[ENG80]

THE UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng (Hons) CIVIL ENGINEERING

SEMESTER 2 EXAMINATION 2024/2025

ADVANCED STRUCTURAL ANALYSIS AND DESIGN

MODULE CIE6018

Date: 16 May 2025 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions

Answer ALL questions.

Marks for each question are shown in brackets.

For Question 4, use the Multiple choice answer sheet in the Appendix B. Include it in your answer booklet.

Total 100 marks for the paper.

Extracts from EC3 to be used with Question 2 are included with this paper.

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Module No. CIE6018

Question 1

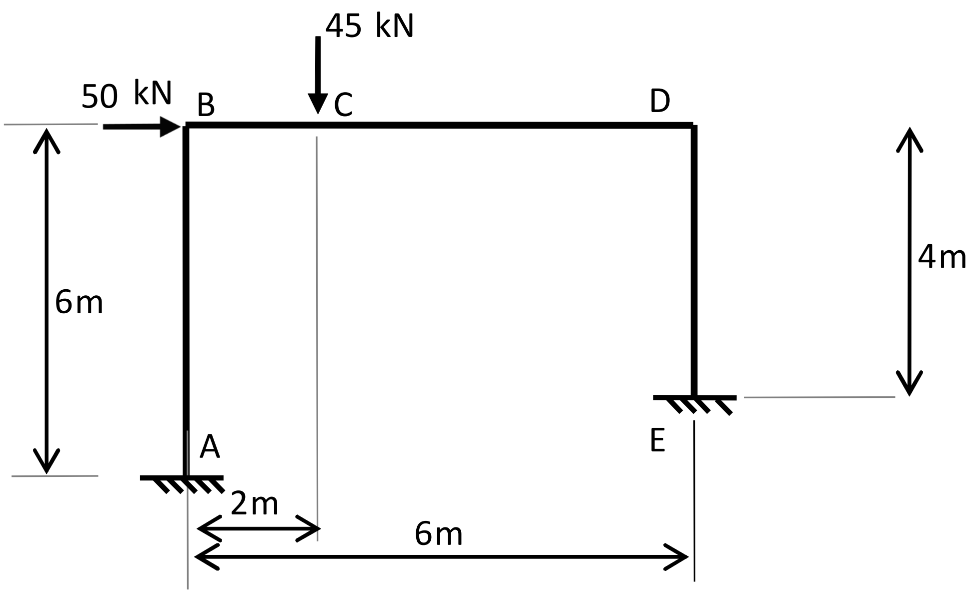

Figure Q1

Figure Q1 shows a rigid-jointed frame ABCDE fixed to supports at A and at E. The plastic moment of resistance $\mathbf{M_p}$ is constant throughout.

The frame carries vertical point load of **45kN** and a horizontal load of **50kN** as shown.

a. Find the values of $\mathbf{M_P}$ which correspond to the following collapse mechanisms:

   i) Plastic hinges at B, C and D.
   ii) Plastic hinges at A, B, D and E
   iii) Plastic hinges at A, C, D and E **(15 marks)**

b. Draw the bending moment diagram for the most critical of the collapse mechanisms in part (a), showing values at A, B, C, D, and E.

(10 marks)

Total 25 marks

Please turn the page

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Question 2

a) Explain the difference in the mode of failure between a stocky and slender column. What is the limiting value of the non-dimensional slenderness ratio for a slender column when using the EC3 method?

(5 marks)

b) The column shown in Figure Q2 is pin ended about both the z-z and y-y axes with the addition of a tie at mid-height providing restraint in the y-y plane. If the column forms part of a braced framework, design the column in Grade S275 steel. The column is subjected to a design load **N_{Ed} = 2560** kN. The size of the column is 254 x 254 x 89 UKC in S275 steel.

Determine the buckling resistance of the column about both axes using EC3 method. Comment on the results.

