[ENG03]

THE UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng (Hons) CIVIL ENGINEERING

SEMESTER 2 EXAMINATION 2023/2024

ADVANCED STRUCTURAL ANALYSIS & DESIGN

MODULE NO. CIE6001

Date: **15th May 2024** **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions.

Answer ALL questions.

Marks are shown in bracket for each question.

For Question 4, use the Multiple Choice answer sheet in the Appendices. Include it in your answer booklet, including your student number.

Total 100 marks for the paper.

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

Question 1.

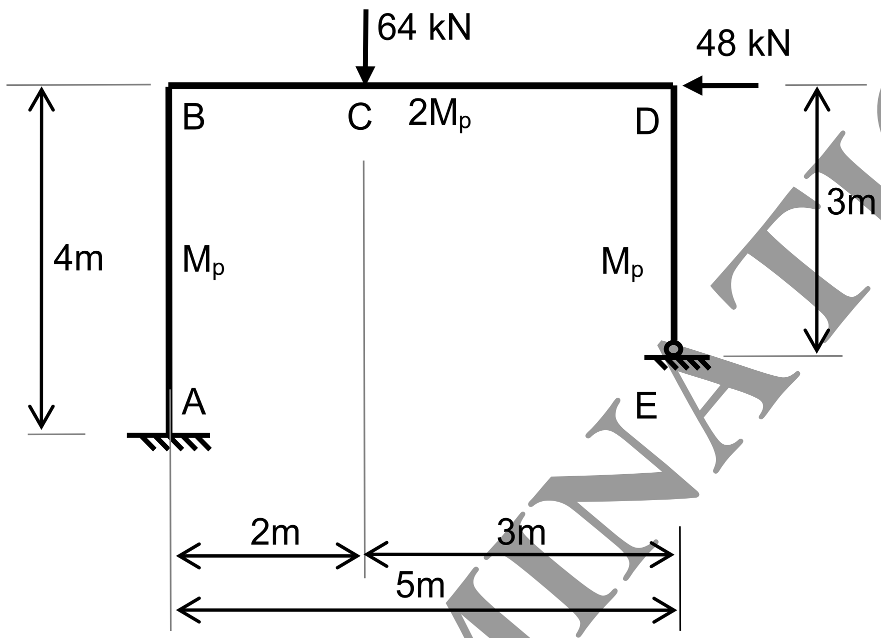

Figure Q1

Figure Q1 shows a rigid-jointed frame ABCDE fixed to a support at A and pinned to a support at E. The plastic moment of resistance of the columns AB and DE is $\mathbf{M_p}$, the plastic moment of resistance of the beam BCD is $\mathbf{2M_p}$

The frame carries a vertical point load of 64 kN at C and a horizontal point load of 48 kN at D.

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 and D.
   iii) Plastic hinges at A, B and C. (15 marks)

b. Draw the bending moment diagram for the critical collapse mechanism showing values at A, B, C, D and E. (10 marks)

c. Without additional calculations, describe the effect of reducing the strength of beam BCD from $\mathbf{2M_p}$ to $\mathbf{M_p}$. (5 marks)

(Total 30 marks)

Please turn the page

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Question 2.

A multi-storey UC column is shown in Figure Q2, it is nominally pinned at the top and fixed at the bottom ($L_{cr} = 0.85L$). The intermediate beams are all nominally pinned. The steel grade of the column is S275 (f_y = 275 N/mm2). The UC is a rolled section with section data shown in Figure Q2.

i) Determine the buckling resistance of the column about both axes using EC3 method. Comment on the results.
EC3 buckling formulae sheet is attached at the end of this paper.
(20 Marks)

ii) Calculate the axial load capacity about the critical axis using the Perry-Robertson formula:
Comment on the results of parts (i) and (ii). (10 marks)

$$\sigma_c = \frac{1}{2}\left[\sigma_y + (1 + 0.003\lambda)\sigma_{cr}\right] - \sqrt{\frac{1}{4}\left[\sigma_y + (1 + 0.003\lambda)\sigma_{cr}\right]^2 - \sigma_y \sigma_{cr}}$$

