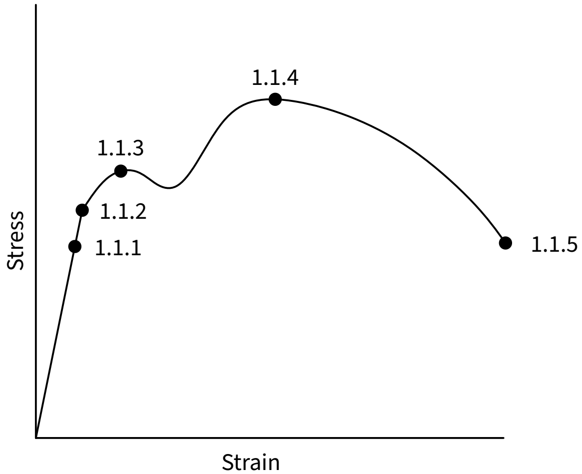


Figure 6

Exemplar examination paper memorandum

QUESTION 1

1.1



1.1.1 Proportional limit
1.1.2 Elastic limit
1.1.3 Yield point
1.1.4 Maximum load point
1.1.5 Point of fracture

1.2 1.2.1 The stress at the proportional limit (lop)

$$\sigma = \frac{F}{A} = \frac{32k \times 4}{\pi \times 0{,}013^2} = 241{,}087 \text{ MPa}$$

1.2.2 Young's modulus of elasticity

$$E = \frac{\sigma_{lop} \times l}{x_{lop}} = \frac{241{,}087M \times 0{,}07}{0{,}22 \times 10^{-3}} = 76{,}71 \text{ GPa}$$

1.2.3 The ultimate tensile strength

$$\sigma_{ult} = \frac{F_{ult}}{A} = \frac{70k \times 4}{\pi 0{,}013^2} = 527r, 377 \text{ MPa}$$

1.2.4 The fracture stress

$$\sigma_{frac} = \frac{F_{frac}}{A} = \frac{52k \times 4}{\pi 0{,}013^2} = 391{,}766 \text{ MPa}$$

1.2.5 The percentage elongation

$$\%X = \frac{x}{l} = \frac{8{,}33}{70} \times \frac{100}{1} = 11{,}9 \ \%$$

QUESTION 2

2.1 The length of 70 mm diameter section:

$$U_T = U_1 + U_2 = 0{,}5F x_1 + 0{,}5F x_2 = 0{,}5F\left(\frac{FL_1}{A_1 E} + \frac{FL_2}{A_2 E}\right)$$

$$\therefore 12 = \frac{0{,}5F^2}{215G}\left(\frac{0{,}9 \times 4}{\pi \times 0{,}05^2} + \frac{L_2 \times 4}{\pi \times 0{,}07^2}\right)$$

$$\therefore \frac{12 \times 215G}{0{,}5(2\,038 \times 9{,}81)^2} = 45{,}837 + 259{,}845L_2$$

$$\therefore L_2 = \frac{12\,909{,}319 - 45{,}837}{259{,}845} = 49{,}504 \text{ m}$$

2.2 The total change in length

$$U_T = 0{,}5F x_T \therefore X_T = \frac{12}{0{,}5(2\,038 \times 9{,}81)} = 1{,}2 \text{ mm}$$

2.3 The total strain

$$\varepsilon_T = \varepsilon_1 + \varepsilon_2 = \left(\frac{x}{L}\right)_1 + \left(\frac{x}{L}\right)_2 = \frac{FL_1}{L_1 A_1 E} + \frac{FL_2}{L_2 A_2 E}$$

$$\therefore \varepsilon_T = \frac{F}{E}\left(\frac{1}{A_1} + \frac{1}{A_2}\right) = \frac{2\,038 \times 9{,}81}{215G}\left(\frac{4}{\pi \times 0{,}05^2} + \frac{4}{\pi \times 0{,}07^2}\right) = 7{,}152 \times 10^{-5}$$

2.4 The maximum stress in the smallest area

$$\therefore \sigma_{max} = \frac{F}{A} = \frac{2\,038 \times 9{,}81 \times 4}{\pi \times 0{,}05^2} = 10{,}182 \text{ MPa}$$

