[ESS21]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng (Hons) CIVIL ENGINEERING

SEMESTER TWO EXAMINATION 2018/2019

ADVANCED STRUCTURAL ANALYSIS & DESIGN

MODULE NO. CIE6001

Date: Thursday 23rd May 2019 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions

Answer ALL questions.

All questions carry equal marks

For Question 4, use the Multiple choice answer sheet in the Appendices. 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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Question 1.

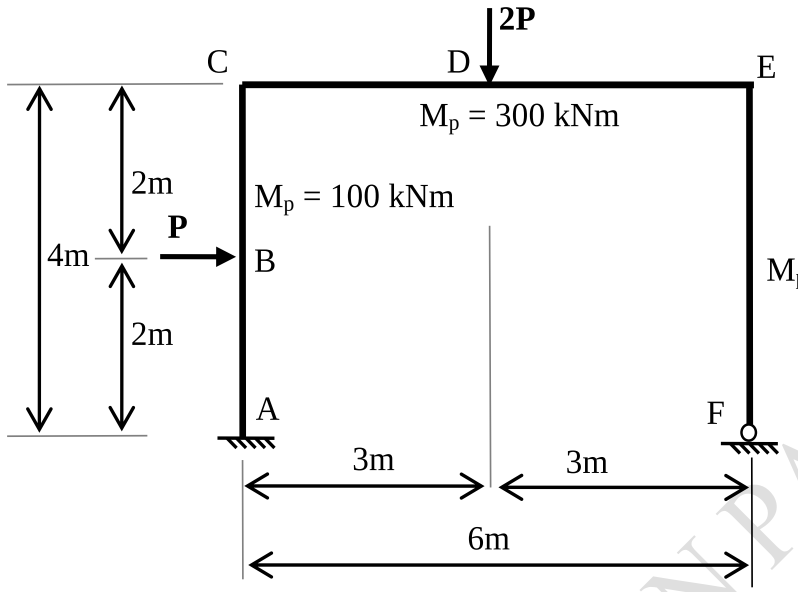

Figure Q1

Figure Q1 shows a rigid-jointed frame ABCDEF fixed to a support at A and pinned to a support at F. Member ABC has M_p = 100 kNm, members CDE and EF both have M_p = 300 kNm.

There is a horizontal point load **P** at B and a vertical point load of **2P** at D

a. Find the values of P which correspond to the following collapse mechanisms:
   i) Plastic hinges at A, B and C
   ii) Plastic hinges at C, D and E
   iii) Plastic hinges at A, C and E
   iv) Plastic hinges at A, B and E **(15 marks)**

b. Draw the bending moment diagram for the critical collapse mechanism showing the important values, and state the value of P that will cause the frame to collapse. **(10 marks)**

Total 25 marks

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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) A column is laterally restrained every 3.5 m against buckling about the minor axis but has no intermediate restraints against buckling about the major axis as shown in Figure Q2. The column is considered to be pinned in both directions.
The column is subjected to a design load **N_{Ed} = 1000** kN.
The size of the column is UKC 203x203x71 with a steel grade S275.

Determine the buckling resistance of the column about both axes using EC3 method. Comment on the results. **(20 marks)**

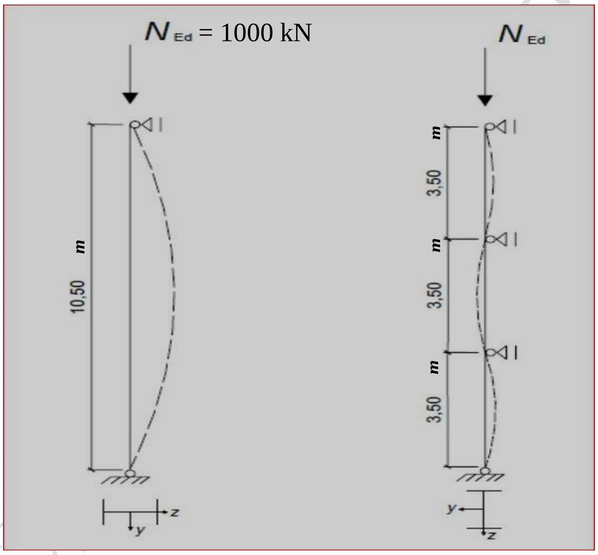
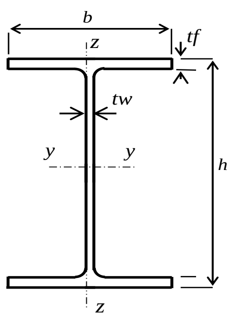