Where $\sigma_y = 275 N/mm^2$ $\quad \sigma_{cr} = \frac{\pi^2 E}{\lambda^2}$ $\quad \lambda = \frac{L_{cr}}{r}$

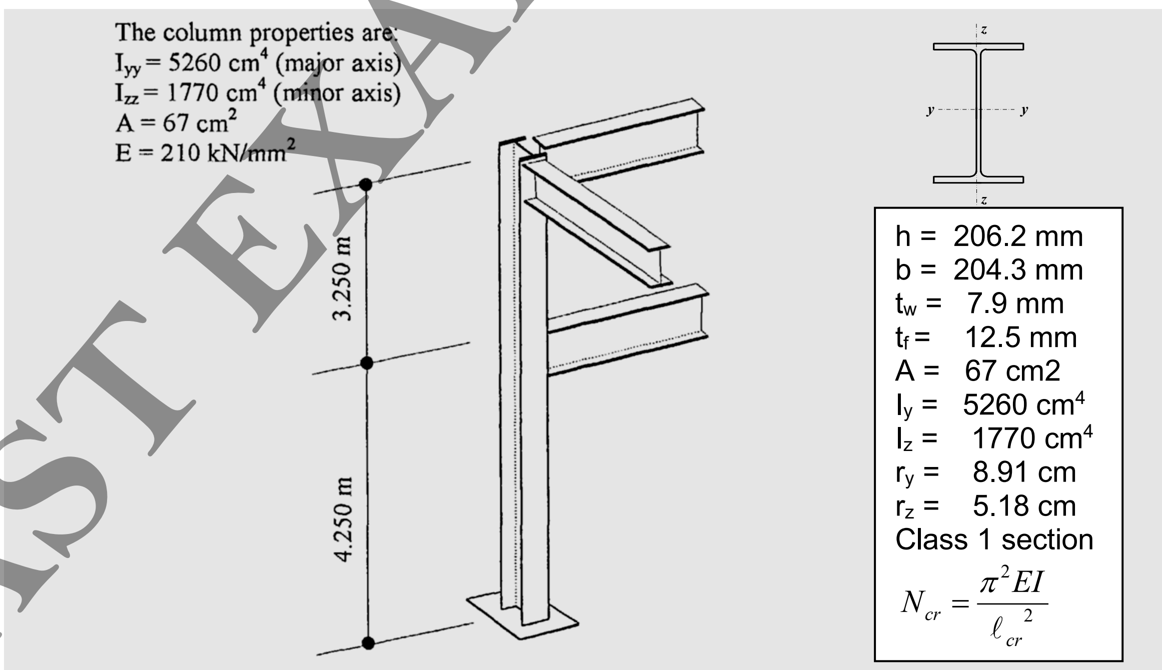

Figure Q2 (Total 30 Marks)

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

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Question 3: COMPOSITE SECTION

Figure Q3(a) shows a simply supported composite beam made of steel and concrete slab. Figure Q3(b) on the following page shows its cross section. The beam carries at ULS a uniformly distributed load w= 12 kN/m (including the self-weight) and a point load P=75 kN applied at mid-span of the beam.

(a) The reaction at support A is 85.5 kN, find the maximum bending moment at mid-span M_{max}. (5 marks)

(b) Considering that the steel beam (UB 533x312x151) has a cross-sectional area of 192 cm^2 and a moment of inertia I_{xx}=101000 cm^4, calculate the following:

i) Find the Neutral Axis and the Moment of Inertia of the composite section

ii) Find the Elastic Section Modulus at the top and the bottom of the composite section

iii) Find the maximum stresses under the action of M_{max} calculated above in (a), at the following locations, as shown in Figure Q3(b) on the following page:
- in the steel at level 1
- in the concrete at the top of the slab at level 3
- in the steel and concrete at level 2 (at the interface)

Comment on the adequacy of the composite beam. (20 marks)

