STEEL BUILDINGS IN EUROPE

Multi-Storey Steel Buildings
Part 8: Description of member resistance calculator

Multi-Storey Steel Buildings
Part 1: Description of member resistance calculator

FOREWORD

This publication is part eight of the design guide, *Multi-Storey Steel Buildings*.

The 10 parts in the *Multi-Storey Steel Buildings* guide are:

Part 1: Architect's guide
Part 2: Concept design
Part 3: Actions
Part 4: Detailed design
Part 5: Joint design
Part 6: Fire Engineering
Part 7: Model construction specification
Part 8: Description of member resistance calculator
Part 9: Description of simple connection resistance calculator
Part 10: Guidance to developers of software for the design of composite beams

Multi-Storey Steel Buildings is one of two design guides. The second design guide is *Single-Storey Steel Buildings.*

The two design guides have been produced in the framework of the European project "Facilitating the market development for sections in industrial halls and low rise buildings (SECHALO) RFS2-CT-2008-0030".

The design guides have been prepared under the direction of Arcelor Mittal, Peiner Träger and Corus. The technical content has been prepared by CTICM and SCI, collaborating as the Steel Alliance.

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SUMMARY

This document describes the member resistance calculator, created in Excel, for members in axial compression, in bending, in combined axial compression and bending and in tension, used in steel buildings. It explains the scope of the workbook and lists the National Annexes and languages that are supported in the workbook. A description is given of each of the worksheets and the input information on each sheet. A screenshot of typical output is presented.

1 INTRODUCTION

This document provides an introduction to the Excel workbook that calculates the design resistance of steel members (beams and columns) in accordance with EN 1993-1-1, as part of the design guide *Multi-storey steel buildings*. The workbook offers the alternative of different languages, and selection of National Annex values.

The operation of the spreadsheet is described in the following Section 2. Screenshots of the various sheets in the workbook are given in Section 3.

1.1 Visual Basic

The spreadsheet depends on extensive visual basic code. Some users may have security settings set to disable such code.

The security level can be changed by selecting: "Tools", "Options". Select the "Security" tab and select "Macro security". The setting must be at least "Medium". Usually, Excel must be closed and re-started for the changes in security levels to become effective.

1.2 Scope

The spreadsheet calculates resistances of steel members subject to the following types of forces and moments:

- Axial compression
- Bending
- Combined axial compression and bending
- Tension
- Shear
- Point load (Web bearing and buckling)

Each worksheet provides a cross-sectional view of the selected section as well as the main geometric data. In the case of tension and web bearing and buckling resistance, it also provides a graphic illustration drawn to scale showing what the detail looks like.

Member resistances and drawn details are immediately updated as input data is modified by the user.

1.2.1 National Annex

The workbook includes National Annex values for γ_{M0}, γ_{M1} and γ_{M2}. for the following countries:

- Belgium
- France
- Germany
- Italy

- Netherlands
- Poland
- Spain
- United Kingdom

The user has the option to overwrite the in-built National Annex values, allowing flexibility should the values be modified by the national standards body. If this option is selected, then the calculation procedure reverts to the recommended options for all engineering methods, such as design strength of steel, buckling curves or imperfection factors, rather than those in the National Annex.

1.2.2 Language

The language for input and output may be set by the user. The following languages are supported:

- French
- German
- Italian
- Polish
- Spanish
- English

1.3 Design rules

The design resistances of members are evaluated in accordance with EN 1993-1-1 and EN 1993-1-5 and the selected National Annexes.

2 OPERATION OF THE WORKBOOK

2.1 Introduction worksheet

The “introduction” sheet merely records the scope of the spreadsheet. On the initial loading of the spreadsheet, this is the only tab visible. Choosing to “continue” reveals the remaining tabs.

2.2 Localisation Worksheet

The “localisation” worksheet allows the user to select the language and the National Annex (which determines the Nationally Determined Parameters (NDPs) that are to be used in calculations).

Checking the “overwrite” option allows the user to enter partial factor values of their choice. The engineering functionality which is set by the National Annex is taken from the recommended options in the Eurocodes.

Deselecting the “overwrite” option leaves the National Annex selection as a blank – the user must select National Annex from the drop down menu.

Default settings of Language and National Annex may be saved. The values are written to a simple text file, stored in the same folder as the workbook. Subsequent saving will merely overwrite this file.

Loading defaults will import whatever settings of language and National Annex that had previously been saved.

User Information

User name, project name and job number may be entered. Any data entered will appear on the printed output.

2.3 Functionalities on the member resistance worksheets

Each of the worksheets for axial compression, bending, combined axial compression and bending, tension, shear and point load have three buttons – “Print”, “Create new comparison file” and “Add to comparison file”.

2.3.1 Print

A new sheet will open, where the user information (see section 2.2) and the details of the calculated resistance will appear. The print window will open up, where the user can select a printer and print.

2.3.2 Add to comparison file

By clicking on this button, a compare worksheet will open up where the main details of the resistance calculated are registered (see Section 2.9).

2.3.3 Create new comparison file

This option deletes any existing calculations in the comparison file and adds the most recent values. Therefore when this option is selected, a single calculation will appear in this file.

2.4 Bending Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

C_1 factor

The C_1 factor related to the bending moment diagram may be selected from the following:

- 1,13
- 1,21
- 1,23
- 1,35
- 1,49
- 1,68
- Linear

A diagram shows which bending moment diagram corresponds to a given C_1 factor. If the option “linear” is selected then two additional input boxes appear where the user must input:

- The maximum bending moment
- The minimum bending moment

Buckling length

The calculated resistance that is displayed is the design value of the lateral torsional buckling (LTB) resistance in kNm.

The figure shows a cross-section of the selected section, to scale, and the main geometric properties.