Figure Q2

UKC 203x203x71:
A= 90.4 cm^2
I_y = 7618 cm^4
I_z = 2537 cm^4
h = 215.8 mm
b = 206.4 mm
t_w = 10.0 mm
t_f = 17.3 mm
E = 210 kN/mm^2
f_y = 275 N/mm^2
Partial safety factor $\gamma_{M1} = 1$
Cross-section is Class 2

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



Total 25 Marks

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

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Question 3

Figure Q3 shows a pre-stressed concrete beam. The beam contains six pre-stressing strands (10 mm diameter) at an average height of 100 mm from the bottom of the beam. The beam supports a store area and so the proportion of the variable load to be considered in the quasi permanent loading condition is 0.3. In service, the beam is simply supported over a span of 10.0m and carries the following loads:

- Permanent load (**excluding** beam self-weight) = 4.3 kN/m
- Variable (imposed) load = 25 kN/m

Table Q3: Additional data

Materials strength	Characteristic breaking load of one strand	65 kN
	Initial pre-stress	75% of UTS
	Pre-stress losses	25% of initial pre-stress
	Concrete unit weight	25 kN/m^3
	Concrete strength at transfer, f_{ck}	40 N/mm^2
	Concrete strength in service, f_{ck}	55 N/mm^2
For the whole concrete section	Area	185 x 10^3 mm^2
	I_{NA}	21.65 x 10^9 mm^4
Limiting stresses in concrete	At transfer: (in compression) (in tension)	0.6xf_{ck} 1 N/mm^2
	In service: (in compression) (in tension)	0.45xf_{ck} 3.8 N/mm^2

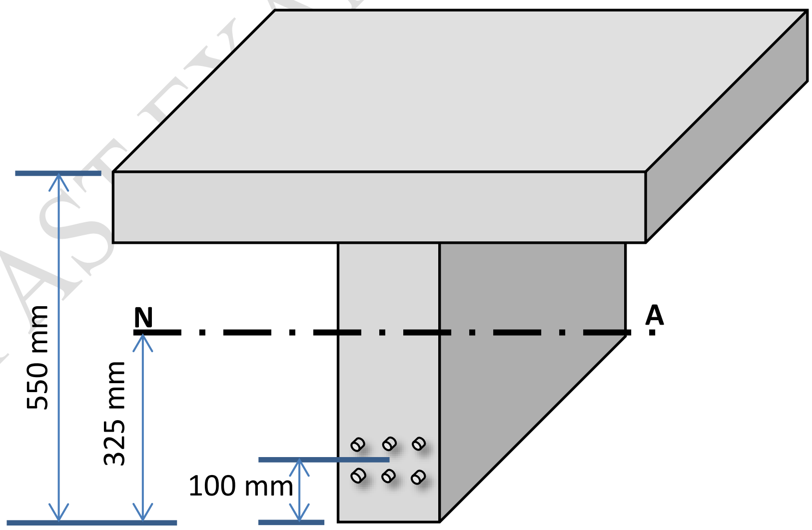

Figure Q3

Question 3 continues over the page….

Question 3 continued….

(a) Give the advantages of bonded pre-stressed concrete construction over unbonded construction.

(2 marks)

(b) Calculate the stresses in the concrete at the top and bottom of the beam:
(i) at transfer;
(ii) in service under quasi-permanent loads.

(13 marks)

(c) Draw the distribution of stress over the height of the beam:
(i) at transfer;
(ii) in service under quasi-permanent loads.

(4 marks)

(d) Compare the calculated values of stress in the concrete with the limiting values of stress in the concrete:
(i) at transfer;
(ii) in service under quasi-permanent loads.

Comment on the adequacy of the beam.