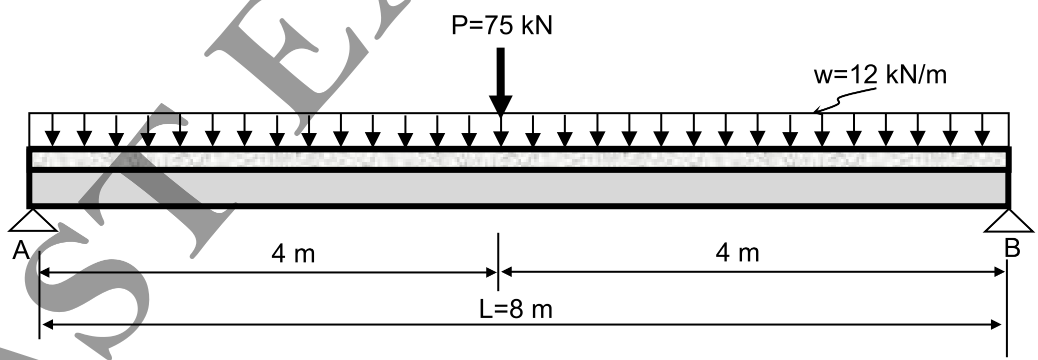
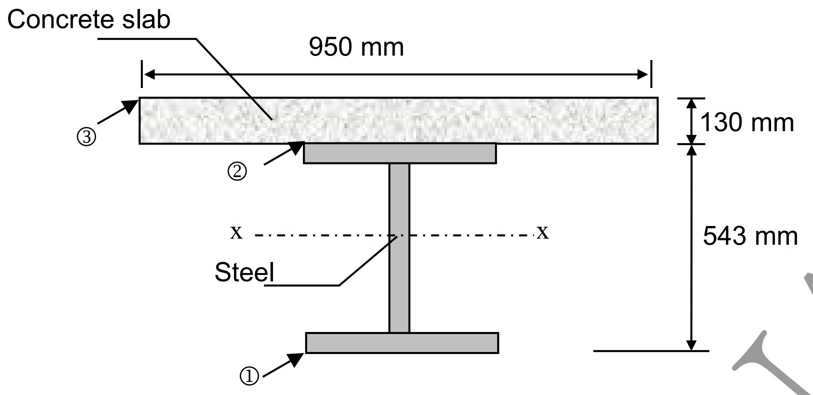


Figure Q3 (a)

Question 3 continues over the page…

…Question 3 continued



Concrete Elastic Modulus:
E_c = 16 GPa

Steel Elastic Modulus
E_s = 200 GPa

Figure Q3 (b)

(Total 25 marks)

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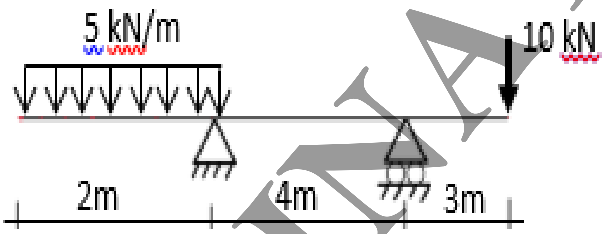
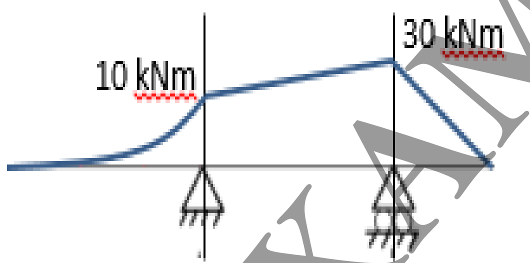
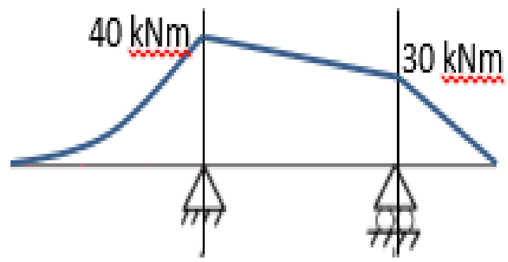
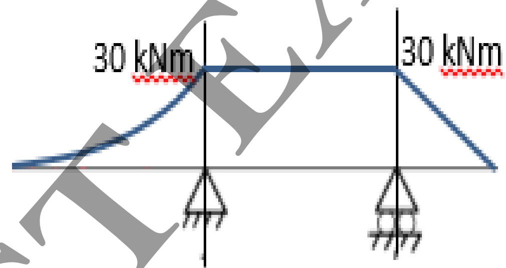
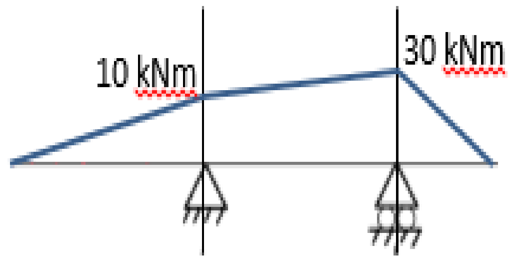
Question 4: Understanding Structural Behaviour

