

CVX7640 - Structural Design

FINAL EXAMINATION - 2023/2024

Time Allowed: Four (04) Hours

Date: 2025 - 03 - 05 (Wednesday)

Time: 0930 - 1330 hrs.

Paper consists of five (05) questions. Answer any four (04) questions.

You may use the booklet named "Extracts From Codes" provided to you with the course material, which also contain concrete design charts & steel sectional properties

You may assume and state reasonable values for any factors not provided.

**Q1.** A Class 2, post-tensioned prestressed concrete beam for the roof of an industrial structure has a simply supported span of 12m. The beam supports a dead load of 50 kN/m (not including self-weight) together with an imposed load of 40 kN/m in addition to self-weight. The proposed cross-section of the prestressed beam with the tendon arrangement for the midspan section is given in Figure Q1.

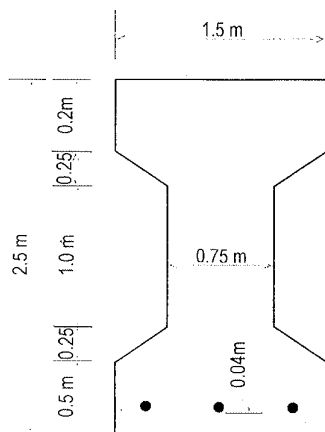


Figure Q1

**Strengths**

$f_{cu}$  at 28 days = 40 N/mm<sup>2</sup>  
 $f_{ct}$  at 7 days (transfer) = 28 N/mm<sup>2</sup>

Transfer is 7 day after casting

$f_{pu}$  Super strand 25.0 mm dia. Strands  
(assume 70 % effective after losses) = 1500 N/mm<sup>2</sup>

**Loads**

Unit weight of concrete = 24 kN/m<sup>3</sup>  
Dead load other than self-weight = 50.0 kN/m  
Imposed load = 40.0 kN/m  
(Assuming loads to be distributed evenly.)