(3 marks)

(e) It is proposed that the bending moment capacity of the beam would be greater if the amount of pre-stress was increased. Without further calculation, discuss this proposal.

(3 marks)

Total 25 marks

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Question 4
PART A – COMPOSITE SECTION

Figure Q4 (a) shows a simply supported composite beam made of steel and concrete slab. Figure Q4 (b) 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) Draw the shear force and the bending moment diagrams for the composite beam and show where the maximum bending moment M_{max} occurs.

(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 maximum stresses under the action of M_{max} calculated above in (a), at the following locations, as shown in Figure Q4 (b):

i) in the steel at level 1
ii) in the steel and concrete at level 2 (at the interface)
iii) in the concrete at the top of the slab at level 3

Comment on the adequacy of the composite beam. **(12 marks)**

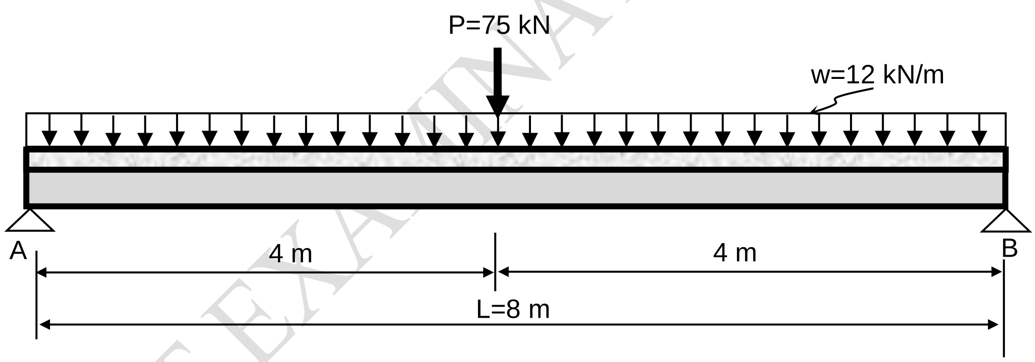

Figure Q4 (a)

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Question 4 continued….

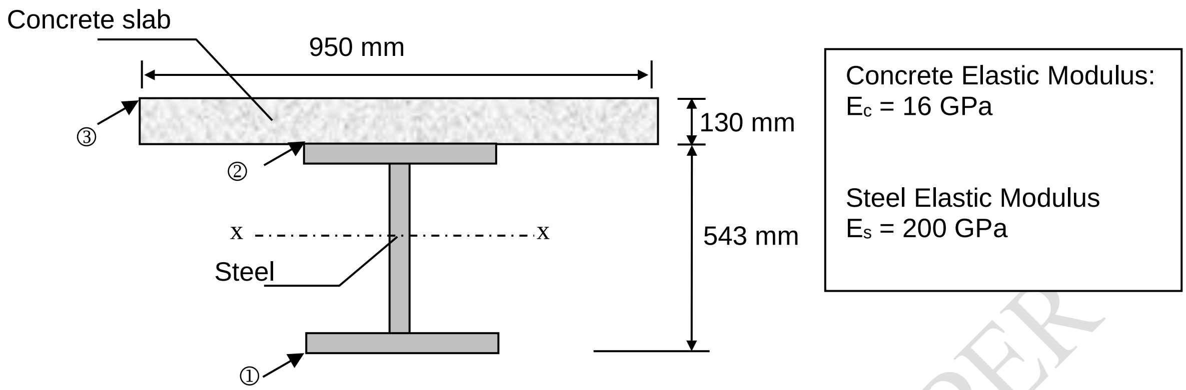

Figure Q4 (b)

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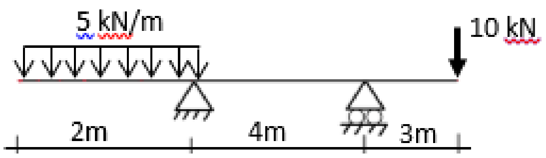
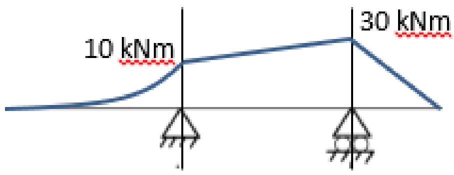
Question 4 continued….