(20 marks)

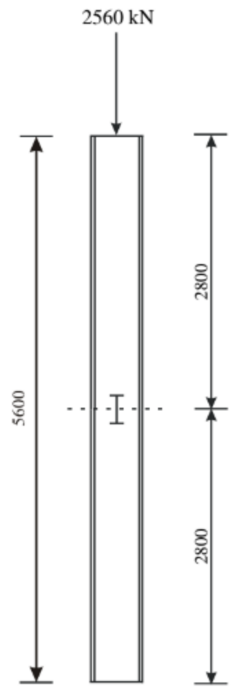

Figure Q2

Total 25 Marks

Please turn the page

From section property tables:

Depth h = 260.3 mm

Width b = 255.9 mm

Web thickness t_w = 10.5 mm

Flange thickness t_f = 17.3 mm

Root radius r = 12,7 mm

Depth between fillets d = 200.3 mm

Radius of gyration y axis i_y = 11.2 cm

Radius of gyration z axis i_z = 6.52 cm

Area A = 114 cm^2

Modulus of elasticity E = 210 000 N/mm^2

Shear modulus G ≈ 81 000 N/mm^2

Partial safety factor γM_1 =1   Cross-section is Class 1

Additional information:

$$N_{cr} = \frac{\pi^2 EI}{\ell_{cr}^2}$$

Extracts from EC3 to be used with Question 2 are included in Appendix A.

Please turn the page

Question 3 - COMPOSITE SECTION

Figure Q3(a) shows a simply supported composite beam made of steel and concrete slab. Figure Q3(b) shows its cross section. The beam is simply supported over a span of **6m** that carries a uniformly distributed load of **60 kN/m** (including the self-weight).

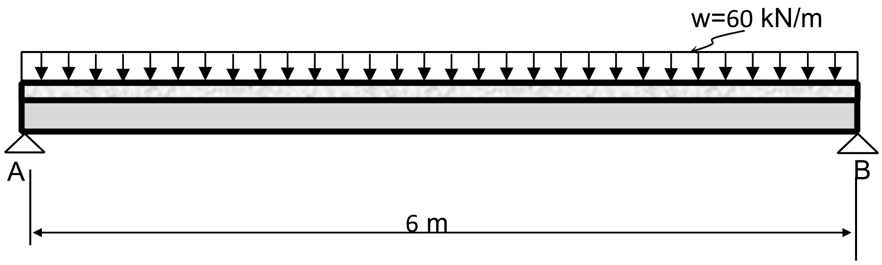

Figure Q3 (a)

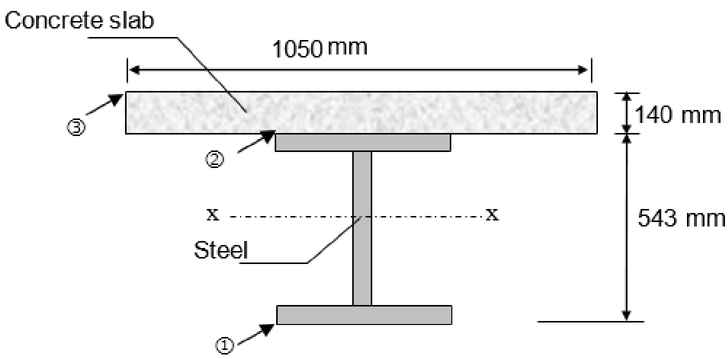

Figure Q3 (b)

The steel elastic modulus, E_s, is 210 kN/mm^2 and the concrete elastic modulus, E_c, is 20 kN/mm^2. The steel beam has a cross-sectional area of 192 cm^2 and a moment of inertia Ixx=101000 cm^4.

(a) Transform the composite section to an equivalent steel beam. Find the position of neutral axis from the bottom of the section and second moment of area **I** value of the transformed beam.

(10 marks)

Question 3 continues on the next page…

(b) Calculate the maximum stress in the steel, maximum stress in the concrete and the maximum deflection of the composite beam.

(10 marks)

(c) If the steel beam carried the load without composite action, find the maximum stress and maximum deflection of the steel beam.