QUESTION 3

3.1 3.1.1 The stress in each material under load 65 kN

$$F_T = 65k = F_c + F_s \ldots (1)$$

$$\text{And: } x_c = x_s \therefore \frac{F_C L_c}{A_c E_c} = \frac{F_s L_s}{A_s E_s} \; (L_c = L_s)$$

$$\div \text{by L:} \therefore F_c = \frac{F_s A_c E_c}{A_s E_s} = \frac{F_s \times 0{,}02^2 \times 145}{0{,}015^2 \times 215}$$

$$\therefore F_c = 1{,}199F_s \ldots (2)$$

Substitute: (2) into (1) $\therefore 65k = 1{,}199F_s + F_s$

$\therefore F_s = 29{,}559$ kN

$F_c = 29{,}559k \times 1{,}199 = 35{,}441$ kN

$$\sigma_s = \frac{F_s}{A_s} = \frac{29\,559 \times 4}{\pi \times 0{,}015^2} = 167{,}27 \text{ MPa (C)}$$

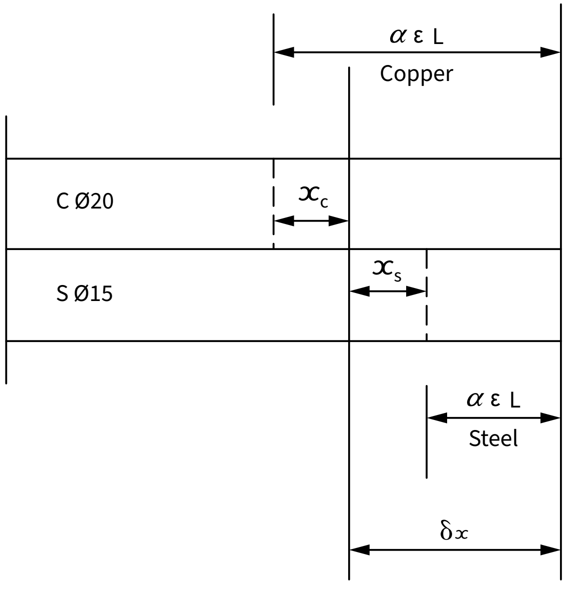
$$\sigma_c = \frac{F_c}{A_c} = \frac{35\,441 \times 4}{\pi \times 0{,}02^2} = 112{,}812 \text{ MPa (C)}$$

3.1.2 Final length: L_F

$$x_c = x_s \therefore X_C = \frac{\sigma_c L_c}{E_c} = \frac{112{,}812M \times 0{,}127}{145G} = 0{,}098 \text{ mm}$$

$$\therefore L_F = L_{original} + x_c = 127 + 0{,}098 = 127{,}098 \text{ mm}$$

3.2.1



$$\delta_{XC} = \delta_{XS}$$

$$\therefore (\alpha tL)_c - x_c = (\alpha tL)_s + x_s$$

$$\therefore X_s + X_c = (\alpha tL)_c - (\alpha tL)_s$$

$$\therefore \frac{F_s L}{A_s E_s} + \frac{F_c L}{A_c E_c} = tL(\alpha_c - \alpha_S)$$

$$\div L: \frac{F_s \times 4}{\pi \times 0{,}015^2 \times 215G} + \frac{F_c \times 4}{\mu \times 0{,}02^2 \times 145G} = 37(18 - 12)\,10^{-6}$$

$$\therefore 2{,}632 \times 10^{-8} F_s + 2{,}195 \times 10^{-8} F_c = 2{,}22 \times 10^{-4}$$

$$\therefore F_s = F_c = 4{,}599 \text{ kN}$$

$$\therefore \sigma_c = \frac{4\,599 \times 4}{\pi \times 0{,}02^2} = 14{,}639 \text{ MPa (T)}$$

$$\therefore \sigma_s = \frac{4\,599 \times 4}{\pi \times 0{,}015^2} = 26{,}025 \text{ MPa (C)}$$