2.5 N-M (combined axial force and bending moment) Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

The internal moments and forces

- Maximum bending moment about the major axis, $M_{y,Ed,max}$
- Minimum bending moment about the major axis, $M_{y,Ed,min}$
- Maximum bending moment about the minor axis, $M_{z,Ed,max}$
- Minimum bending moment about the minor axis, $M_{z,Ed,min}$
- Axial force, N_{Ed}

Buckling lengths

- Major axis buckling length, L_y
- Minor axis buckling length, L_z
- Torsional buckling length, L_T
- Lateral torsional buckling length, L_{LTB}

Choice of Annex A or Annex B

The result that is displayed is the unity factor from the interaction equations 6.61 and 6.62 from EN 1993-1-1 and according to the chosen National Annex.

2.6 Tension Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HE
- UPE
- Equal Angles
- Unequal Angles (long leg attached)
- Unequal Angles (short leg attached)

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Number of bolts

When designing an angle, the number of bolts may be selected from the following :

- No bolt (weld)
- 1 bolt
- 2 bolts
- 3 bolts

Bolt size

The bolt size may be selected from the following:

- M12
- M14
- M16
- M18
- M20
- M22
- M24
- M27

The output is the tension resistance, calculated as the resistance of the gross section at yield for I sections or the minimum resistance of the gross section at yield and the net section at ultimate for angles, all given in kN.

The top figure shows a cross-section of the selected section, to scale and the main geometric properties.

The bottom figure shows the bolted detail, only when angle sections are selected.

2.7 Compression Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE
- Equal Angles
- Unequal Angles

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Buckling lengths

- Major axis buckling length, L_y
- Minor axis buckling length, L_z
- Torsional buckling length, L_T

The calculated resistances are the design values of compression resistance, for flexural buckling resistance about the major axis and the minor axis ($N_{b,y,Rd}$ and $N_{b,z,Rd}$) as well as the torsional buckling resistance ($N_{b,T,Rd}$), all given in kN for the relevant buckling lengths. In addition, the worksheet displays the minimum of these values.

The figure shows a cross-section of the selected section, to scale and the main geometric properties.

2.8 Web resistance (bearing and buckling) Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Position of the transverse load

- d: distance from the end of the load to the member end.
- s_s: stiff bearing length.

The output is the web bearing and buckling resistance, calculated as per EN 1993-1-5, given in kN.

The top figure shows a cross-section of the selected section, to scale and the main geometric properties.

The bottom figure shows the detail of the transverse load with respect to the end of the member.

2.9 Compare worksheet

The compare worksheet will display in a single line the main details of the resistance calculated. This sheet also shows any previously added calculations for any members, so it serves as a summary of all calculations.

Additional calculations can be added to this worksheet by selecting the “Add to comparison file” button on any other member resistance worksheets (see section 2.3.2).

Note that the compare worksheet is hidden if no details have been added to comparison file.

2.9.1 Print comparison file

This button formats the comparison file and opens up the print window, where the user can select a printer and print.