**Loss of prestress**

at transfer = 10 %  
at service = 25 %

You may use following inequalities (in standard notation) for your calculations

$$Z_t \geq (\alpha M_s - \beta M_i) / (\alpha f_{max} - \beta f'_{min})$$

$$Z_b \geq (\alpha M_s - \beta M_i) / (\beta f_{max} - \alpha f_{min})$$

$$P_i \geq (Z_t f'_{min} - M_i) / \alpha (Z_t / A - e)$$

$$P_i \leq (Z_b f'_{max} + M_i) / \alpha (Z_b / A + e)$$

$$P_s \leq (Z_t f_{max} - M_s) / \beta (Z_t / A - e)$$

$$P_s \geq (Z_b f_{min} + M_s) / \beta (Z_b / A + e)$$

$$e \leq (M_i - Z_t f'_{min}) / \alpha P_i + Z_t / A$$

$$e \leq (M_i + Z_b f'_{max}) / \alpha P_i - Z_b / A$$

$$e \geq (M_s - Z_t f_{max}) / \beta P_i + Z_t / A$$

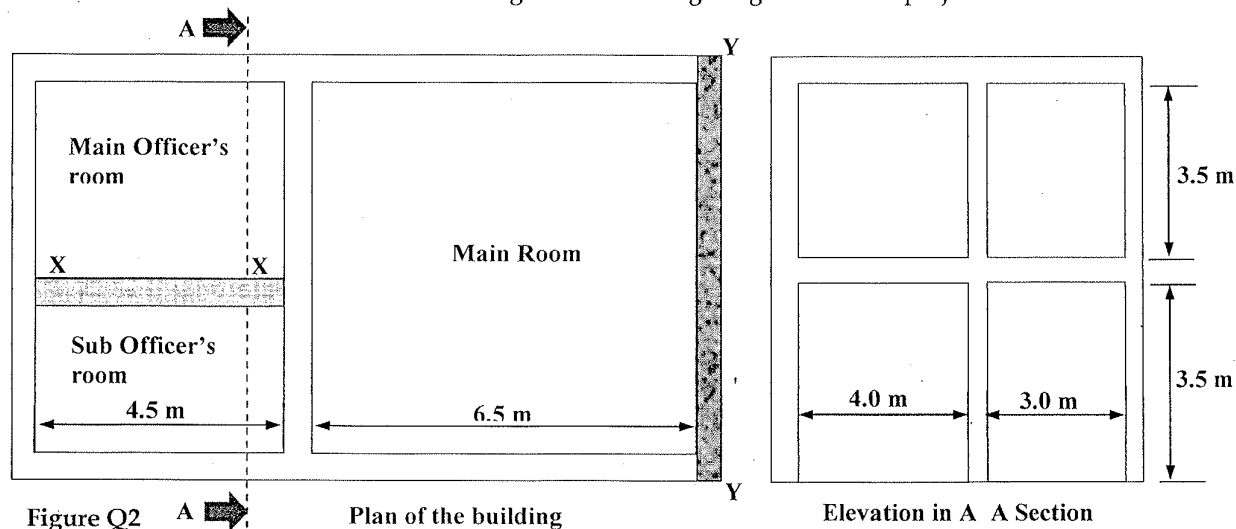
$$e \geq (M_s + Z_b f_{min}) / \beta P_i - Z_b / A$$

Using the above data, design the beam according to the following steps;

- Find the following  $A$ ,  $Z_t$  and  $Z_b$  of the given section. Second Moment of the area -  $I$  of the section is given as 1.07 m<sup>4</sup>. (03 Marks)
- Evaluate the dead and imposed loads on the beam at transfer and in service and calculate the critical bending moments at the two instances. (02 Marks)
- Check the adequacy of the section in carrying the stresses at transfer and in service for the range of spans. (02 Marks)
- State the four stress conditions applied in the beam for mid span critical section. (04 Marks)
- By using the four equations stated in iv). or with any other method show that the tendon arrangement given below is suitable for the mid span of the beam. (04 Marks)
- Show that the details are given in the tendon arrangement in v). is appropriate regarding the spacings of the tendons. (01 Mark)
- Check whether the given tendon arrangement is suitable for the support of the beam. If not find the solution to this problem. (02 Marks)
- Check the suitability of the designed section with respect to Ultimate Moment capacity. (03 Marks)
- Check the suitability of the designed section considering ultimate shear strength of the beam. (04 Marks)



Q2. As shown in Figure Q2, a two story building has to be constructed for security persons employed in a garment factory of a BOI company in Thulhiriya. It is load bearing masonry wall construction with two reinforced concrete slabs. You have been assigned as the design engineer for the project.



It has identical floor allocation in the ground and the 1<sup>st</sup> floor levels. 2<sup>nd</sup> floor is roof slab. Walls are constructed with locally made high quality bricks and their dimensions are 210mm\*105mm\*50mm, length, breath, height, respectively. Half brick wall construction is 105 mm, one brick wall construction is 220 mm, one & half brick wall construction is 335 mm. Further, wall thickness for the ground and the first floors are 355 mm and 240 mm (including plaster thickness), respectively. The stair cases are externally fixed and do not contribute to loadings of the building.