The resultant stresses: load and temperature

$$\sigma_{RC} = \sigma_L - \sigma_T = 112{,}812 - 14{,}639 = 98{,}173 \text{ MPa (C)}$$

$$\sigma_{RS} = \sigma_L + \sigma_T = 167{,}27 + 26{,}025 = 193{,}295 \text{ MPa (C)}$$

3.2.2 The final length after load and temperature

$$\therefore x_T = \delta_{xc} = (\alpha tL)_c - x_c = \left(18 \times 10^{-6} \times 37 \times 0{,}127\right) - \left(\frac{F_c L_c}{A_c E_c}\right)$$

$$\therefore X_T = 8{,}458 \times 10^{-5} - \left(\frac{4\,599 \times 0{,}127 \times 4}{\pi \times 0{,}02^2 \times 145G}\right) = 0{,}072 \text{ m}$$

The final length:

$$L_{final} = L_{original} + x_{load} - X_{temp} = 127 + 0{,}098 - 0{,}072 = 127{,}026 \text{ mm}$$

QUESTION 4

4.1 The allowable stress means it must be taken for longitudinal stress as well as tensile stress or hoop stress.

Considered as tensile stress:

$$\therefore \sigma_t = \frac{p_i D}{2t\cap_L} = 150M = \frac{3Md}{2 \times 0{,}018 \times 0{,}85}$$

$$\therefore d = \frac{150M \times 2 \times 0{,}018 \times 0{,}85}{3\ M} = 1{,}53 \text{ m}$$

Considered as longitudinal stress:

$$\therefore \sigma_L = \frac{p_i D}{4t\cap_c} = 150M = \frac{3Md}{4 \times 0{,}018 \times 0{,}52}$$

$$\therefore d = \frac{150M \times 4 \times 0{,}018 \times 0{,}52}{3M} = 1{,}872 \text{ m}$$

Use a diameter of 1,53 m. Because of a diameter of 1,872 m, the tensile stress will be more than 150 MPa and the cylinder will fail.

4.2.1 The longitudinal strain

Longitudinal stress for the diameter of 1,53 m:

$$\therefore \sigma_L = \frac{pd}{4t\cap_c} = \frac{3M \times 1{,}53}{4 \times 0{,}018 \times 0{,}52} = 122{,}6 \text{ MPa}$$

$$\text{Longitudinal strain} = \varepsilon_L = \frac{(\sigma_L - \gamma\sigma_H)}{E}$$

$$\varepsilon_L = \frac{(122{,}6M - 0{,}3 \times 150M)}{200G} = 3{,}88 \times 10^{-4}$$

4.2.2 The circumferential strain

$$\text{Circumferential or hoop strain} = \varepsilon_H = \frac{(\sigma_H - \gamma\sigma_L)}{E}$$

$$\varepsilon_H = \frac{(150M - 0{,}3 \times 122{,}6M)}{200G} = 5{,}661 \times 10^{-4}$$

4.2.3 The change in volume

Original volume = $V = \frac{\pi d^2 L}{4}$

$V = \frac{\pi \times 1{,}53^2 \times 3}{4} = 5{,}516 \text{ m}^3$

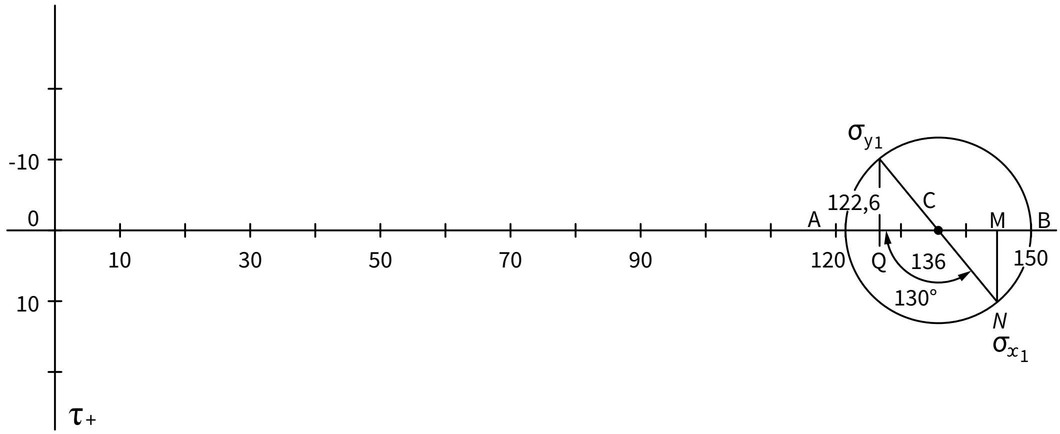
Change in volume = $\delta_V = \frac{pdV}{4tE}(5 - \gamma 4)$