3 SCREENSHOTS

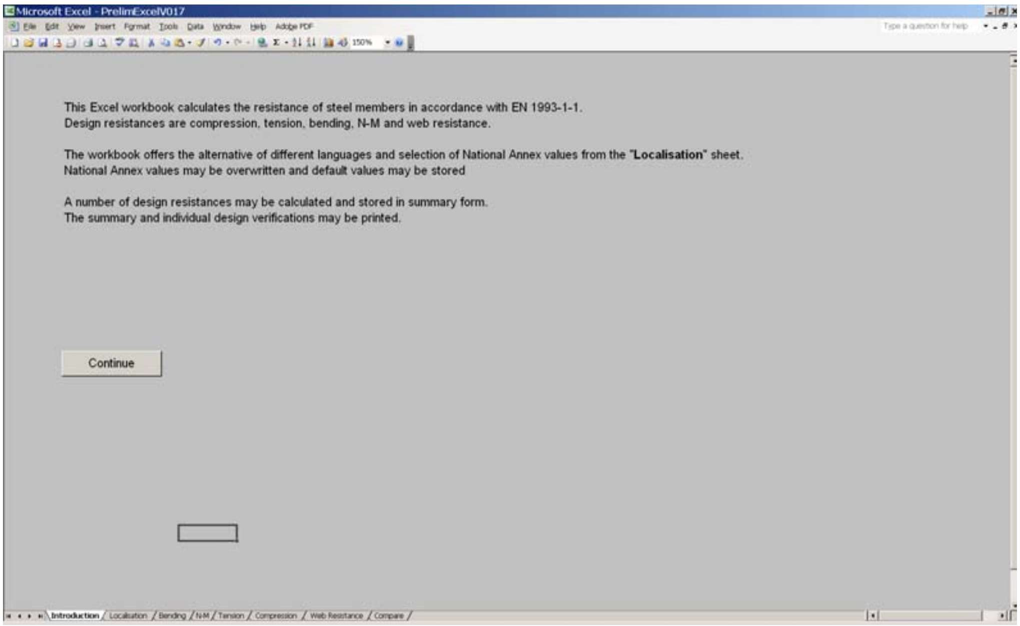


Figure 3.1 Introduction worksheet

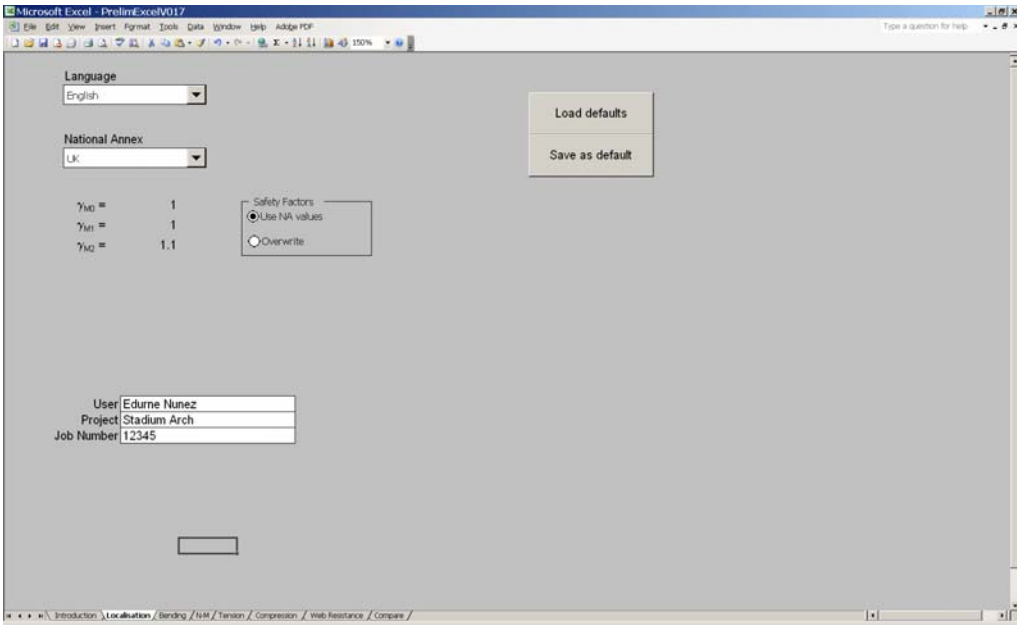


Figure 3.2 Localisation worksheet

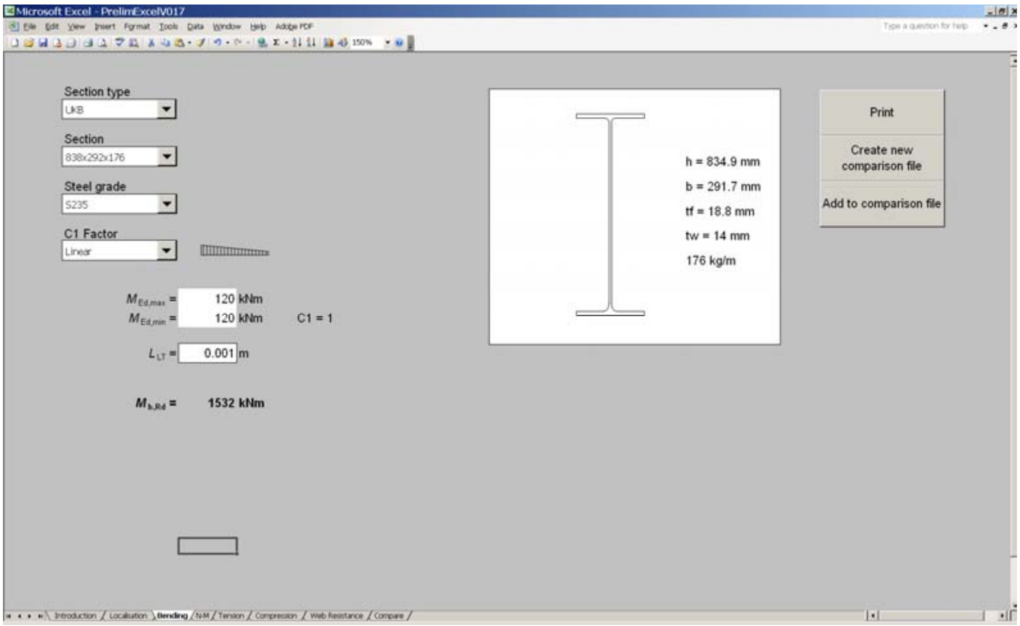


Figure 3.3 Bending worksheet

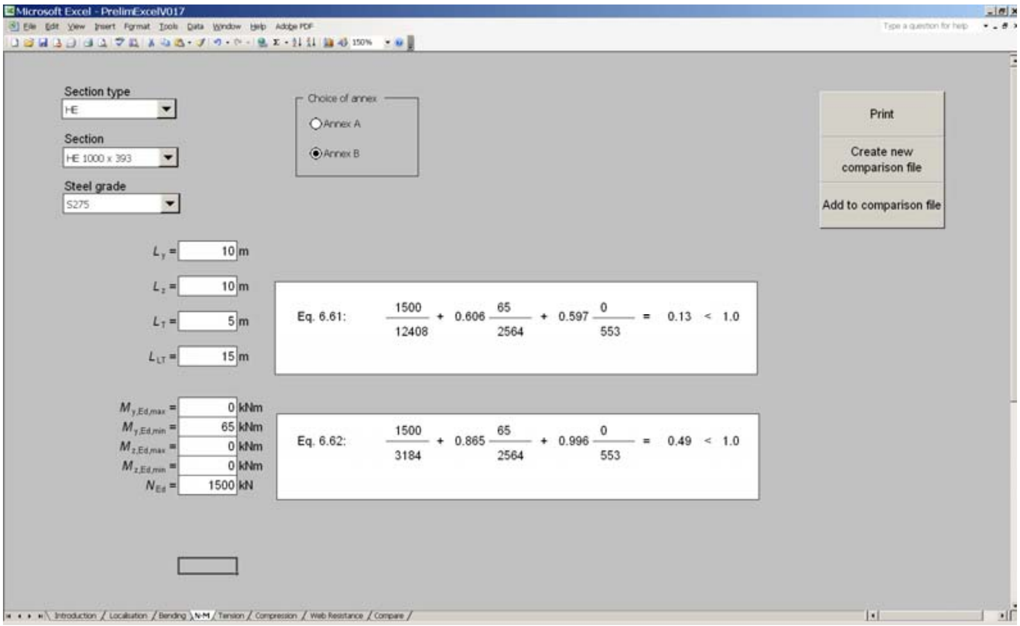


Figure 3.4 N-M worksheet

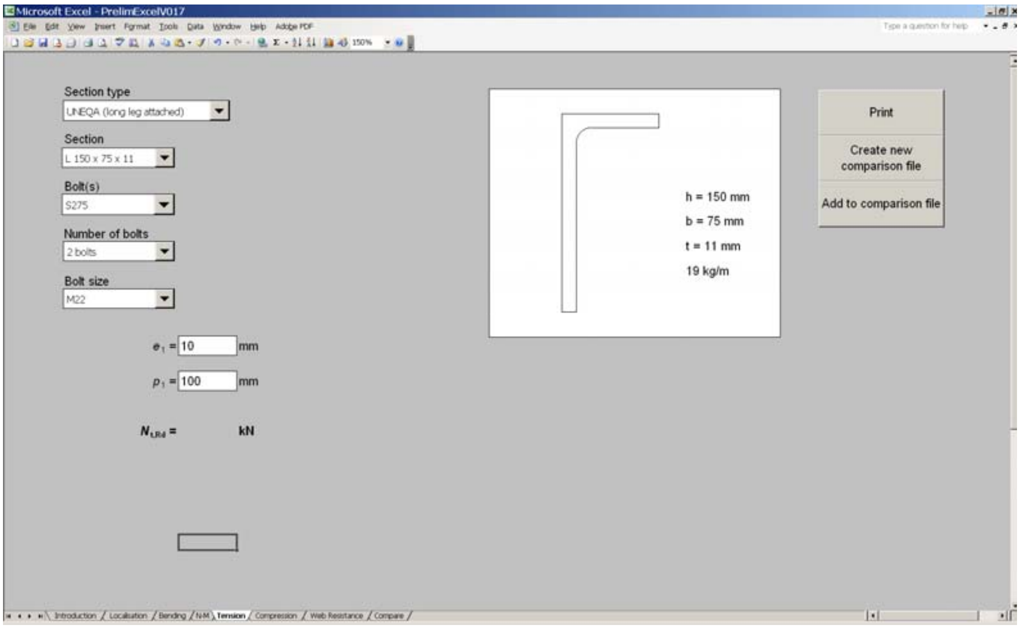


Figure 3.5 Tension worksheet

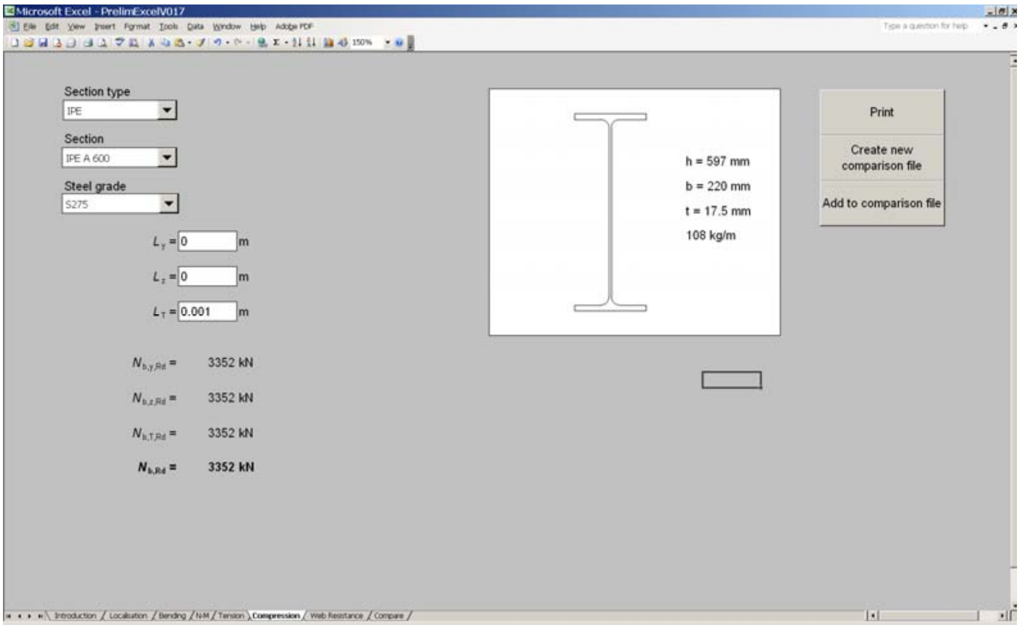


Figure 3.6 Compression worksheet

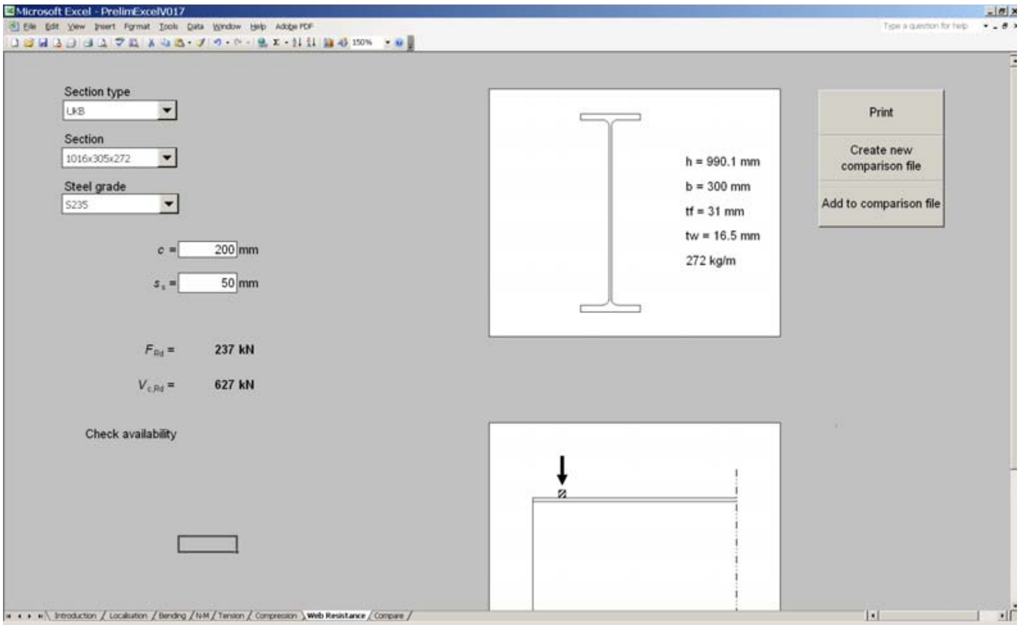


Figure 3.7 Web resistance worksheet

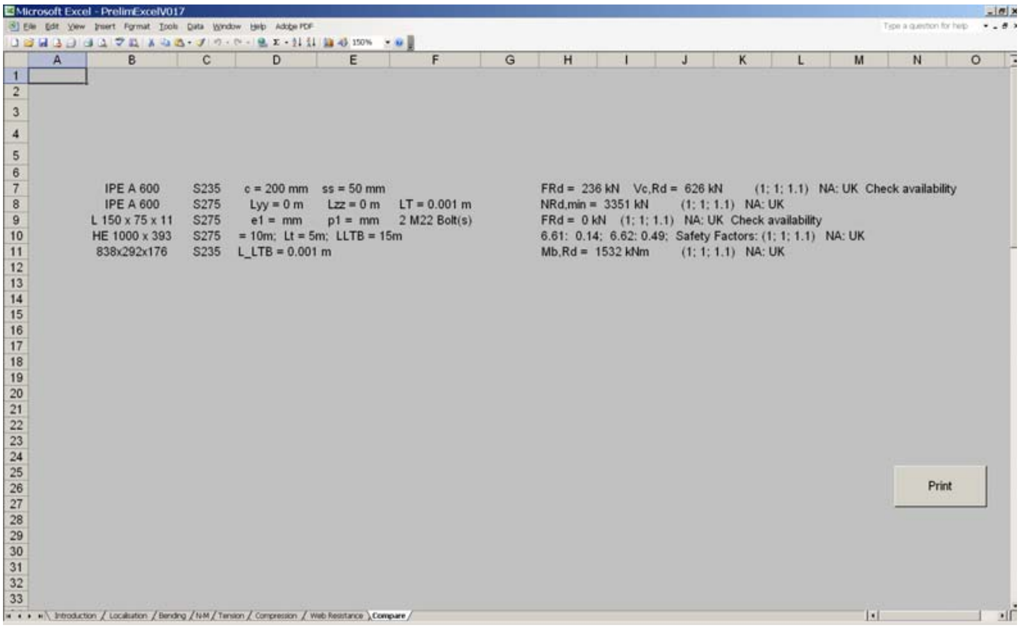


Figure 3.8 Compare worksheet

APPENDIX A Worked Examples

The worked examples show the design procedure used by the member resistance calculator for members in multi-storey building according to the Eurocodes.

The worked examples cover different type of designs:

1. Bending moment resistance
   - Supplementary calculations to demonstrate the influence of the French National Annex
2. Combined axial force and bending moment (N-M interaction)
3. Tension resistance
4. Compression resistance
5. Web resistance

Note that supplementary calculations are included to show that the influence of the French National Annex has been incorporated into the calculation routines.

References are to EN 1993-1-1 unless otherwise stated

1. Bending moment resistance