#### Loads

Imposed load on the 2<sup>nd</sup> floor = 4.0 kN/m<sup>2</sup>

Imposed load on the 1<sup>st</sup> floor = 3.5 kN/m<sup>2</sup>

Dead load due to finishes on slab = 0.5 kN/m<sup>2</sup>

#### Geometry

Thickness of floor slabs = 125mm

Floor to floor clear height = 3.5 m

#### Material Properties

Unit weight of RC = 24.0 kN/m<sup>3</sup>

Unit weight of masonry = 20.0 kN/m<sup>3</sup>

Mortar Designation II

Compressive Strength of Brick = 5.0 N/mm<sup>2</sup>

$\gamma_m$  for compression and flexure = 3.5

Water absorption - between 7%- 12%

#### Part I

- Evaluate characteristic dead and imposed loads acting on the internal wall X-X (at the ground floor level). (04 Marks)
- Find different load combinations and corresponding design loads and eccentricities at the first floor level. (03 Marks)
- Check the eccentricities with the allowable eccentricity of the wall ( $0.05 \times \text{wall thickness}$ ) and obtain the ultimate limit state design load at the ground floor level (02 Marks)
- Determine the slenderness ratio of the wall (ground floor level) and compare with its permissible value. (02 Marks)
- Check whether the internal wall (ground floor level) is able to carry the design compressive load considering vertical load resistance of the wall. (02 Marks)

#### Part II

- Draw a figure showing boundary conditions for the external wall Y-Y in 1<sup>st</sup> floor level to 2<sup>nd</sup> floor level. (02 Marks)
- Check the limiting dimensions of the wall panel Y-Y. (02 Marks)
- Determine the orthogonality ratio of the wall panel Y-Y at the 1<sup>st</sup> floor to the 2<sup>nd</sup> floor level (02 Marks)
- Determine the bending moments parallel and perpendicular to the bed joint if it is subjected to a lateral load of 5 kN/m<sup>2</sup> from the 1<sup>st</sup> floor level to the 2<sup>nd</sup> floor level. (04 Marks)
- Check the safety of the external wall panel under the given lateral load considering moment failures. (02 Marks)



**Q3.** An outdoor platform to appreciate the scenic beauty of the mountain ranges while having meals, need to be constructed for a tourist hotel in the Ella area. For better natural feeling the hotel management preferred a timber deck abutting on an external wall. As shown in the Cross-Section (Figure Q3A) and Part-Plan (Figure Q3B) of the proposed platform, the structure is to be finally supported on corbels protruding from the abutting wall and timber columns supported on concrete pads constructed on sloping rock. The floor is to be a wooden plank decking supported by a timber beam framework.

Transverse beams support the longitudinal beams topped by the decking. Transverse beams are supported on corbels extending from the rear wall and on timber columns in the front with a cantilevering portion as shown in the dimensioned sketch below.

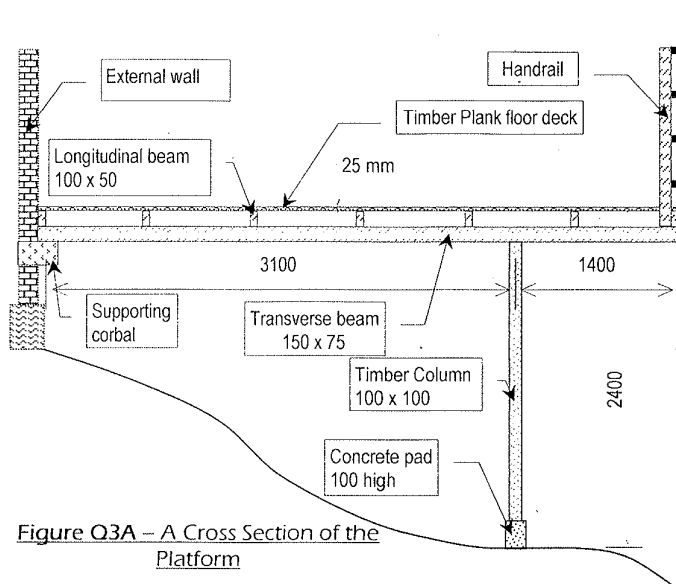


**Figure Q3A – A Cross Section of the Platform**

#### Loads

Imposed load on the platform =  $1.0 \text{ kN/m}^2$   
[You may assume the loads transferred to a Transverse beam by the longitudinal beams, as uniformly distributed loads(udl)]

#### Assumptions

- Halmilla Timber (Class D70) for all applications
- Exposure condition is Wet
- Dead load by handrail could be neglected

