NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2019-2020

CV3012 – STEEL DESIGN

November / December 2019 **Time Allowed: 2½ hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SEVEN (7)** pages.
2. Answer **ALL FOUR (4)** questions.
3. All questions carry equal marks.
4. This paper is an Open Book Examination.

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1. Figure Q1 shows a two-span continuous beam carrying three (3) concentrated actions. The characteristic values of permanent actions *PA* and variable actions *VA* are indicated in Figure Q1. A standard hot-rolled section UB 610 x 305 x 149 kg/m in Grade S275 steel is used to form the beam. Member AB is 10 m long, and Member BD is 1.5 m long. The lateral restraints are provided at the pinned supports A and B, and pinned connections at C and E only.

   Determine the adequacy of Member EB in terms of the resistance against lateral torsional buckling by using the primary method (general case).

   The following equation and its value for this beam are provided for your reference.

$$\frac{\pi^2 EI_z}{L_{cr}^2}\sqrt{\frac{I_w}{I_z}+\frac{L_{cr}^2 GI_T}{\pi^2 EI_z}} = 2545 \text{ kNm}, \text{ for } L_{cr} = 5.0 \text{ m}$$

   You may ignore the self-weight of the beam. State clearly your other design assumptions, if any.

(25 Marks)

Note: Question No. 1 continues on page 2

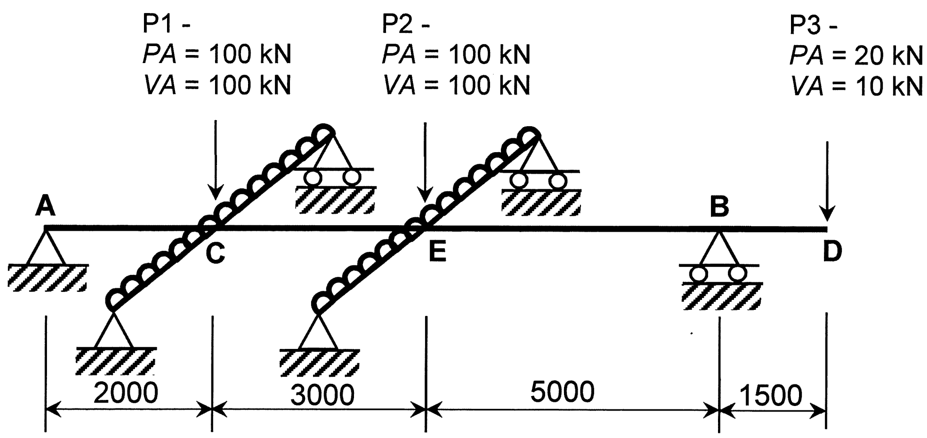


Figure Q1

(All dimensions are in mm unless otherwise stated)

2. Figure Q2 shows an internal column in a braced multi-storey building of simple connection. A standard hot-rolled section UC 356 x 368 x 202 kg/m in Grade S275 is used to form the column. One end of the column is a pinned connection and the other end of the column is a fixed connection, with an inter-storey floor-to-floor height of 10 m.

   The design axial compression force N_{Ed} acting to the column is 4800 kN.

   Determine the adequacy of this column if a cross beam, which provides restraint against buckling about the minor axis (z-z) only, is connected via a pinned connection to the beam web at mid-height as shown in Figure Q2.

   Self-weight of the column may be neglected. State clearly your other design assumptions, if any.

(25 Marks)