This example presents the method used in the member resistance calculator for calculating the bending moment resistance, adopting the recommended values of EN 1993-1-1.

Section: IPE 500

Steel grade: S355

$L \quad = 3{,}8 \text{ m}$

1.1. Cross-section classification

1.1.1. The web

Table 5.2 (Sheet 1)

$$\frac{c}{t_w} = \frac{426}{10{,}2} = 41{,}8$$

The limit for Class 1 is : $72\varepsilon = 72 \times 0{,}81 = 58{,}3$

Then : $\frac{c}{t_w} = 41{,}8 < 58{,}3$

→ The web is class 1.

1.1.2. The flange

Table 5.2 (Sheet 2)

$$\frac{c}{t_f} = \frac{73{,}9}{16} = 4{,}6$$

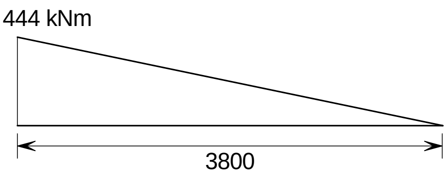
The limit for Class 1 is : $9\varepsilon = 9 \times 0{,}81 = 7{,}3$

Then : $\frac{c}{t_f} = 4{,}6 < 8{,}3$

→ The flange is Class 1

Therefore the section is Class 1. The verification of the member will be based on the plastic resistance of the cross-section.

1.2. Lateral-torsional buckling resistance, $M_{b,Rd}$



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$$\psi = \frac{0}{444} = 0 \qquad \rightarrow C_1 = 1{,}77$$

$$M_{cr} = C_1 \frac{\pi^2 EI_z}{L^2} \sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{\pi^2 EI_z}}$$

$$= 1,77 \times \frac{\pi^2 \times 210000 \times 2142 \times 10^4}{3800^2}$$

$$\times \sqrt{\frac{1249 \times 10^9}{2142 \times 10^4} + \frac{3800^2 \times 81000 \times 89,3 \times 10^4}{\pi^2 \times 210000 \times 2142 \times 10^4}}$$