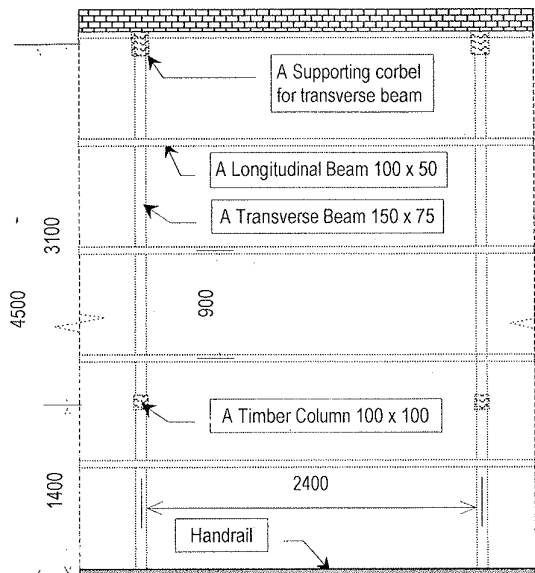


**Figure Q3B – A Part Plan of the Platform**

Check the design adequacy of a **Transverse beam** according to BS 5268-1996, using following steps;

- Evaluate the loading on a Transverse Beam due to **live and dead** loads and sketch Bending Moment and Shear Force diagrams. (03 Marks)
- Check the proposed flexural member against **lateral stability** criteria. (01 Marks)
- Compute the applied **bending stress** at the critical section of a beam and check whether this is within the permissible limit for the flexural member. (03 Marks)
- Check whether the **maximum allowable deflection** is within the permissible limit which is generally equal to  $0.003L$ . (03 Marks)  
(You may use; Deflection at midspan =  $5wL^4 / (384EI)$  Simply supported section loaded with a udl  
Deflection at tip =  $wL^4 / (8EI)$  Cantilever section loaded with a udl )
- Check whether the flexural member is safe against failure due to **shear**. (02 Marks)
- Evaluate the minimum corbal **protrusion length** required to support a transverse beam. (02 Marks)
- Comment on the selection of **timber Class** and **section size** of the transverse beam. (03 Marks)

Check the design adequacy of a structural timber **column** according to BS 5268-1996, using following steps;

- Evaluate the loading (including moment due to nominal eccentricity) on the column due to **live and dead** loads and check for slenderness limits. (02 Marks)
- Compute the applied maximum **compressive stress** in the column and check whether this is within the permissible limit. (03 Marks)
- Check the column for combined flexural (due to nominal eccentricity) and compressive stresses. (03 Marks)

Q4. A typical floor plan and a sectional view of a three storied commercial building is shown in Figure Q4A and Figure Q4B. The beams are cast monolithically with the floor slab.