Note: Question No. 2 continues on page 3

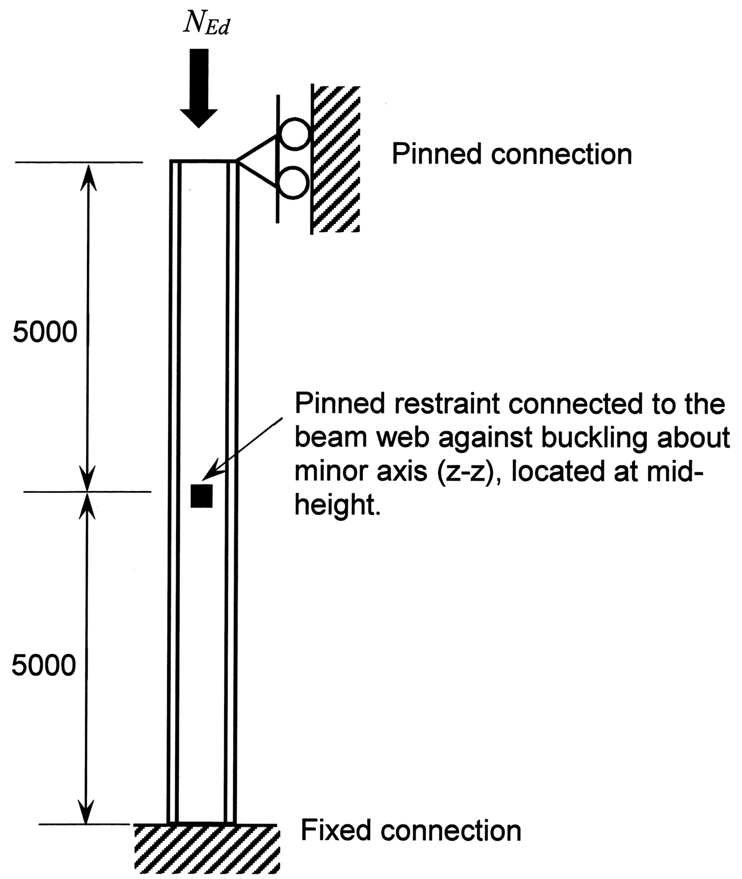


Figure Q2

(All dimensions are in mm unless otherwise stated)

3. A column FG shown in Figure Q3(a) supports a simply supported beam EF where a fin-plate connection is used at point F. While Figure Q3(b) shows the sectional view A-A of the column orientation. The base at point G is a fixed end connection. All the actions shown in the figure have been factored; the self-weight of the beam and column may be neglected in the design calculations.

(a) Calculate the total compression action and nominal moment at F about the y-y axis which need to be carried by the 254 x 254 x 89 UC column.

(5 Marks)

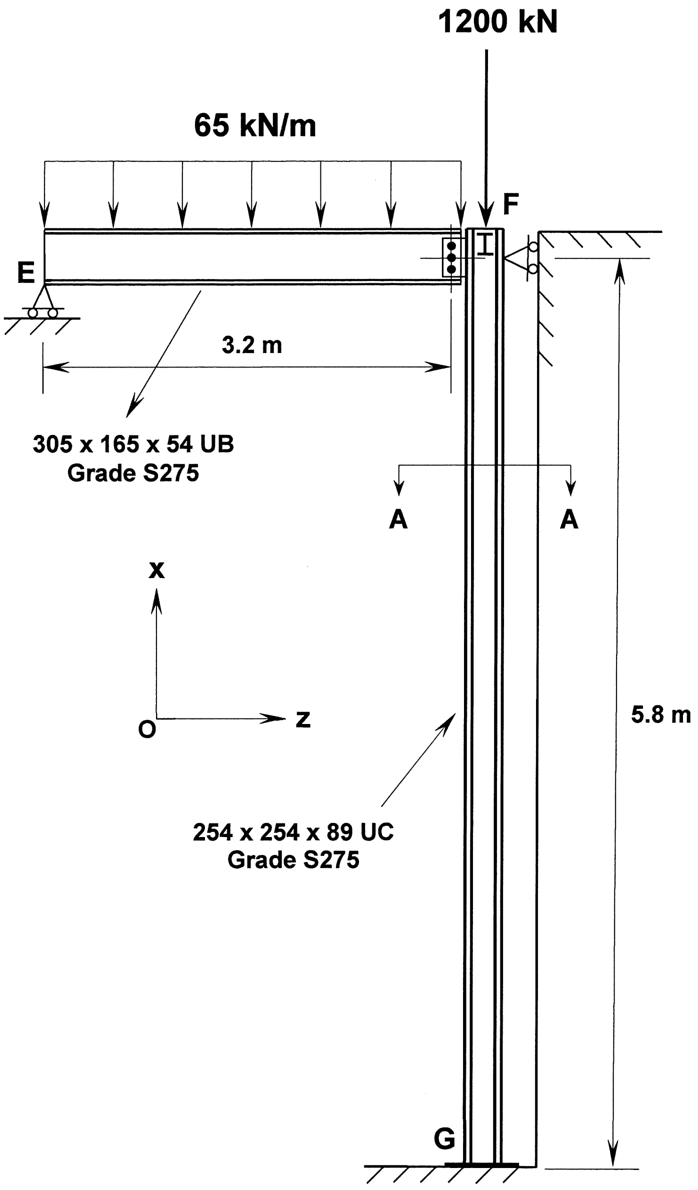
(b) Check the buckling and lateral torsional buckling resistance of this 254 x 254 x 89 UC column. Use the appropriate column effective length in your calculations.