(5 marks)

The central deflection of a simply supported beam carrying a uniformly distributed load is given by: $\delta = 5wL^4/384EI$

(Total 25 marks)

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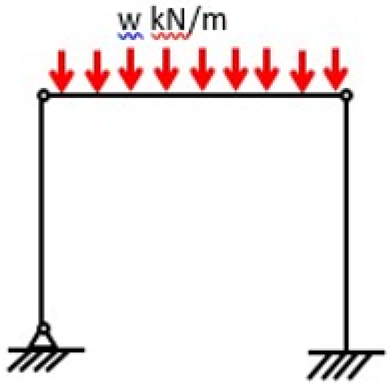
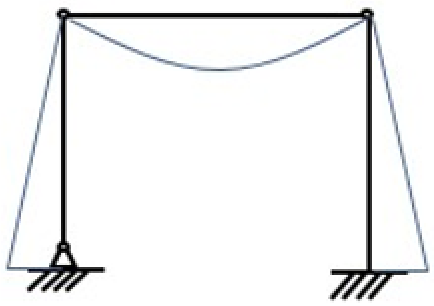
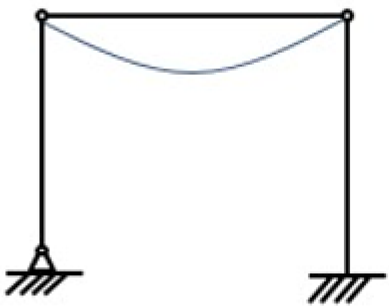
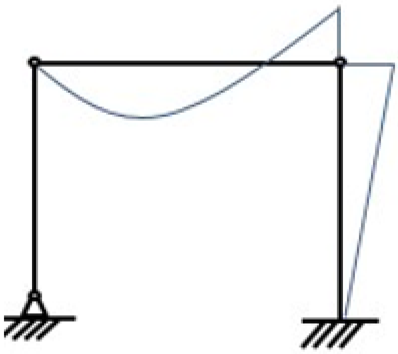
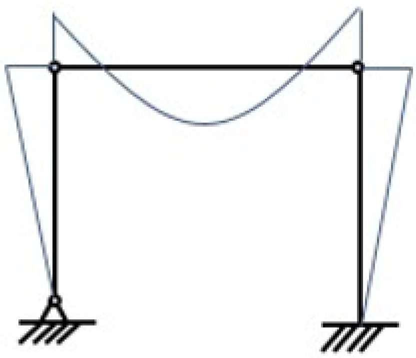
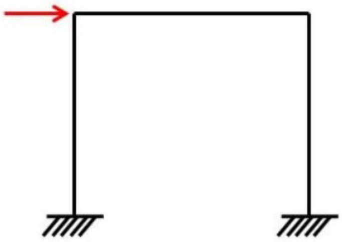
Question 4 - Understanding structural behaviour

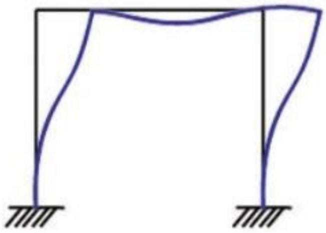
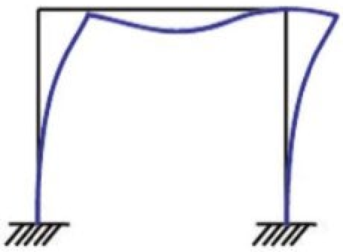
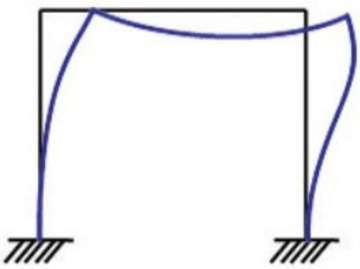
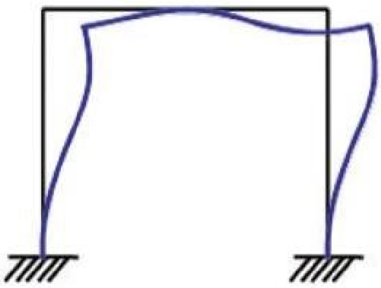
In answering Question **4** use the multiple-choice marking sheet in **Appendix B**

Q4-1	Choose the bending moment diagram (BMD) that matches the structure shown. **(5 marks)**		
			