Appendix C of Single-Storey Steel Building, Part 4

$M_{cr} = 1556 \times 10^6$ Nmm

§6.3.2.2

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{2194 \times 10^3 \times 355}{1556 \times 10^6}} = 0,708$$

For hot rolled sections

§6.3.2.3

$$\phi_{LT} = 0,5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta \bar{\lambda}_{LT}^2\right]$$

$\bar{\lambda}_{LT,0} = 0,4$ and $\beta = 0,75$

$$\frac{h}{b} = 2,5$$

Table 6.3
Table 6.5

$\rightarrow$ Curve **c** for hot rolled I sections

$\rightarrow \alpha_{LT} = 0,49$

$$\phi_{LT} = 0,5\left[1 + 0,49\left(0,708 - 0,4\right) + 0,75 \times 0,708^2\right] = 0,763$$

§6.3.2.3

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \beta \bar{\lambda}_{LT}^2}}$$

$$\chi_{LT} = \frac{1}{0,763 + \sqrt{0,763^2 - 0,75 \times 0,708^2}} = 0,822$$

$$\frac{1}{\bar{\lambda}_{LT}^2} = \frac{1}{0,708^2} = 1,99$$

Therefore $\chi_{LT} = 0,822$

$$f = 1 - 0,5\,(1 - k_c)\,[1 - 2,0\,(\bar{\lambda}_{LT} - 0,8)^2]$$

$$k_c = \frac{1}{1,33 + 0,33\,\psi} = \frac{1}{1,33 + 0,33 \times 0} = 0,75$$

$$f = 1 - 0,5\,(1 - 0,75)\,[1 - 2,0\,(0,708 - 0,8)^2] = 0,877$$

$$\chi_{LT\,mod} = \frac{\chi_{LT}}{f} = \frac{0,822}{0,877} = 0,937$$

$$M_{b,Rd} = \frac{\chi_{LT} W_{pl,y} f_y}{\gamma_{M1}} = \frac{0,937 \times 2194 \times 10^3 \times 355}{1,0} \times 10^{-6} = 730 \text{ kNm}$$