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

Q4B-1	Choose the bending moment diagram (BMD) that matches the structure shown. (3 marks)		
			
A		B	
C		D	

Question 4 continued on next page…..

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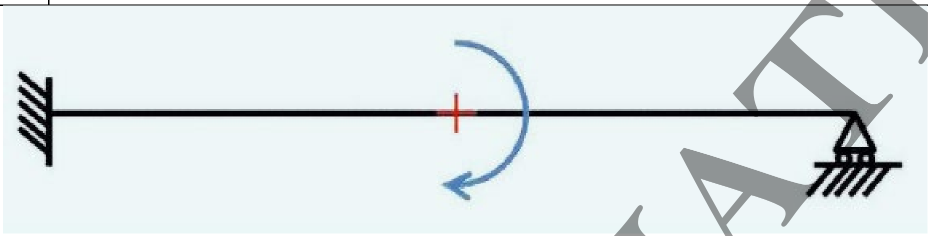
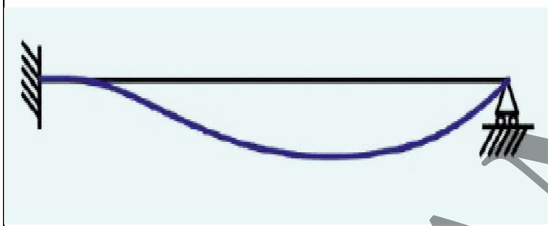
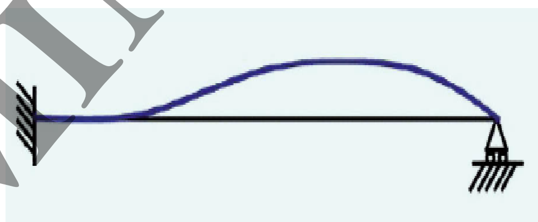
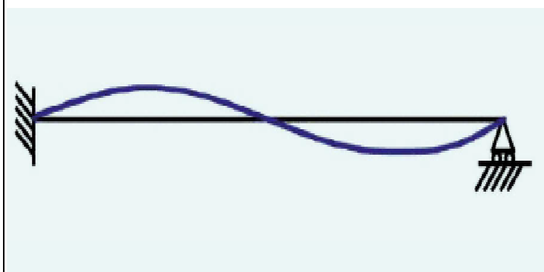
Question 4 (continued)

Understanding structural behaviour

Q4B-2	Choose the correct deflected shape of the beam under the load shown. (3 marks)		
			
A		B	
C		D	

Question 4 continues on next page…..

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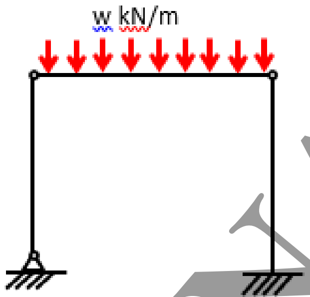
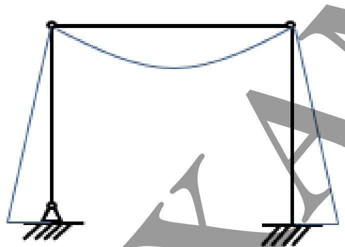
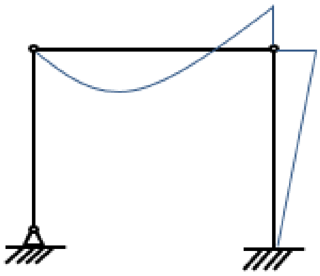
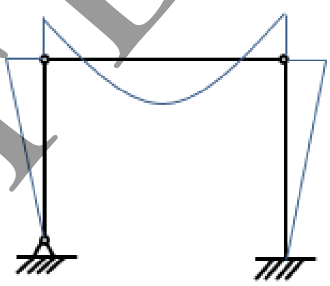
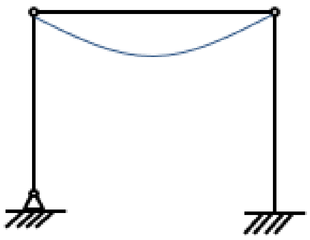
Question 4 (continued)