PART B Understanding structural behaviour
In answering Question **4 PART B** please tear out and use the multiple choice marking sheet in **Appendix B**

Q4B-1 Choose the bending moment diagram (BMD) that matches the structure shown. (2 marks)



A



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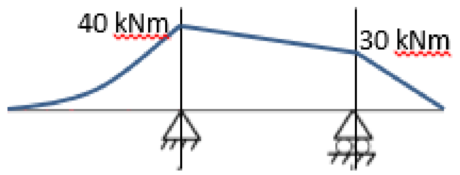

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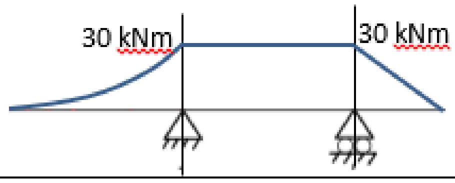

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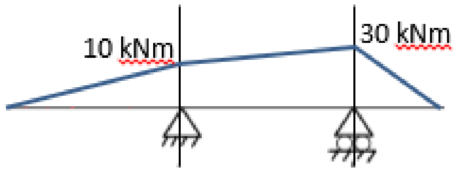
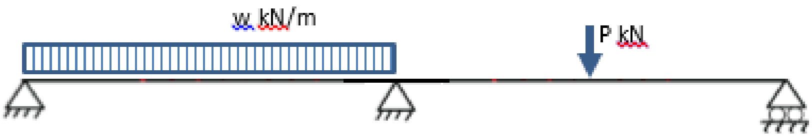


Q4B-2 Choose the shear force diagram (SFD) and bending moment diagram (BMD) that match the structure shown. (2 marks)



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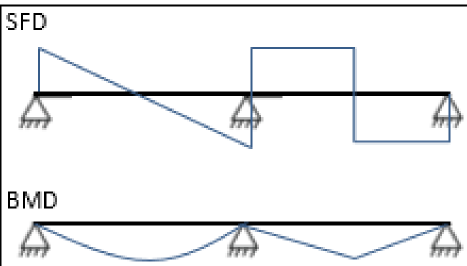

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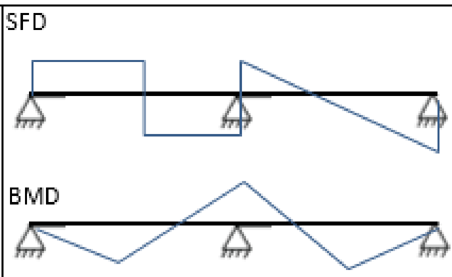

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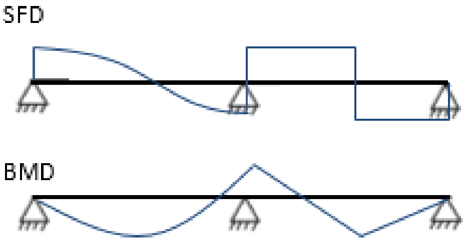

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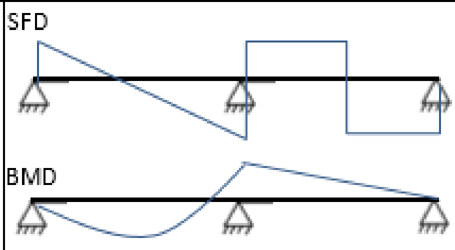

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Question 4 continued….