The French National Annex requires alternative values for $\bar{\lambda}_{\mathrm{LT,0}}$, α_{LT} and β. The revised calculations are demonstrated below.

$$\bar{\lambda}_{\mathrm{LT,0}} = 0{,}2 + 0{,}1\frac{b}{h} \quad = 0{,}2 + 0{,}1\frac{1}{2{,}5} = 0{,}24$$ French NA

$\beta = 1{,}0$ French NA

$$\alpha_{\mathrm{LT}} = 0{,}4 - 0{,}2\frac{b}{h}\bar{\lambda}_{\mathrm{LT}}^{2} \quad = 0{,}4 - 0{,}2 \times \frac{1}{2{,}5} \times 0{,}708^{2} = 0{,}36$$ French NA

$$\phi_{\mathrm{LT}} = 0{,}5\left[1 + 0{,}36(0{,}708 - 0{,}24) + 0{,}708^{2}\right] = 0{,}835$$

$$\chi_{\mathrm{LT}} = \frac{1}{0{,}835 + \sqrt{0{,}835^{2} - 0{,}708^{2}}} = 0{,}783$$

$$\chi_{\mathrm{LT\,mod}} = \frac{\chi_{\mathrm{LT}}}{f} = \frac{0{,}783}{0{,}877} = 0{,}892$$

$$M_{\mathrm{b,Rd}} = \frac{0{,}892 \times 2194 \times 10^{3} \times 355}{1{,}0} \times 10^{-6} = 695 \text{ kNm}$$

References are to EN 1993-1-1 unless otherwise stated

1. Combined axial force and bending moment

This example presents the method used in the member resistance calculator for calculating the out-of-plane buckling resistance and in-plane buckling resistance, adopting the recommended values of EN 1993-1-1.

Section: IPE 450

Steel grade: S355

$N_{\text{Ed}} = 127$ kN

$M_{\text{y,Ed}} = 356$ kNm (bending moment constant along the beam)

$M_{\text{z,Ed}} = 0$ kNm

$L_{\text{y}} = L_{\text{z}} = L_{\text{LT}} = L_{\text{cr}} = 1{,}7$ m

1.1. Cross-section classification

1.1.1. The web

Table 5.2 (Sheet 1)

$$\frac{c}{t_{\text{w}}} = \frac{378{,}8}{9{,}4} = 40{,}3$$

$$d_{\text{N}} = \frac{N_{\text{Ed}}}{t_{\text{w}} f_{\text{y}}} = \frac{127000}{9{,}4 \times 355} = 38$$

$$\alpha = \frac{d_{\text{w}} + d_{\text{N}}}{2 d_{\text{w}}} = \frac{378{,}8 + 38}{2 \times 378{,}8} = 0{,}55 \ > \ 0{,}50$$

The limit between Class 1 and Class 2 is : $\dfrac{396\varepsilon}{13\alpha - 1} = \dfrac{396 \times 0{,}81}{13 \times 0{,}55 - 1} = 52{,}1$

Then : $\dfrac{c}{t_{\text{w}}} = 40{,}3 < 52{,}1$

→ The web is class 1.

1.1.2. The flange

Table 5.2 (Sheet 2)

$$\frac{c}{t_{\text{f}}} = \frac{69{,}3}{14{,}6} = 4{,}7$$

The limit between Class 1 and Class 2 is : $9\,\varepsilon = 9 \times 0{,}81 = 7{,}3$

Then : $\dfrac{c}{t_{\text{f}}} = 4{,}7 < 7{,}3$

→ The flange is Class 1

Therefore, the section is Class 1. The verification of the member will be based on the plastic resistance of the cross-section.

1.2. Buckling verification

The buckling checks due to the interaction of axial compression and bending moment are carried out using expressions 6.61 and 6.62 from EN 1993-1-1.

Expressions (6.61) and (6.62)

$$\frac{N_{\mathrm{Ed}}}{\dfrac{\chi_{\mathrm{y}} N_{\mathrm{Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{yy}} \frac{M_{\mathrm{y,Ed}} + \Delta M_{\mathrm{y,Ed}}}{\chi_{\mathrm{LT}} \dfrac{M_{\mathrm{y,Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{yz}} \frac{M_{\mathrm{z,Ed}} + \Delta M_{\mathrm{z,Ed}}}{\dfrac{M_{\mathrm{z,Rk}}}{\gamma_{\mathrm{M1}}}} \leq 1{,}0$$

$$\frac{N_{\mathrm{Ed}}}{\dfrac{\chi_{\mathrm{z}} N_{\mathrm{Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{zy}} \frac{M_{\mathrm{y,Ed}} + \Delta M_{\mathrm{y,Ed}}}{\chi_{\mathrm{LT}} \dfrac{M_{\mathrm{y,Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{zz}} \frac{M_{\mathrm{z,Ed}} + \Delta M_{\mathrm{z,Ed}}}{\dfrac{M_{\mathrm{z,Rk}}}{\gamma_{\mathrm{M1}}}} \leq 1{,}0$$

These expressions can be simplified as follows:

- $\Delta M_{\mathrm{y,Ed}} = 0$ and $\Delta M_{\mathrm{z,Ed}} = 0$ for Class 1, Class 2 and Class 3 sections.
- $M_{\mathrm{z,Ed}} = 0$

Therefore expressions (6.61) and (6.62) can be written as:

$$\frac{N_{\mathrm{Ed}}}{N_{\mathrm{b,y,Rd}}} + k_{\mathrm{yy}} \frac{M_{\mathrm{y,Ed}}}{M_{\mathrm{b,Rd}}} \leq 1{,}0 \text{ and } \frac{N_{\mathrm{Ed}}}{N_{\mathrm{b,z,Rd}}} + k_{\mathrm{zy}} \frac{M_{\mathrm{y,Ed}}}{M_{\mathrm{b,Rd}}} \leq 1{,}0$$