$\delta_V = \frac{3M \times 1{,}53 \times 5{,}516}{4 \times 0{,}018 \times 200G}(5 - 0{,}3 \times 4) = 6{,}681 \times 10^{-3} \text{ m}^3$

4.3 Mohr's circle

Scale: 1 cm = 10 MPa

$C = \frac{150 + 122}{2} = 136{,}3 \text{ MPa}$



Normal stress on X face = σ_{X1} = 141 MPa (T)

Normal stress on Y face = σ_{Y1} = 127 MPa (T)

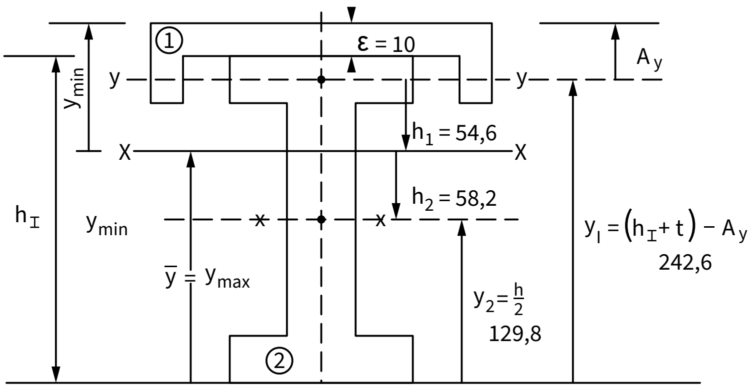
QUESTION 5

5.1 The bending moment for beam

$\therefore M_{max} = M_{pl} + M_{udl} = \frac{WL}{4} + \frac{wL^2}{8}$

$M_{max} = \frac{17k \times 1{,}2}{4} + \frac{25k \times 1{,}2^2}{8} = 8{,}1 \text{ kNm}$

5.2 The position of the *xx*-axis



$\bar{y} A_T = \Sigma$area moments

$y_2 = \frac{h_{\text{I-section}}}{2} = \frac{259,6}{2} = 129,8$ mm

$y_1 = \left(h_{\text{I-section}} + t - A_y\right) = 259,6 + 10 - 27 = 242,6$ mm

Number	**Area**	**Y**	**A × *y***
1	$5,876 \times 10^{-3}$	0,2426	$1,426 \times 10^{-3}$
2	$5,501 \times 10^{-3}$	0,1298	$7,14 \times 10^{-4}$
Total area	$11,377 \times 10^{-3}$	ΣArea moments	$2,14 \times 10^{-3}$

$\bar{y} = \frac{\Sigma\text{area moments}}{\text{total area}} = \frac{2,14 \times 10^{-3}}{11,377 \times 10^{-3}} = 188$ mm

5.3 The bending moment resistance (moment of inertia)

From drawing at Question 5.2:

$h_1 = y - \bar{y} = 242,6 - 188 = 54,6$ mm

$h_2 = \bar{y} - y_2 = 188 - 129,8 = 58,2$ mm

$I_{xx\text{ total}} = \left(I_{1\,yy} + A_1 h_1^2\right)_{\text{channel}} + \left(I_{2\,xx} + A_2 h_2^2\right)_{\text{I-section}}$

For channel: $I_{\text{channel}} = 4,931 \times 10^{-6} + \left(5,876 \times 10^{-3} \times 0,0546^2\right)$

$= 2,245 \times 10^{-5}\ \text{m}^4$

For I-section: $I_{\text{I-section}} = 65,54 \times 10^{-6} + \left(5,501 \times 10^{-3} \times 0,0582^2\right)$