(12 Marks)

(c) If the base of the column at point G is replaced by a pinned connection, will the column still be adequate to carry the design actions?

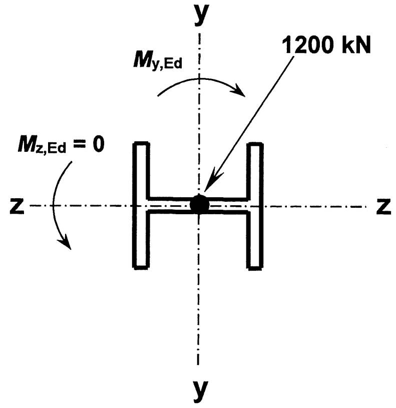
(8 Marks)

Note: Question No. 3 continues on page 5



Elevation

Figure Q3(a)



Section A-A

Figure Q3(b)

(Note: drawings are not drawn to scale)

4. Figure Q4 shows a bracket constructed from a cut 200 x 150 x 12 L unequal angle section. A total of 6 numbers of M16 Class 8.8 non-preloaded bolts in Grade S275 steel is used to connect the bracket to the flange of a 152 x 152 x 37 UC column. The bracket is subjected to a design action of 160 kN acting at an eccentricity of 90 mm from the face of the column.

(a) Assuming the centre of rotation is at point A, and the loads vary linearly, show that the proposed 6-bolt group is adequate under combined shear and tension action.

(15 Marks)

(b) If the bolts are replaced with an equal number of M16 Class 8.8 preloaded bolts in S275 designed to be non-slip in service, and assuming the slip factor μ = 0.5 and there is no prying force, determine the adequacy of these preloaded bolts.

(7 Marks)

(c) What are the advantages of using preloaded bolts in this type of connection?

(3 Marks)

Note: Question No. 4 continues on page 7

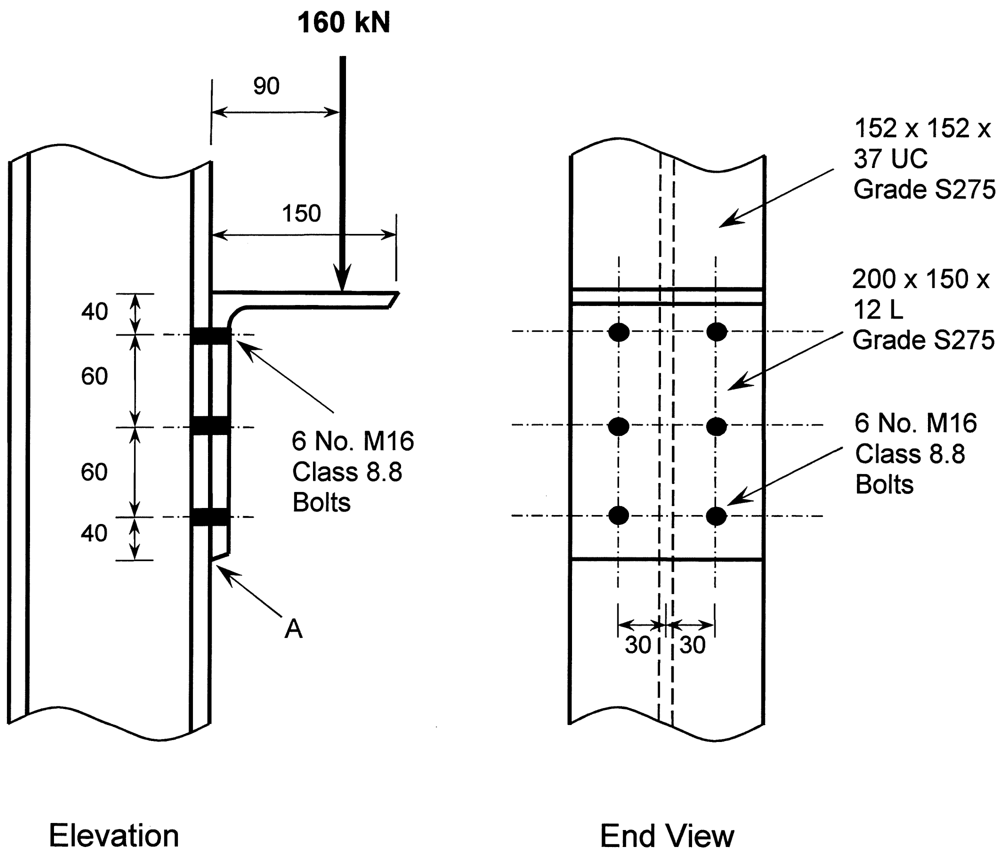


Figure Q4

(Note: drawings are not drawn to scale)