Understanding structural behaviour

Q4B-3	Choose the bending moment diagram (BMD) that matches the structure shown. (3 marks)		
			
A		**B**	
C		**D**	

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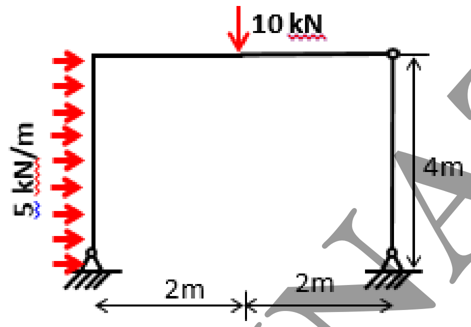
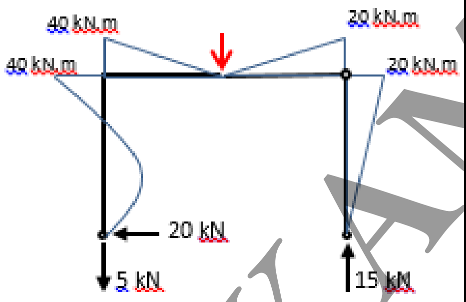
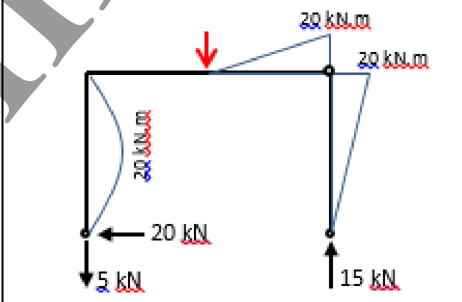
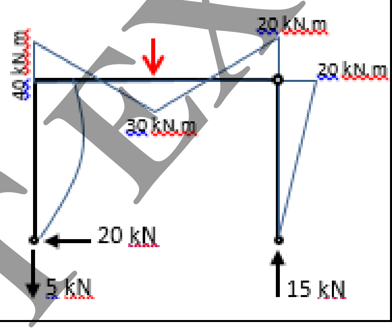
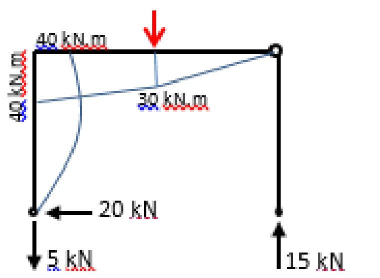
Question 4 (continued)

Understanding structural behaviour

Q4B-4	Choose the bending moment diagram (BMD) that matches the structure shown. Consider the values of the bending moments given in the answer choices. (3 marks)		
			
A		**B**	
C		**D**	

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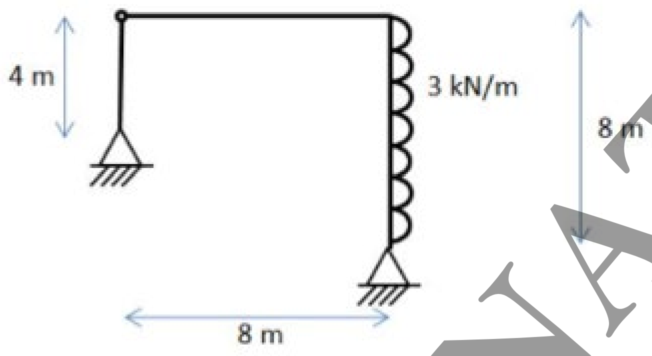
Question 4 (continued)