$= 8,417 \times 10^{-5}\ \text{m}^4$

$\therefore I_{xx} = I_{\text{channel}} + I_{\text{I-section}} = 2,245 \times 10^{-5} + 8,417 \times 10^{-5} = 106,62 \times 10^{-6}\ \text{m}^4$

5.4 The maximum and minimum stress

$y_{max} = 188$ mm and $y_{min} = h_1 + a_y = 54,6 + 27 = 81,6$ mm

$$\therefore \sigma_{min} = \frac{My_{min}}{I_{xx}} = \frac{8,1k \times 0,0816}{106,62 \times 10^{-6}} = 6,199 \text{ MPa}$$

$$\therefore \sigma_{max} = \frac{My_{max}}{I_{xx}} = \frac{8,1k \times 0,188}{106 \times 10^{-6}} = 14,282 \text{ MPa}$$

QUESTION 6

6.1 The maximum shear stress

$$\frac{\tau}{R} = \frac{G\theta}{L} \therefore \tau = \frac{dG\theta}{2L}$$

$$\therefore \tau = \frac{0,6 \times 85 \times 10^9 \times 1,8 \times \pi}{2 \times 1,55 \times 180} = 51,684 \text{ MPa}$$

6.2 The power transmitted

$$T = \frac{\tau J}{R} = \frac{51,684 \times 10^6 \times \pi \times 0,06^4 \times 2}{32 \times 0,06} = 2,192 \text{ kNm}$$

$$P = \frac{2\pi NT}{60} = \frac{2\pi \times 900 \times 2\,192}{60} = 206,591 \text{ kW}$$

6.3 The diameters of the hollow shaft

Maximum power $= 206\,591 \times 1,2 = 247,909$ kW

Torque transmitted $= T = \frac{P60}{2\pi N} = \frac{247\,909 \times 60}{2\pi \times 900} = 2,63$ kNm

$$J = \frac{TR}{\tau} = \frac{2\,630 \times D}{51,684 \times 10^6 \times 2} = 2,544 \times 10^{-5} D \ldots (1)$$

But $J = \frac{\pi}{32}[D^4 - d^4] = 2,544 \times 10^{-5} D \ldots (2)$

$D = 2d \ldots (3)$

Substitute (3)into (2) $\therefore \frac{\pi}{32}\left[(2d)^4 - d^4\right] = 3,544 \times 10^{-5} \times 2d$