(All dimensions are in mm unless otherwise stated)

END OF PAPER

CV3012 STEEL DESIGN

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.

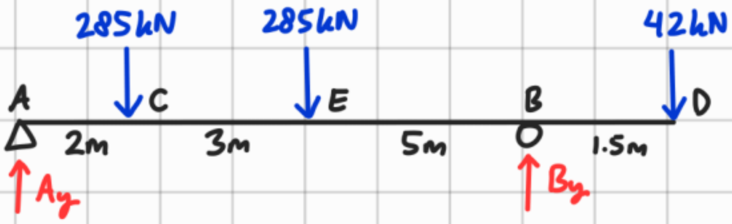
CV3012 2019/20 Sem 1

by Renardi M. (@pardirenardi)

① Design actions :

$P_1 = P_2 = 1.35(100) + 1.5(100) = 285\ kN$

$P_3 = 1.35(20) + 1.5(10) = 42\ kN$

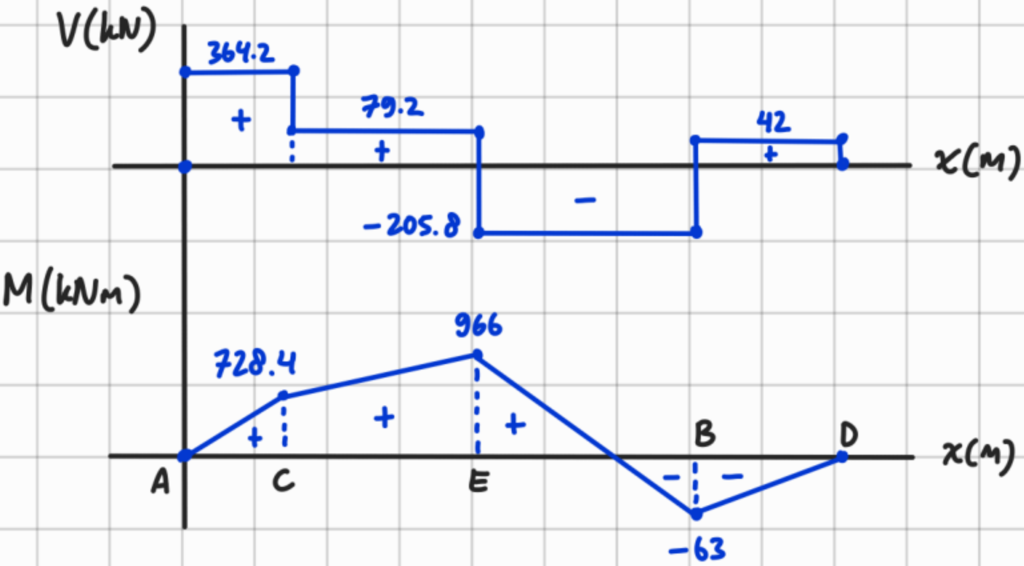


$\circlearrowleft + \Sigma M_B = -A_y(10) + 285(8) + 285(5) - 42(1.5) = 0$

$A_y = 364.2\ kN$

$+\uparrow \Sigma F_y = A_y - 285 - 285 + B_y - 42 = 0$

$B_y = 247.8\ kN$



Most critical section is member CE (longest unrestrained span, biggest M).