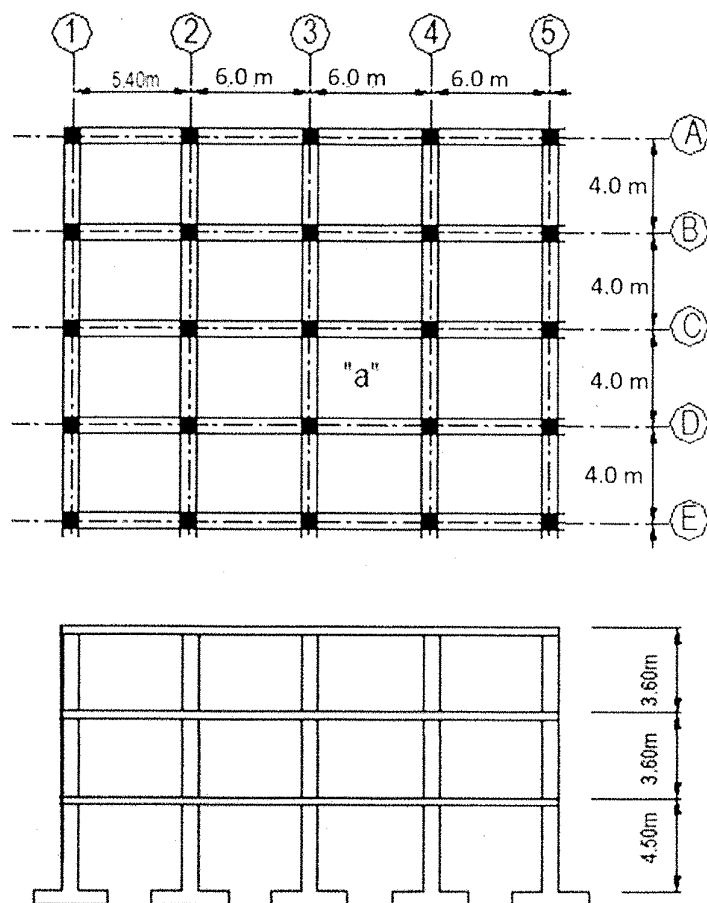


Figure Q4A: Floor plan and a sectional view

|                                                                    |                         |
|--------------------------------------------------------------------|-------------------------|
| <b>Strength of materials:</b>                                      |                         |
| Grade of concrete                                                  | = 30                    |
| Characteristic strength of steel                                   |                         |
| Main r/f                                                           | = 460 N/mm <sup>2</sup> |
| Shear r/f                                                          | = 250 N/mm <sup>2</sup> |
| Nominal cover for reinforcement                                    | = 20 mm                 |
| Order of floors – Ground, 1 <sup>st</sup> , 2 <sup>nd</sup> , Roof |                         |
| * Required design charts are provided in 'Code Extracts' *         |                         |

|                                        |                          |
|----------------------------------------|--------------------------|
| <b>Loads on the structure:</b>         |                          |
| Imposed load on the roof               | = 1.0 kN/m <sup>2</sup>  |
| Dead load by finishes on floors & roof | = 1.0 kN/m <sup>2</sup>  |
| Imposed load on floors                 | = 3.0 kN/m <sup>2</sup>  |
| ** You may neglect the effects of Wind |                          |
| Thickness of floor & roof slabs        | = 130 mm                 |
| <b>Weights of materials</b>            |                          |
| Unit weight of RC                      | = 24.0 kN/m <sup>3</sup> |

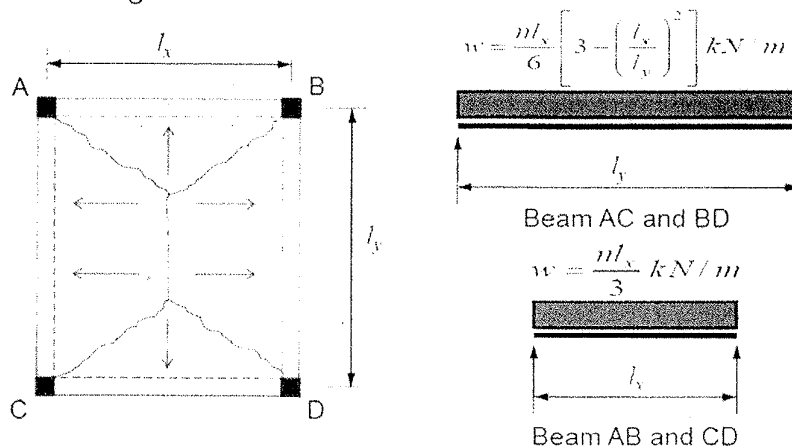


Figure Q4B: Equivalent UDL load transferred from slab to beam

Q 4.1 The first floor slab panel 'a' shown in Figure Q4A has been designed.

Q 4.1.1 Evaluate the design ultimate load (kN/m<sup>2</sup>) acting on the panel 'a'. (02 marks)

Q 4.1.2 Compute the bending moments acting at critical locations (mid-span and supports) of the panel 'a' using the bending moment coefficients from the BS8110-1:1997 (balancing of bending moments at common boundaries is not required). (02 marks)

Q 4.1.3 Design reinforcements for mid-span of this panel 'a' in short direction to satisfy code requirements. (02 marks)

Q 4.1.4 Check for deflection of the panel 'a' in short direction. (01 mark)



Q 4.2 The continuous beam along grid 3 (ABCDE) has to be designed (size : 400 x 300 mm).