$$\therefore 16d^4 - d^4 = 5,183 \times 10^{-4} d$$

$$\therefore 15d^3 = 5,183 \times 10^{-4}$$

$$\therefore d = \sqrt[3]{\frac{5,183 \times 10^{-4}}{15}} = 32,571 \text{ mm}$$

$$\therefore D = 65,142 \text{ mm}$$

QUESTION 7

7.1 True

7.2 True

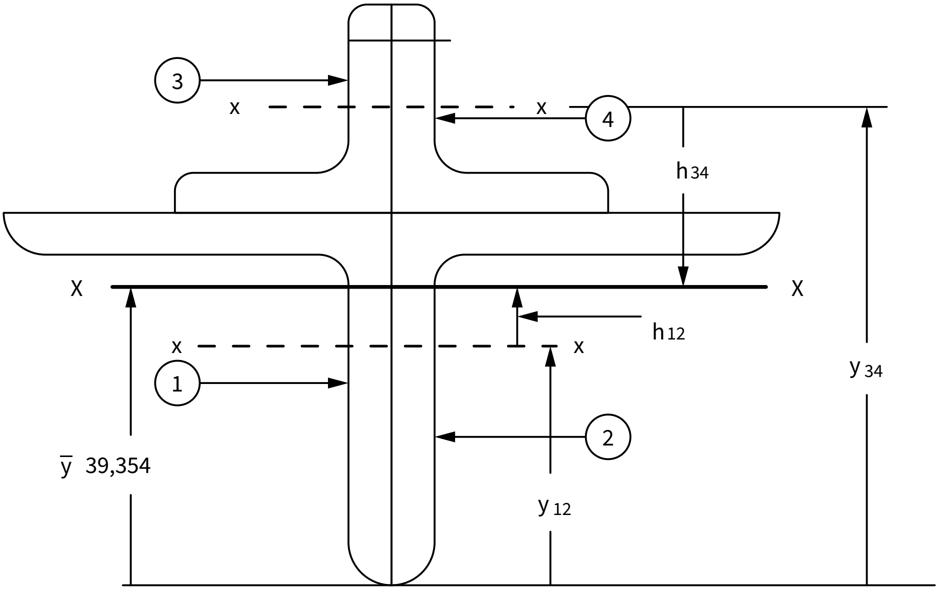
7.3 True

7.4 True

7.5 False

QUESTION 8

The moment of inertia about the *xx*-axis



$h_{12} = \bar{y} - \left(h - A_x\right) = 39{,}354 - (45 - 12{,}8) = 7{,}154 \text{ mm}$

$h_{34} = \left(h + A_x\right) - \bar{y} = (45 + 7{,}98) - 39{,}354 = 13{,}626 \text{ mm}$

$y_{12} = h - A = 45 - 12{,}8 = 32{,}2 \text{ mm}$

$y_{34} = 45 + 7{,}98 = 52{,}98 \text{ mm}$

$\therefore I_{xx} = 2I_{xx12} + 2I_{xx34}$

$\therefore 2\, I_{xx12} = 2\left[I_{xx} + \left(A\, h_{12}^2\right)\right] = 2\left[0{,}0784 \times 10^{-6} + \left(0{,}4303 \times 10^{-3} \times 0{,}007154^2\right)\right]$

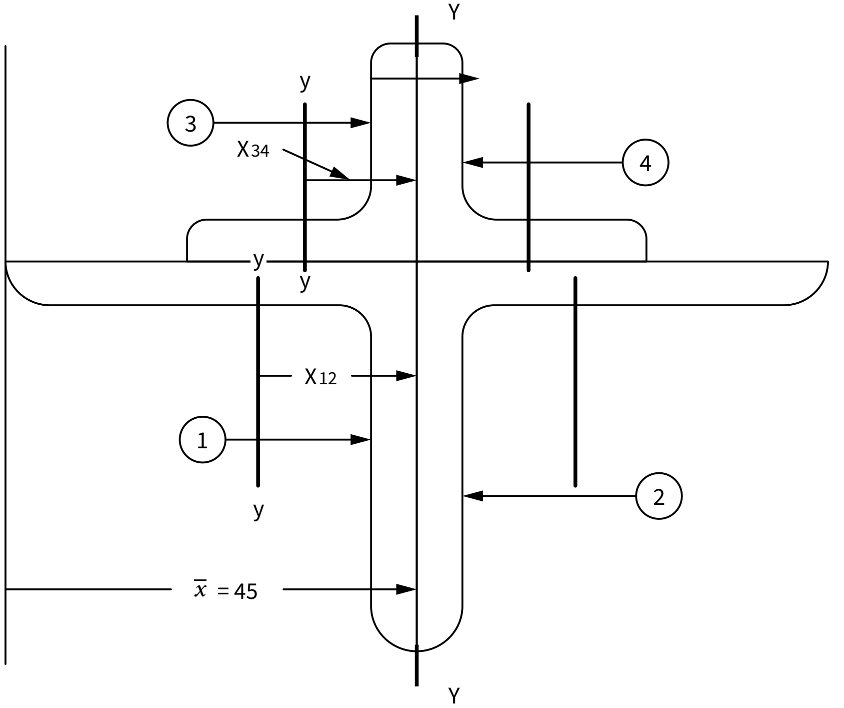
$\therefore 2I_{xx12} = 2{,}008 \times 10^{-7}$

$\therefore 2I_{xx34} = 2\left[I_{xx} + \left(A\, h_{34}^2\right)\right] = 2\left[0{,}012 \times 10^{-6} + \left(0{,}2259 \times 10^{-3} \times 0{,}013626^2\right)\right]$

$2I_{xx34} = 1{,}079 \times 10^{-7}$

$\therefore I_{xx} = 2{,}008 \times 10^{-7} + 1{,}079 \times 10^{-7} = 0{,}3087 \times 10^{-6} \text{ m}^4$