However, task given : check LTB for member EB (UB 610×305×149, S275)

Section Designation	Mass per Metre	Depth of Section h	Width of Section b	Thickness Web t_w	Thickness Flange t_f	Root Radius r	Depth between Fillets d	Ratios for Local Buckling Flange c_f / t_f	Ratios for Local Buckling Web c_w / t_w	Dimensions for Detailing End Clearance C	Notch N	Notch n	Surface Area Per Metre	Surface Area Per Tonne
	kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m^2	m^2
610x305x149	149.2	612.4	304.8	11.8	19.7	16.5	540.0	6.60	45.8	8	158	38	2.39	16.0

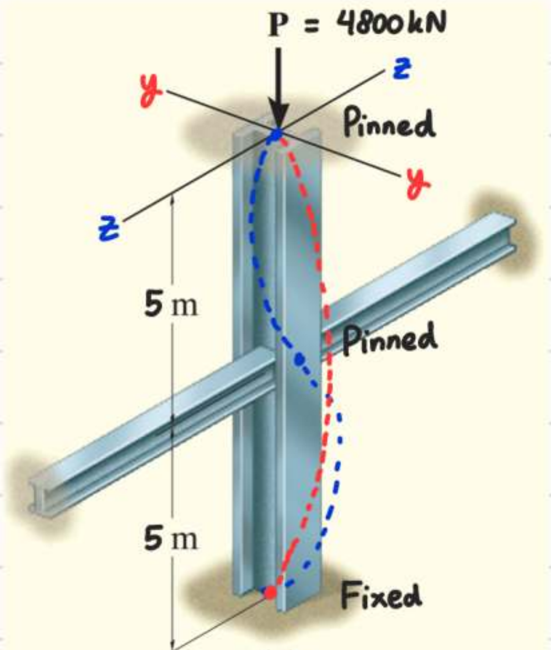
Section Designation	Second Moment of Area Axis y-y	Second Moment of Area Axis z-z	Radius of Gyration Axis y-y	Radius of Gyration Axis z-z	Elastic Modulus Axis y-y	Elastic Modulus Axis z-z	Plastic Modulus Axis y-y	Plastic Modulus Axis z-z	Buckling Parameter U	Torsional Index X	Warping Constant I_w	Torsional Constant I_T	Area of Section A
	cm^4	cm^4	cm	cm	cm^3	cm^3	cm^3	cm^3			dm^6	cm^4	cm^2
610x305x149	126000	9310	25.7	7.00	4110	611	4590	937	0.886	32.7	8.17	200	190

- $L_{EB} = 5.0\text{m}$ (Lateral restraints at E & B)
- $\psi = \dfrac{-63}{966} = -0.0652$
- $C_1 = 1.75 - 1.05(-0.0652) + 0.3(-0.0652)^2 = 1.820 \leq 2.3$
- $M_{cr} = 1.820 \times 2545 \text{ (given)} = 4631.9 \text{ kNm}$
- $\bar{\lambda}_{LT} = \sqrt{\dfrac{4590 \times 275}{4631.9 \times 10^3}} = 0.522 > 0.2$, LTB check needed
- $\dfrac{h}{b} = \dfrac{612.4}{304.8} = 2.01 > 2$, rolled ⇒ ⓑ ⇒ $\alpha_{LT} = 0.34$
- $\phi_{LT} = 0.5\left[1 + 0.34(0.522 - 0.2) + 0.522^2\right] = 0.691$
- $\chi_{LT} = \dfrac{1}{0.691 + \sqrt{0.691^2 - 0.522^2}} = 0.874 < 1.0$
- $M_{b,Rd} = 0.874 \times \dfrac{4590 \times 275}{1.0} \times 10^{-3} \text{ kNm}$

  $= 1103.2 \text{ kNm} > M_{Ed,y} = 966 \text{ kNm}$ OK!

∴ Member EB is adequate to resist LTB.

(2.)



(a)

UC 356 × 368 × 202 S275

Need to check for both z-z and y-y axis:

- z-z is the weaker axis but has a shorter buckling length ($L_{cr} = 1.0 \times 5\ m$)
- y-y is the stronger axis but has a longer buckling length ($L_{cr} = 0.85 \times 10\ m$)

Hence no conclusion which axis is more critical (yet).