A		**B**	
C		**D**	

Question 4 continues over the page…

Q4-2	Choose the correct deflected shape under the load shown. Assume constant EI. **(5 marks)**



A		**B**	
C		**D**	

Question 4 continues over the page…

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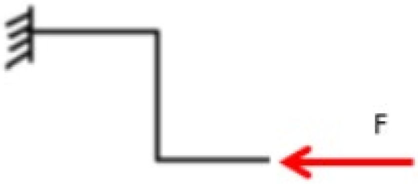
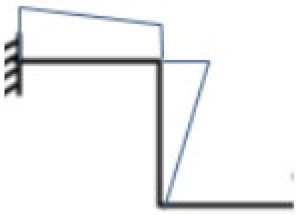
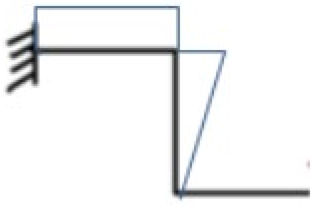
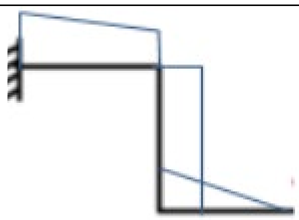
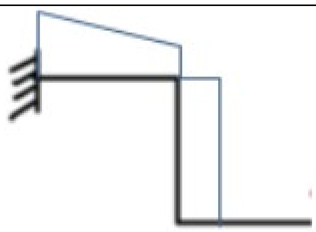
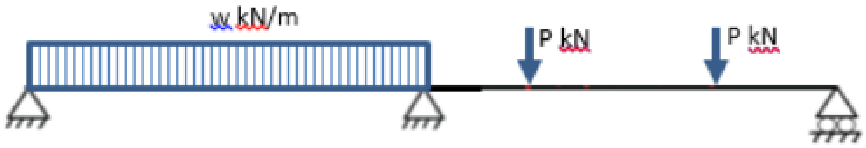
Q4-3	Choose the bending moment diagram (BMD) that matches the structure shown. **(5 marks)**		
 			
A		**B**	
C		**D**	

Question 4 continues over the page…

<table>
<tr><td>Q4-4</td><td colspan="3">Choose the bending moment diagram (BMD) and shear force diagram (SFD) that matches the structure shown.
(5 marks).</td></tr>
<tr><td></td><td colspan="3">
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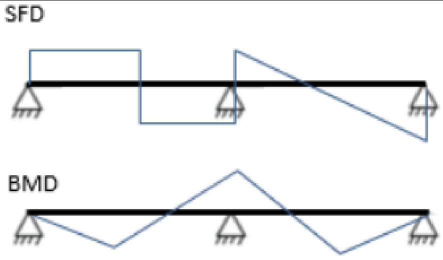
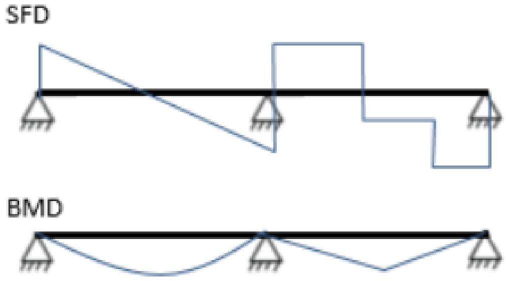
<tr><td>A</td><td>
</td><td>B</td><td>
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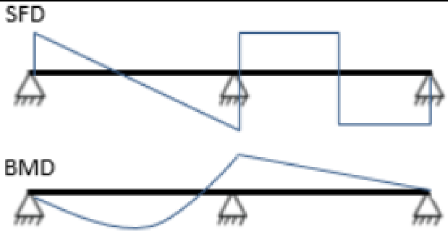
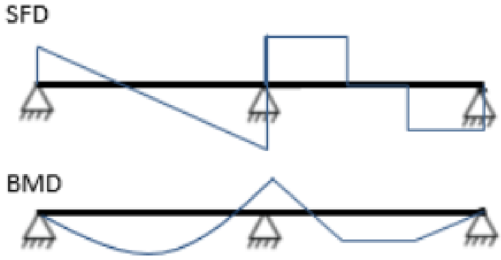
<tr><td>C</td><td>
</td><td>D</td><td>
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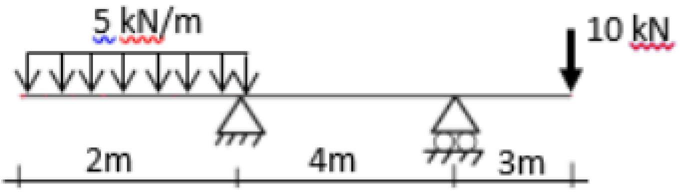
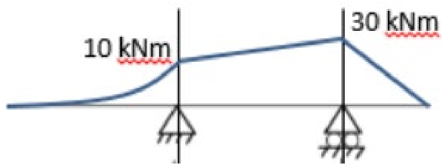
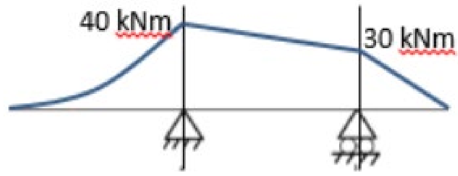
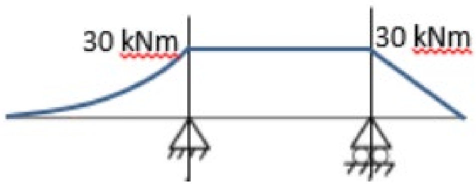
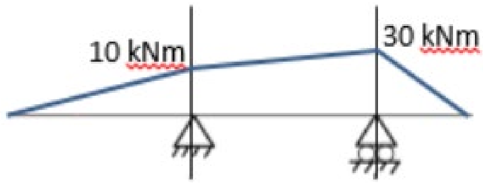
Question 4 continues over the page…