The moment of inertia about the *yy*-axis



$x_{12} = \mathrm{A}y = 12{,}8 \text{ mm}$

$x_{34} = \mathrm{A}y = 7{,}98 \text{ mm}$

$\mathrm{I}_{yy} = 2\mathrm{I}_{yy12} + 2\mathrm{I}_{yy34}$

$\therefore 2\mathrm{I}_{yy12} = 2\left[\mathrm{I}_{yy} + \left(\mathrm{A} + x_{12}^{2}\right)\right] = 2\left[0{,}0784 \times 10^{-6} + \left(0{,}4303 \times 10^{-3} \times 0{,}0128^{2}\right)\right]$

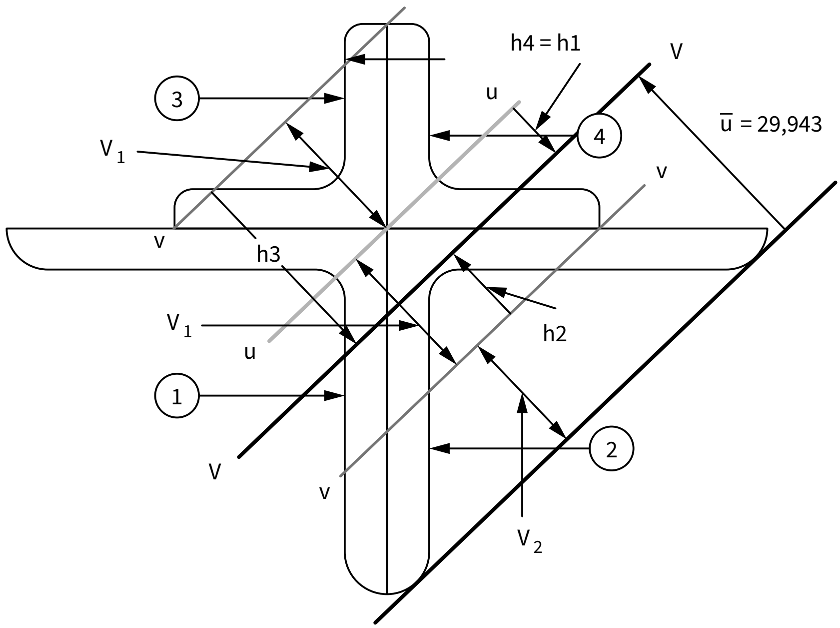
$2\mathrm{I}_{yy12} = 2{,}978 \times 10^{-7}$

$\therefore 2\mathrm{I}_{yy34} = 2\left[\mathrm{I}_{yy} + \left(\mathrm{A} + x_{34}^{2}\right)\right] = 2\left[0{,}012 \times 10^{-6} + \left(0{,}2259 \times 10^{-3} \times 0{,}00798^{2}\right)\right]$

$\therefore 2\mathrm{I}_{yy34} = 5{,}277 \times 10^{-8}$

$\therefore \mathrm{I}_{yy} = 2{,}978 \times 10^{-7} + 5{,}277 \times 10^{-8} = 0{,}35057 \times 10^{-6} \text{ m}^{4}$

The moment of inertia about the UU-axis and VV-axis



$h_2 = 29{,}943 - v_2 = 29{,}943 - 15{,}8 = 14{,}143$ mm

$h_3 = \left[(v_2 + v_1) + v_1\right] - 29{,}943 = [15{,}8 + 18{,}1 + 11{,}3] - 29{,}943 = 15{,}257$ mm

$h_{14} = (v_2 + v_1) - 29{,}943 = (15{,}8 + 18{,}1) - 29{,}943 = 3{,}957$ mm

$I_{VV} = I_{vv2} + I_{uu1} + I_{uu4} + I_{vv3}$

$\therefore I_{vv2} = I_{vv} + \left(A_2 \times h_2^2\right) = 0{,}0326 \times 10^{-6} + \left(0{,}4303 \times 10^{-3} \times 0{,}014143^2\right) = 1{,}187 \times 10^{-7}$

$\therefore I_{uu1} = I_{uu} + \left(A + h_1^2\right) = 0{,}1243 \times 10^{-6} + \left(0{,}4303 \times 10^{-3} \times 0{,}003957^2\right) = 1{,}31 \times 10^{-7}$