Section Designation	Mass per Metre	Depth of Section	Width of Section	Thickness		Root Radius	Depth between Fillets	Ratios for Local Buckling		Dimensions for Detailing			Surface Area	
				Web	Flange			Flange	Web	End Clearance	Notch		Per Metre	Per Tonne
		h	b	t_w	t_f	r	d	c_f / t_f	c_w / t_w	C	N	n		
	kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m^2	m^2
356x368x202	201.9	374.6	374.7	16.5	27.0	15.2	290.2	6.07	17.6	10	190	44	2.19	10.8

Section Designation	Second Moment of Area		Radius of Gyration		Elastic Modulus		Plastic Modulus		Buckling Parameter	Torsional Index	Warping Constant	Torsional Constant	Area of Section
	Axis y-y	Axis z-z	Axis y-y	Axis z-z	Axis y-y	Axis z-z	Axis y-y	Axis z-z	U	X	I_w	I_T	A
	cm^4	cm^4	cm	cm	cm^3	cm^3	cm^3	cm^3			dm^6	cm^4	cm^2
356x368x202	66300	23700	16.1	9.60	3540	1260	3970	1920	0.844	13.35	7.16	558	257

Check z-z buckling:

- $L_{cr} = 1.0 \times 5 = 5\ m$ (Checking the top half (pin-pin) as it is more critical than the bottom half (fixed-pin))
- $\lambda_1 = 93.9 \times \sqrt{\frac{235}{275}} = 86.8$
- $\bar{\lambda}_z = \frac{5}{9.60 \times 10^{-2}} \times \frac{1}{86.8} = 0.6 > 0.2$; need check buckling
  (use i_z)
- $\Rightarrow \frac{h}{b} = \frac{374.6}{374.7} = 1.00 \leq 1.2$
  $\Rightarrow t_f = 27.0\ mm \leq 100\ mm$
  $\Rightarrow$ Buckling about z-z, S275

  } Curve ©, $\alpha = 0.49$

- $\phi = 0.5\left[1 + 0.49\,(0.60 - 0.2) + 0.60^2\right] = 0.778$
- $\chi = \dfrac{1}{0.778 + \sqrt{0.778^2 - 0.60^2}} = 0.785$
- $N_{b,Rd,z} = 0.785 \times \dfrac{(257 \times 10^{-4})(275 \times 10^6)}{1.0} \times 10^{-3}\ kN$

  $= 5548\ kN > N_{Ed} = 4800\ kN$ OK!

Check y-y buckling:

- $L_{cr} = 0.85 \times 10 = 8.5\ m$ (fixed - pin)
- $\lambda_1 = 93.9 \times \sqrt{\dfrac{235}{275}} = 86.8$
- $\bar{\lambda}_z = \dfrac{8.5}{16.1 \times 10^{-2}} \times \dfrac{1}{86.8} = 0.608 > 0.2$; need check buckling

  (use i_y)

- ⇒ $\dfrac{h}{b} = \dfrac{374.6}{374.7} = 1.00 \leq 1.2$

  ⇒ $t_f = 27.0\ mm \leq 100\ mm$

  ⇒ Buckling about y-y, S275

  } Curve ⓑ, $\alpha = 0.34$

- $\phi = 0.5\left[1 + 0.34\,(0.608 - 0.2) + 0.608^2\right] = 0.754$
- $\chi = \dfrac{1}{0.754 + \sqrt{0.754^2 - 0.608^2}} = 0.833$
- $N_{b,Rd,y} = 0.833 \times \dfrac{(257 \times 10^{-4})(275 \times 10^6)}{1.0} \times 10^{-3}\ kN$

  $= 5887\ kN > N_{Ed} = 4800\ kN$ OK!

③ (a) Reaction at F, $R_F = \frac{65 \times 3.2}{2} = 104 \text{ kN}$

- $N_{Ed} = 1200 + 104 = 1304 \text{ kN}$
- $M_{Ed,y} = R_F \times e_y = 104 \times \left(100 + \frac{260.3}{2}\right) \times 10^{-3} \text{ kNm} = 23.94 \text{ kNm}$
- $M_{Ed,z} = 0 \text{ kNm}$

$f_y = 275 \text{ N/mm}^2$

Section Designation	Mass per Metre (kg/m)	Depth of Section h (mm)	Width of Section b (mm)	Thickness Web t_w (mm)	Thickness Flange t_f (mm)	Root Radius r (mm)	Depth between Fillets d (mm)	Ratios for Local Buckling Flange c_f / t_f	Ratios for Local Buckling Web c_w / t_w	Dimensions for Detailing End Clearance C (mm)	Notch N (mm)	Notch n (mm)	Surface Area Per Metre (m^2)	Surface Area Per Tonne (m^2)
254x254x89	88.9	260.3	256.3	10.3	17.3	12.7	200.3	6.38	19.4	7	134	30	1.50	16.9
254x254x73	73.1	254.1	254.6	8.6	14.2	12.7	200.3	7.77	23.3	6	134	28	1.49	20.4