Q 4.2.1 Evaluate the ultimate design load acting on the above beam (you may assume that the loads transferred to the beam from the slab are uniformly distributed along its span as shown in Figure 4B).

(02 marks)

Q 4.2.2 Calculate the ultimate bending moments of the above beam at critical locations using the table 3.5 given in BS8110-1:1997 for uniformly loaded continuous beams.

(02 marks)

Q 4.2.3 Design reinforcements for mid span moment of span AB of the above beam.

(02 marks)

Q 4.2.4 Check for deflection for span AB of the above beam

(01 mark)

Q 4.3 The column C4 which is at the point of intersection of grids C and 4 has to be designed (size 300x300mm)

Q 4.3.1 Assuming the column C4 is unbraced and no bending moments are transferred from beams framing into the column, evaluate the design ultimate axial load on the column at ground floor level.

(01 mark)

Q 4.3.2 Check whether ground floor column C4 is a slender column or short column. You may use simple method given in BS 8110:Part 1 or rigorous method given in BS 8110:Part 2.

(01 mark)

Q 4.3.3 Design reinforcement for ground floor column C4

(02 marks)

Q 4.4 A square pad footing to support the column C4 has to be designed.

Q 4.4.1 Explain with a neat sketch what is meant by "punching shear" failure of a pad footing. (01 mark)

Q 4.4.2 Explain the procedure you would follow to make sure that the footing is safe against ULS direct shear and punching shear failures. (01 mark)

Q5. A middle Column A in a two-storey office building needs to be designed according to BS5950-1:2000 and Figure Q5A shows the typical arrangement of beams and columns of the building. A UC 203x203x52 section is proposed for Column A and the loads applied at the top of the beam-column joint of Column A is shown in Figure Q5B.

Consider the following details for the design calculations;

- Clear height of the Column A is 4 m.
- Loads shown in Figure Q5B are unfactored loads.
- S275 steel sections are used for all beams and columns in the building.
- Column A is effectively held in position at both ends but only restrained in direction at bottom.
- Neglect the self-weight of the column.
- The imposed load from the first floor need NOT to be reduced by 10%.
- Consider the bending moments applied about **both axes** (X-axis and Y-axis) due to a minimum eccentricity of 100 mm from the face of the column section.
- Sectional Properties of UC 203x203x52 steel section are given in the Annex Table Q5.

(You have to mention the relevant clauses and tables of BS5950-1:2000 near your calculation steps.)