$\therefore I_{uu4} = I_{uu} + \left(A \times h_4^2\right) = 0{,}0189 \times 10^{-6} + \left(0{,}2259 \times 10^{-3} \times 0{,}003957^2\right) = 2{,}244 \times 10^{-8}$

$\therefore I_{vv3} = I_{vv} + \left(A + h_3^2\right) = 0{,}0052 \times 10^{-6} + \left(0{,}2259 \times 10^{-3} \times 0{,}015257^2\right) = 5{,}778 \times 10^{-8}$

$\therefore I_{VV} = 0{,}32992 \times 10^{-6}$

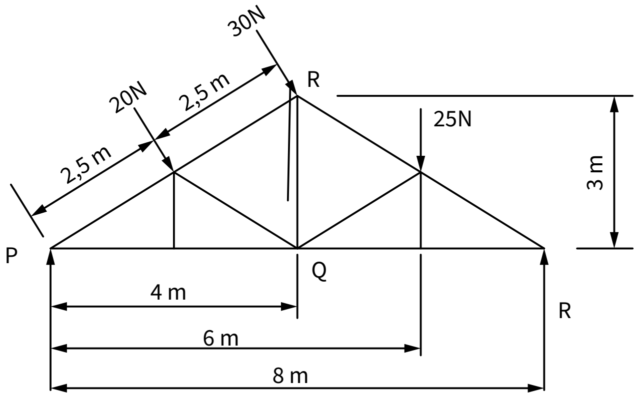
The smallest moment of inertia = $0{,}3087 \times 10^{-6}$ m^4

Effective length = $l_e = 2L = 2 \times 3 = 6$ m

Maximum buckling load = $P_E = \dfrac{\pi^2 EI}{l_e} = \dfrac{\pi^2 \times 200 \times 10^9 \times 0{,}3087 \times 10^{-6}}{6} = 101{,}59$ MN

QUESTION 9

The reaction at the roller



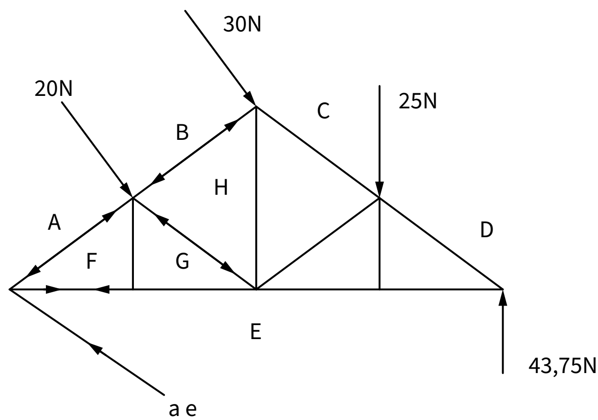
From triangle PQR:

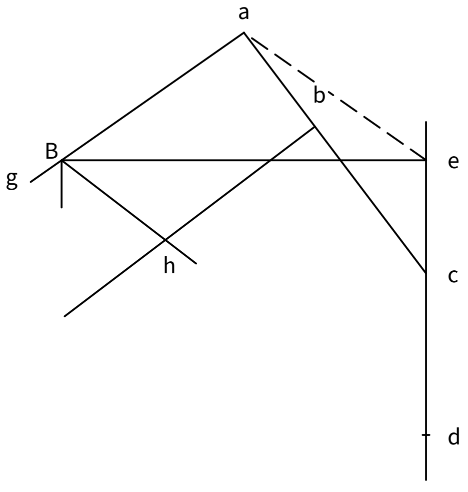
$\therefore \text{PR} = \sqrt{3^2 + 4^2} = 5 \text{ m}$

Moments about the fixed end: $\therefore 8\text{R} = (20 \times 2{,}5) + (30 \times 5) + (25 \times 6)$

$\therefore \text{R} = \frac{50 + 150 + 150}{8} = 43{,}75 \text{ N}$

Scale: 1 cm = 1 m and 1 cm = 10 N





The reaction at the fixed support = 32 N

Member	Magnitude	Nature
af	35 N	Strut
ef	60 N	Tie
gh	22 N	Strut