Section Designation	Second Moment of Area Axis y-y (cm^4)	Second Moment of Area Axis z-z (cm^4)	Radius of Gyration Axis y-y (cm)	Radius of Gyration Axis z-z (cm)	Elastic Modulus Axis y-y (cm^3)	Elastic Modulus Axis z-z (cm^3)	Plastic Modulus Axis y-y (cm^3)	Plastic Modulus Axis z-z (cm^3)	Buckling Parameter U	Torsional Index X	Warping Constant I_w (dm^6)	Torsional Constant I_T (cm^4)	Area of Section A (cm^2)
254x254x89	14300	4860	11.2	6.55	1100	379	1220	575	0.850	14.46	0.717	102	113
254x254x73	11400	3910	11.1	6.48	898	307	992	465	0.849	17.24	0.562	57.6	93.1

(b) **Buckling Check**

Check z-z axis as it is more critical than y-y.
(Same $L_z = L_y$ but $I_z < I_y$)

- $L_{cr} = \underline{0.85} \times 5.8 = 4.93 \text{ m}$
  (pin-fixed)
- $\lambda_1 = 93.9 \times \sqrt{\frac{235}{275}} = 86.8$
- $\bar{\lambda} = \frac{4.93}{6.55 \times 10^{-2}} \times \frac{1}{86.8} = 0.867$
- $\Rightarrow \frac{h}{b} = \frac{260.3}{256.3} = 1.02 \leq 1.2$
  $\Rightarrow t_f = 17.3 \text{ mm} \leq 100 \text{ mm}$
  $\Rightarrow$ Buckling about z-z, S275

  } Curve ©, $\alpha = 0.49$

- $\phi = 0.5\left[1 + 0.49(0.867 - 0.2) + 0.867^2\right] = 1.039$

- $\chi = \dfrac{1}{1.039 + \sqrt{1.039^2 - 0.867^2}} = 0.621$

- $N_{b,Rd} = 0.621 \times \dfrac{(113 \times 10^{-4})(275 \times 10^{6})}{1.0} \times 10^{-3}\ kN$

  $= 1930\ kN > N_{Ed} = 1304\ kN$ OK!

LTB Check

- $L_{FG} = 5.8m$ (Lateral restraints at F & G)
- $\psi = +1.0 \Rightarrow C_1 = 1.0$ →

  (fixed - pin)

  (if it's pin-pin, $\psi = 0$, $C_1 = 1.77$)

- $M_{cr} = 1.0 \times \dfrac{\pi^2 (210\times\cancel{10^9})(4860\times\cancel{10^{-8}})}{(5.8)^2} \times \sqrt{\dfrac{0.717\times10^{\cancel{-6}\,2}}{4860\times\cancel{10^{-8}}} + \dfrac{(5.8)^2(81\times\cancel{10^9})(102\times\cancel{10^{-8}})}{\pi^2(210\times\cancel{10^9})(4860\times\cancel{10^{-8}})}} \times 10^{-3}\ kNm$

  $= 616.2\ kNm$

- $\bar{\lambda}_{LT} = \sqrt{\dfrac{1220 \times 275}{616.2 \times 10^3}} = 0.738 > 0.2$, LTB check needed

- $\dfrac{h}{b} = \dfrac{260.3}{256.3} = 1.02 < 2$, rolled ⇒ ⓐ ⇒ $\alpha_{LT} = 0.21$

- $\phi_{LT} = 0.5\left[1 + 0.21(0.738 - 0.2) + 0.738^2\right] = 0.829$

- $\chi_{LT} = \dfrac{1}{0.829 + \sqrt{0.829^2 - 0.738^2}} = 0.829 < 1.0$

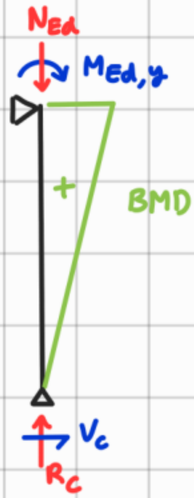
- $M_{b,Rd} = 0.829 \times \dfrac{1220 \times 275}{1.0} \times 10^{-3}\ kNm$

  $= 278.1\ kNm > M_{Ed,y} = 23.94\ kNm$ OK!