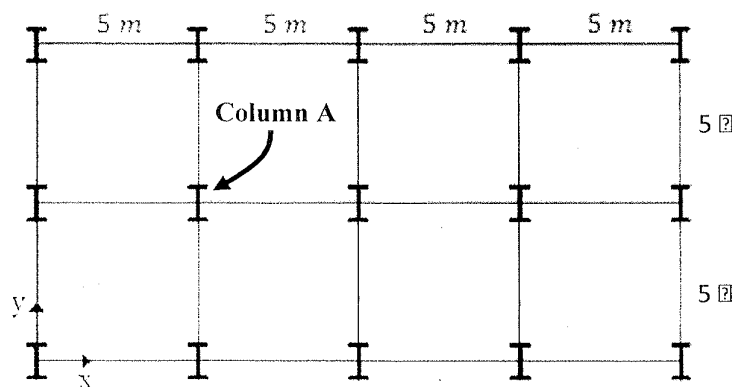


Figure Q5A - Typical beam and column arrangement of the building



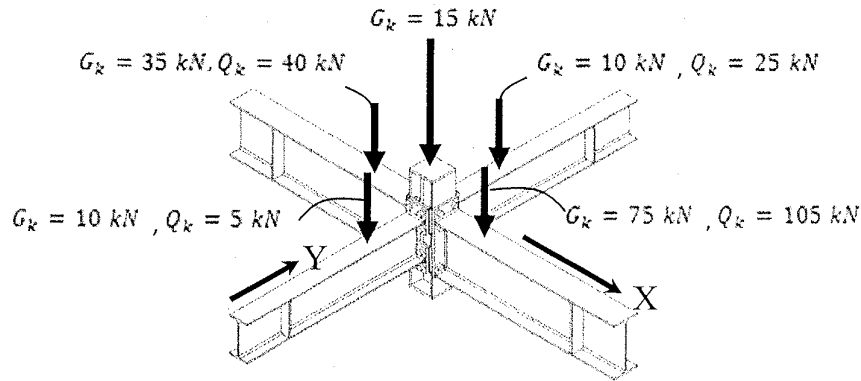
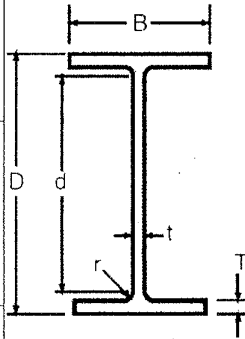


Figure Q5B - Loads applied at the top beam-column joint of Column A (unfactored loads)

- Briefly explain why 'section classification' is done when designing the steel sections? [05 Marks]
- Calculate the design axial load and design bending moments (due to eccentricities) applied on Column A. [04 Marks]
- Conduct the section classification and identify the class of the steel section which is being used for Column A. [04 Marks]
- Calculate the slenderness  $\lambda$  of both  $x -$  axis and  $y -$  axis of Column A. [04 Marks]
- Check the adequacy of the UC 203x203x52 section for Column A. [08 Marks]

Table Q5 – Sectional Properties of UC 203 × 203 × 52 steel section

| Section Designation | Mass per meter [kg/m]       | Depth of section (D) [mm]   | Width of section (B) [mm]   | Thickness of web (t) [mm]   | Thickness of Flange (T) [mm] | Root radius (r) mm  | Depth between fillets (d) [mm]          | Ratios for local buckling                 |                                    | Second moment of area            |                             | Radius of gyration                                                                    |               |
|---------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------------------------------|---------------------|-----------------------------------------|-------------------------------------------|------------------------------------|----------------------------------|-----------------------------|---------------------------------------------------------------------------------------|---------------|
|                     |                             |                             |                             |                             |                              |                     |                                         | Flange (B/2T)                             | Web (d/t)                          | Axis x-x [cm <sup>4</sup> ]      | Axis y-y [cm <sup>4</sup> ] | Axis x-x [cm]                                                                         | Axis y-y [cm] |
| 203x203x52          | 52.0                        | 206.2                       | 204.3                       | 7.9                         | 12.5                         | 10.2                | 160.8                                   | 8.17                                      | 20.4                               | 5259                             | 1778                        | 8.91                                                                                  | 5.18          |
| Section Designation | Elastic modulus             |                             | Plastic modulus             |                             | Buckling parameter (u)       | Torsional index (x) | Warping constant (H) [dm <sup>6</sup> ] | Torsional constant (J) [cm <sup>4</sup> ] | Area of section [cm <sup>2</sup> ] | Indicative values for Advance275 |                             |  |               |
|                     | Axis x-x [cm <sup>3</sup> ] | Axis y-y [cm <sup>3</sup> ] | Axis x-x [cm <sup>3</sup> ] | Axis y-y [cm <sup>3</sup> ] |                              |                     |                                         |                                           |                                    | $M_{cx}$ [kNm]                   | $P_{cy}$ for $L_e=3.5$ [kN] |                                                                                       |               |
| 203x203x52          | 510                         | 174                         | 567                         | 264                         | 0.848                        | 15.8                | 0.167                                   | 31.8                                      | 66.3                               | 156                              | 1230                        |                                                                                       |               |