1.3. Equation 6.61 (EN 1993-1-1)

1.3.1. Flexural buckling resistance about the major axis, $N_{\mathrm{b,y,Rd}}$

$$\frac{h}{b} = \frac{450}{190} = 2{,}37$$

$t_{\mathrm{f}} = 14{,}6$ mm

buckling about y-y axis:

Table 6.1
Table 6.2

→ Curve **a** for hot rolled I sections

→ $\alpha_{\mathrm{y}} = 0{,}21$

§6.3.1.3

$$\lambda_1 = \pi \sqrt{\frac{E}{f_{\mathrm{y}}}} = \pi \sqrt{\frac{210000}{355}} = 76{,}4$$

$$\bar{\lambda}_{\mathrm{y}} = \frac{L_{\mathrm{cr}}}{i_{\mathrm{y}}} \frac{1}{\lambda_1} = \frac{1700}{185} \times \frac{1}{76{,}4} = 0{,}12$$

§6.3.1.2

$$\phi_{\mathrm{y}} = 0{,}5\left[1 + \alpha_{\mathrm{y}}\left(\bar{\lambda}_{\mathrm{y}} - 0{,}2\right) + \bar{\lambda}_{\mathrm{y}}^{\,2}\right]$$

$$\phi_{\mathrm{y}} = 0{,}5\left[1 + 0{,}21\left(0{,}12 - 0{,}2\right) + 0{,}12^2\right] = 0{,}50$$

$$\chi_{\mathrm{y}} = \frac{1}{\phi_{\mathrm{y}} + \sqrt{\phi_{\mathrm{y}}^{\,2} - \bar{\lambda}_{\mathrm{y}}^{\,2}}} = \frac{1}{0{,}50 + \sqrt{0{,}50^2 - 0{,}12^2}} = 1{,}0$$

$$N_{\mathrm{b,y,Rd}} = \frac{\chi_{\mathrm{y}} A f_{\mathrm{y}}}{\gamma_{\mathrm{M1}}} = \frac{1,0 \times 9880 \times 355}{1,0} \times 10^{-3} = 3507 \text{ kN}$$

N_{Ed} = 127 kN < 3507 kN OK

1.3.2. Lateral-torsional buckling resistance for bending, $M_{\mathrm{b,Rd}}$

In order to determine the critical moment of the rafter, the C_1 factor takes account of the shape of the bending moment diagram.

In this case the bending moment diagram is constant along the segment in consideration, so $\psi = 1,0$. Therefore:

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$\rightarrow C_1 = 1,0$

Appendix C of Single-Storey Steel Building, Part 4

$$M_{\mathrm{cr}} = C_1 \frac{\pi^2 E I_{\mathrm{z}}}{L^2} \sqrt{\frac{I_{\mathrm{w}}}{I_{\mathrm{z}}} + \frac{L^2 G I_{\mathrm{t}}}{\pi^2 E I_{\mathrm{z}}}}$$

$$= 1,0 \times \frac{\pi^2 \times 210000 \times 1676 \times 10^4}{1700^2}$$

$$\times \sqrt{\frac{791 \times 10^9}{1676 \times 10^4} + \frac{1700^2 \times 81000 \times 66,9 \times 10^4}{\pi^2 \times 210000 \times 1676 \times 10^4}}$$

$M_{\mathrm{cr}} = 2733 \times 10^6$ Nmm

§6.3.2.2

$$\bar{\lambda}_{\mathrm{LT}} = \sqrt{\frac{W_{\mathrm{pl,y}} f_{\mathrm{y}}}{M_{\mathrm{cr}}}} = \sqrt{\frac{1702 \times 10^3 \times 355}{2733 \times 10^6}} = 0,470$$

§6.3.2.3

$$\phi_{\mathrm{LT}} = 0,5\left[1 + \alpha_{\mathrm{LT}}\left(\bar{\lambda}_{\mathrm{LT}} - \bar{\lambda}_{\mathrm{LT,0}}\right) + \beta \bar{\lambda}_{\mathrm{LT}}^2\right]$$

$\bar{\lambda}_{\mathrm{LT,0}} = 0,4$ and $\beta = 0,75$

$$\frac{h}{b} = 2,37$$

$\rightarrow$ Curve **c** for hot rolled I sections

Table 6.3
Table 6.5

$\rightarrow \alpha_{\mathrm{LT}} = 0,49$

$$\phi_{\mathrm{LT}} = 0,5\left[1 + 0,49(0,470 - 0,4) + 0,75 \times 0,470^2\right] = 0,60$$

§6.3.2.3

$$\chi_{\mathrm{LT}} = \frac{1}{\phi_{\mathrm{LT}} + \sqrt{\phi_{\mathrm{LT}}^2 - \beta \bar{\lambda}_{\mathrm{LT}}^2}}$$

$$\chi_{\mathrm{LT}} = \frac{1}{0,60 + \sqrt{0,60^2 - 0,75 \times 0,470^2}} = 0,961$$

$$\frac{1}{\bar{\lambda}_{\mathrm{LT}}^2} = \frac{1}{0,470^2} = 4,53$$

Therefore $\chi_{\mathrm{LT}} = 0,961$

$$M_{b,Rd} = \frac{\chi_{LT} W_{pl,y} f_y}{\gamma_{M1}} = \frac{0,961 \times 1702 \times 10^3 \times 355}{1,0} \times 10^{-6} = 581 \text{ kNm}$$

$M_{Ed} = 356$ kNm < 581 kNm   OK

1.3.3. Interaction of axial force and bending moment

The interaction factor, k_{yy}, is calculated as follows:

$$k_{yy} = \min\left[C_{my}\left(1 + (\bar{\lambda}_y - 0,2)\frac{N_{Ed}}{N_{b,y,Rd}}\right); C_{my}\left(1 + 0,8\frac{N_{Ed}}{N_{b,y,Rd}}\right)\right]$$