Q4-5	Choose the bending moment diagram (BMD) that matches the structure shown **(5 marks)**		
			
A		**B**	
C			

(Total 25 marks)

Appendix A & B over the page

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APPENDIX A – Extract from EC3 to be used with Question 2

6.3 Buckling resistance of members

6.3.1 Uniform members in compression

6.3.1.1 Buckling resistance

(1) A compression member shall be verified against buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1,0 \qquad (6.46)$$

where

N_{Ed} is the design value of the compression force
$N_{b,Rd}$ is the design buckling resistance of the compression member.

(3) The design buckling resistance of a compression member should be taken as:

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} \quad \text{for Class 1, 2 and 3 cross-sections} \qquad (6.47)$$

$$N_{b,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}} \quad \text{for Class 4 cross-sections} \qquad (6.48)$$

where χ is the reduction factor for the relevant buckling mode.

NOTE For determining the buckling resistance of members with tapered sections along the member or for non-uniform distribution of the compression force second-order analysis according to 5.3.4(2) may be performed. For out-of-plane buckling see also 6.3.4.

(4) In determining A and A_{eff} holes for fasteners at the column ends need not to be taken into account.

6.3.1.2 Buckling curves

(1) For axial compression in members the value of χ for the appropriate non-dimensional slenderness $\bar{\lambda}$ should be determined from the relevant buckling curve according to:

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \quad \text{but } \chi \leq 1,0 \qquad (6.49)$$

where $\Phi = 0,5\left[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2\right]$

$\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}}$ for Class 1, 2 and 3 cross-sections

$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}}$ for Class 4 cross-sections

α is an imperfection factor
N_{cr} is the elastic critical force for the relevant buckling mode based on the gross cross sectional properties.

(2) The imperfection factor α corresponding to the appropriate buckling curve should be obtained from Table 6.1 and Table 6.2.

Table 6.1 — Imperfection factors for buckling curves

Buckling curve	a_0	a	b	c	d
Imperfection factor α	0,13	0,21	0,34	0,49	0,76

(3) Values of the reduction factor χ for the appropriate non-dimensional slenderness $\bar{\lambda}$ may be obtained from Figure 6.4.

(4) For slenderness $\bar{\lambda} \leq 0,2$ or for $\frac{N_{Ed}}{N_{cr}} \leq 0,04$ the buckling effects may be ignored and only cross-sectional checks apply.