Q4B-5	Choose the correct bending moment diagram. Ignore the self-weight. The bending moment should be drawn on the tension face. (3 marks)



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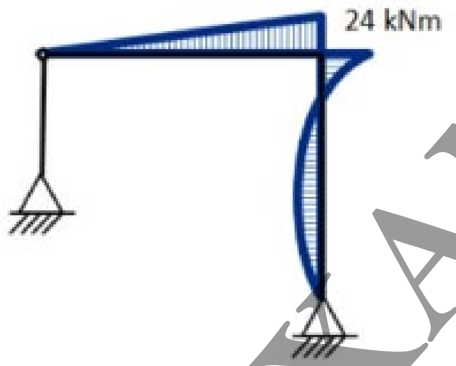

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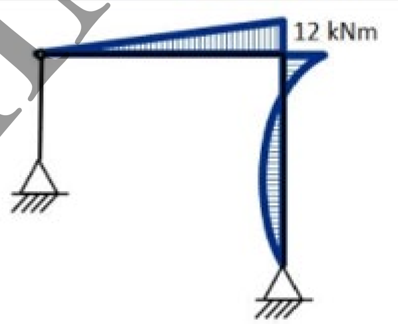

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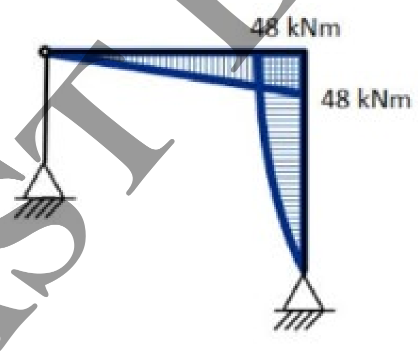

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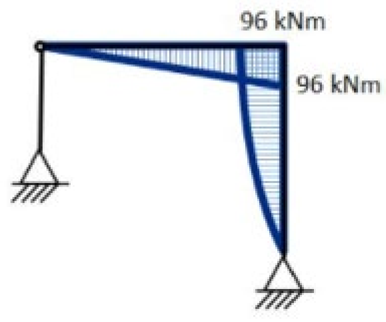

Total 15 marks)

End of Questions

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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.

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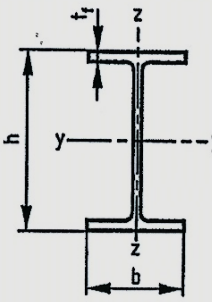
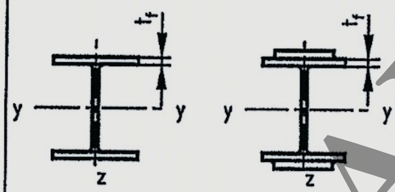
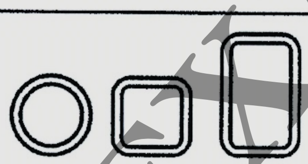
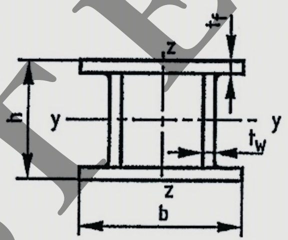
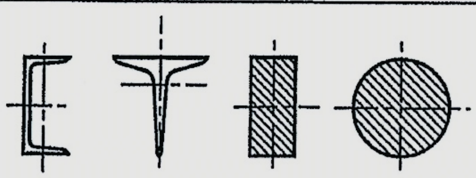
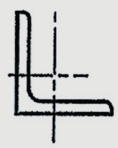
APPENDIX A – Extract from EC3 to be used with Question 2

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

APPENDIX B

Student ID Number ______________________________

Please remove this sheet and insert into answer booklet

Multiple choice answer sheet to be used with Question 4

	Student number:					
Questions	**Circle** the correct answers					**Marks (please leave this column blank)**
Q4B - 1	**A**	**B**	**C**	**D**	**3**	
Q4B – 2	**A**	**B**	**C**	**D**	**3**	
Q4B – 3	**A**	**B**	**C**	**D**	**3**	
Q4B – 4	**A**	**B**	**C**	**D**	**3**	
Q4B – 5	**A**	**B**	**C**	**D**	**3**	
				TOTAL	**15**	

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