(c) From (b) we know that flexural buckling is much more critical than LTB, so we just use flexural buckling check as reference.

Buckling Check

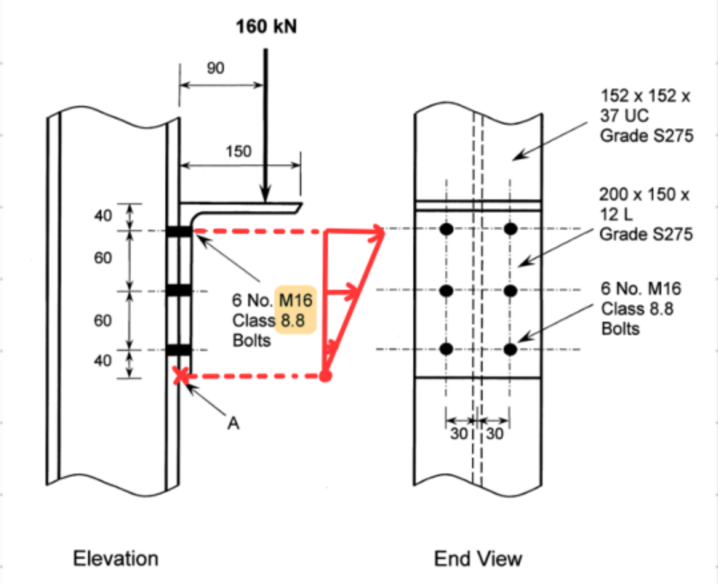
Check z-z axis as it is more critical than y-y.
(Same $L_z = L_y$ but $I_z < I_y$)



- $L_{cr} = \underset{\text{(pin-pin)}}{1.0} \times 5.8 = 5.8 \text{ m}$
- $\lambda_1 = 93.9 \times \sqrt{\frac{235}{275}} = 86.8$
- $\bar{\lambda} = \frac{5.8}{6.55 \times 10^{-2}} \times \frac{1}{86.8} = 1.02$
- $\Rightarrow \frac{h}{b} = \frac{260.3}{256.3} = 1.02 \leq 1.2$
  $\Rightarrow t_f = 17.3 \text{ mm} \leq 100 \text{ mm}$
  $\Rightarrow$ Buckling about z-z, S275
  } Curve ©, $\alpha = 0.49$
- $\phi = 0.5\left[1 + 0.49\left(1.02 - 0.2\right) + 1.02^2\right] = 1.221$
- $\chi = \frac{1}{1.221 + \sqrt{1.221^2 - 1.02^2}} = 0.528$
- $N_{b,Rd} = 0.528 \times \frac{(113 \times 10^{-4})(275 \times 10^6)}{1.0} \times 10^{-3} \text{ kN}$
  $= 1640 \text{ kN} > N_{Ed} = 1304 \text{ kN}$ // OK!

∴ Column will still be adequate to resist design actions.

④ (a)



Center of rotation at A.

1. Break down forces

- $F_s = \frac{160}{6} = 26.7 \text{ kN}$

-

y	y^2
160	25600
100	10000
40	1600 +

$\Sigma y^2 = 37\,200 \text{ mm}^2$

$$F_T = \frac{Pey_1}{2\Sigma y_i^2} = \frac{(160)(90)(160)}{2 \times 37\,200} = 31.0 \text{ kN}$$

(2 → 2 columns of bolt)

2. Design Check (top-most bolt)

Ø16mm Class 8.8 (S275) : from section properties table,

$F_{v,Rd} = 60.3 \text{ kN} > F_{v,Ed} = 26.7 \text{ kN}$ // OK!

$F_{t,Rd} = 90.4 \text{ kN} > F_{t,Ed} = 31.0 \text{ kN}$ // OK!

(b) $F_{p,C} = 0.7 \times 800 \times 157 \times 10^{-3} \text{ kN} = 87.92 \text{ kN}$

$$F_{s,Rd} = \frac{1 \times 1 \times 0.5\,(87.92 - 0.8\,(31.0))}{1.1} = 28.7 \text{ kN} > F_{v,Ed} = 26.7 \text{ kN}$$ // OK!

(c) **Pros of preloaded HSFG bolts**

1. Rigidity in joints (no slip in service)
2. No loosening of bolts due to vibrations
3. Tolerance for fabrication/erection due to the use of clearance holes //

atb glhf ☺