APPENDIX A continued on the next page…

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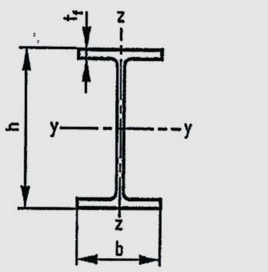
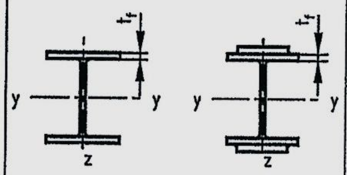
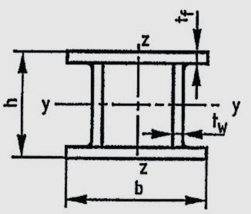
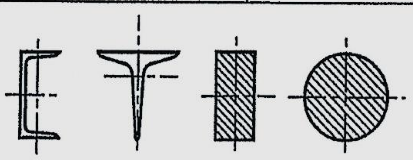
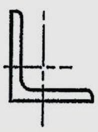
APPENDIX A continued….

Extract from EC3 to be used with Question 2

Table 6.2 — Selection of buckling curve for a cross-section

Cross section		Limits		Buckling about axis	Buckling curve S 235 S 275 S 355 S 420	Buckling curve S 460
Rolled sections		$h/b > 1,2$	$t_f \le 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm $< t_f \le 100$	y – y z – z	b c	a a
		$h/b \le 1,2$	$t_f \le 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c
Welded I sections		$t_f \le 40$ mm		y – y z – z	b c	b c
		$t_f > 40$ mm		y – y z – z	c d	c d
Hollow sections		hot finished		any	a	a_0
		cold formed		any	c	c
Welded box sections		generally (except as below)		any	b	b
		thick welds: $a > 0,5t_f$ $b/t_f < 30$ $h/t_w < 30$		any	c	c
U, T and solid sections				any	c	c
L sections				any	b	b

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APPENDIX B

Multiple choice answer sheet to be used with Question 4

Please tear out this page of the exam paper and enclose it with your exam script.

Student ID:_____________

	Student number:					
Questions	**Circle** the correct answers					**Marks (please leave this column blank)**
Q4 - 1	**A**	**B**	**C**	**D**		
Q4 – 2	**A**	**B**	**C**	**D**		
Q4– 3	**A**	**B**	**C**	**D**		
Q4 – 4	**A**	**B**	**C**	**D**		
Q4 – 5	**A**	**B**	**C**	**D**		
				TOTAL		

It is essential that your answers are clear, as ambiguous answers and crossing out may make it impossible to award marks for parts of this question.

END OF PAPER

Design of composite sections – Formulae sheet

- **Modular ratio (MR)** $= \frac{E_s}{E_c}$

  Where E_s is the elastic modulus of steel
  E_c is the elastic modulus of concrete

- **Neutral axis from the base of the beam:**

$$y_{bottom} = \frac{\sum A\ y}{A_{total}}$$

  Where A is the cross-section area of each part
  y is the distance from the centre of each part to the bottom of the section
  A_{total} is the total cross-section area

- **Second moment of area about neutral axis and Elastic section modulus:**

$$I_{NA} = \sum I + Ah^2$$

  Where I is the second moment of area of each part $\left(I = \frac{bd^3}{12}\right)$
  A is the cross-section area of each part
  h is the distance from the centre of each part to the neutral axis

$$Z = \frac{I_{NA}}{y}$$

  Where Z is the elastic section modulus
  I_{NA} is second moment of area about neutral axis
  y is the distance from the bottom or top of the beam to neutral axis

- **Bending moment:**

$$M = \frac{w\ L^2}{8}$$

  Where w is the uniformly distributed load
  L is the span of the beam

Please turn the page

- **Stress**

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

Where M is the bending moment
y is the distance from the bottom or top of the beam to neutral axis
I is the second moment of area

- **Maximum deflection at centre of a simply supported beam with a UDL :**

$$\delta = \frac{5\,w\,L^4}{384\,EI}$$