PART B Understanding structural behaviour

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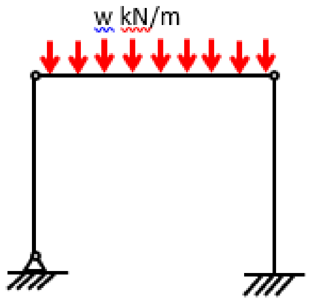
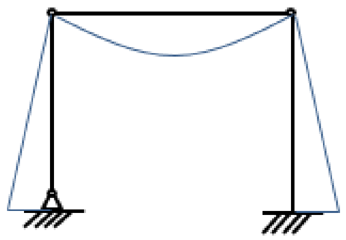
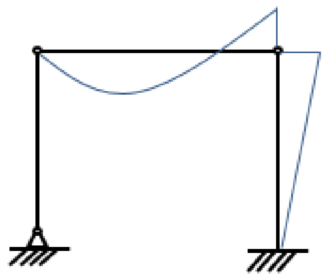
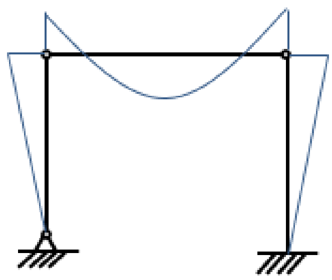
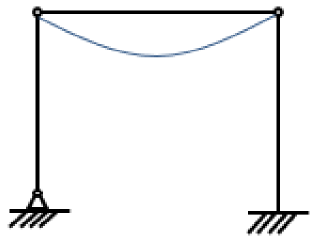
<tr><td colspan="4">
</td></tr>
<tr><td>A</td><td></td><td>B</td><td></td></tr>
<tr><td>C</td><td></td><td>D</td><td></td></tr>
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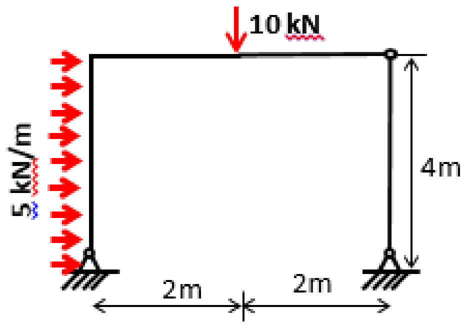
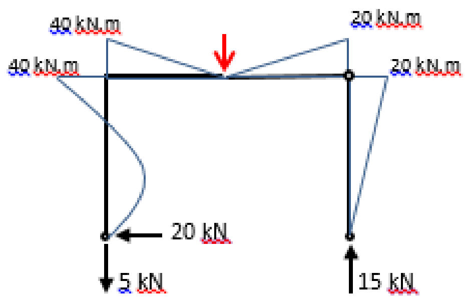
Question 4 continued….

PART B 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. (2 marks)



A



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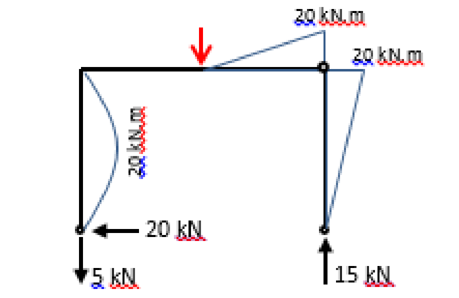

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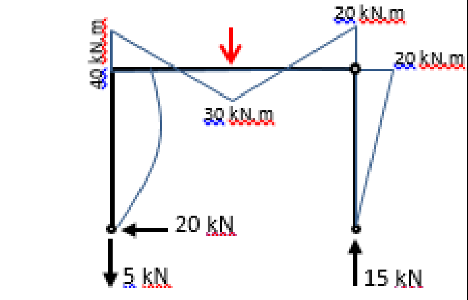

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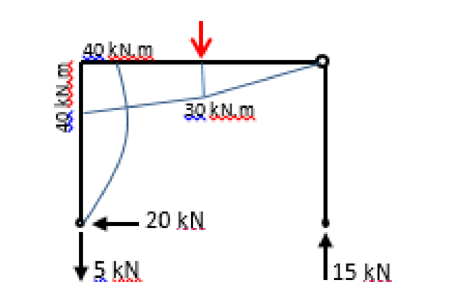

Total 25 marks

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:

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

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

6.3 Buckling resistance of members

6.3.1 Uniform members in compression

6.3.1.1 Buckling resistance

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

where

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

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

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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

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

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APPENDIX B

Multiple choice answer sheet to be used with Question 4 PART B

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

	Student number:					
Questions	**Circle** the correct answers					**Marks (please leave this column blank)**
Q4B - 1	**A**	**B**	**C**	**D**	**2**	
Q4B – 2	**A**	**B**	**C**	**D**	**2**	
Q4B – 3	**A**	**B**	**C**	**D**	**2**	
Q4B – 4	**A**	**B**	**C**	**D**	**2**	
				TOTAL	**8**	

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