The expression for C_{my} depends on the values of α_h and ψ.   Annex B Table B.3

$\psi = 1,0.$

Therefore C_{my} is calculated as:

$C_{my} = 0,6 + 0,4\,\psi = 0,4 + 0,4 \times 1,0 = 1,0$

$$k_{yy} = \min\left[1,0\left(1 + (0,12 - 0,2)\frac{127}{3507}\right); \; 1\left(1,0 + 0,8\frac{127}{3507}\right)\right]$$ Annex B Table B.2

$= \min\,[0,997;\ 1,029] = 0,997$

$$\frac{N_{Ed}}{N_{b,y,Rd}} + k_{yy}\frac{M_{y,Ed}}{M_{b,Rd}} = \frac{127}{3507} + 0,997\frac{356}{581} = 0,647 < 1,0$$ OK

The member satisfies the in-plane buckling check.

1.4. Expression 6.62 (EN 1993-1-1)

1.4.1. Flexural buckling resistance about minor axis bending, $N_{b,z,Rd}$

$$\frac{h}{b} = \frac{450}{190} = 2,37$$

$t_f = 14,6$ mm

buckling about z-z axis   Table 6.1 Table 6.2

→ Curve **b** for hot rolled I sections

→ $\alpha_z = 0,34$

$$\lambda_1 = \pi\sqrt{\frac{E}{f_y}} = \pi\sqrt{\frac{210000}{355}} = 76,4$$ §6.3.1.3

$$\bar{\lambda}_z = \frac{L_{cr}}{i_z}\frac{1}{\lambda_1} = \frac{1700}{41,2} \times \frac{1}{76,4} = 0,540$$

$$\phi_z = 0,5\left[1 + \alpha_z(\bar{\lambda}_z - 0,2) + \bar{\lambda}_z^2\right]$$ §6.3.1.2

$$\phi_z = 0,5\left[1 + 0,34(0,540 - 0,2) + 0,540^2\right] = 0,704$$

$$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z^2 - \bar{\lambda}_z^2}} = \frac{1}{0,704 + \sqrt{0,704^2 - 0,540^2}} = 0,865$$

$$N_{b,z,Rd} = \frac{\chi_z A f_y}{\gamma_{M1}} = \frac{0,865 \times 9880 \times 355}{1,0} \times 10^{-3} = 3034 \text{ kN}$$

N_{Ed} = 127 kN < 3034 kN OK

1.4.2. Interaction of axial force and bending moment

§6.3.3(4)

The interaction factor, k_{zy} is calculated as follows:

For $\bar{\lambda}_z \geq 0,4$:

$$k_{zy} = \max\left[\left(1 - \frac{0,1\bar{\lambda}_z}{(C_{mLT} - 0,25)}\frac{N_{Ed}}{N_{b,z,Rd}}\right); \left(1 - \frac{0,1}{(C_{mLT} - 0,25)}\frac{N_{Ed}}{N_{b,z,Rd}}\right)\right]$$

The bending moment is linear and constant. Therefore C_{mLT} is 1,0.

Annex B Table B.3

Annex B Table B.2

$$k_{zy} = \max\left[\left(1 - \frac{0,1 \times 0,540}{(1 - 0,25)}\frac{127}{3034}\right); \left(1 - \frac{0,1}{(1 - 0,25)}\frac{127}{3034}\right)\right]$$

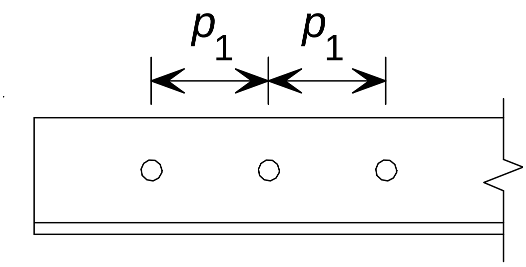
$= \max (0,997, 0,994) = 0,997$

$$\frac{N_{Ed}}{N_{b,z,Rd}} + k_{zy}\frac{M_{y,Ed}}{M_{b,Rd}} = \frac{127}{3034} + 0,997\frac{356}{581} = 0,653 < 1,0 \quad \text{OK}$$

1. Tension Resistance

References are to EN 1993-1-8 unless otherwise stated

This example presents the method used in the member resistance calculator for calculating the tension resistance, adopting the recommended values of the EN 1993-1-8.



Section: L 120 × 80 × 12

Steel grade: S235

Area: $A = 2270$ mm^2

Bolts: M20, grade 8.8

Spacing between bolts $p_1 = 70$ mm

Total number of bolts $n = 3$

Diameter of the holes $d_0 = 22$ mm

Partial safety factors

$\gamma_{M0} = 1,0$

$\gamma_{M2} = 1,25$ (for shear resistance of bolts)

1.2. Angle in tension

§3.10.3

$$N_{Rd} = \frac{\beta_3 A_{net} f_u}{\gamma_{M2}}$$

$2,5\ d_0 = 2,5 \times 22 = 55$ mm

$5\ d_0 = 5 \times 22 = 110$ mm

$2,5\ d_0 < p_1 < 5\ d_0$

Table 3.8

β_3 can be determined by linear interpolation:

Therefore $\beta_3 = 0,59$

$$A_{net} = A - t_{ac} d_0 = 2270 - 12 \times 22 = 2006\ \text{mm}^2$$

$$N_{Rd} = \frac{0,59 \times 2006 \times 360}{1,25} \times 10^{-3} = 341\ \text{kN}$$

1. Compression Resistance

References are to EN 1993-1-1 unless otherwise stated

This example presents the method used in the member resistance calculator for calculating the flexural and the torsional buckling resistance of members subject to pure compression, adopting the recommended values of EN 1993-1-1.

Section: IPE 500

Steel grade: S235

$L_y = 3,8$ m

$L_z = 3,8$ m

1.1. Cross-section classification

1.1.1. The web

Table 5.2 (Sheet 1)

$$\frac{c}{t_w} = \frac{426}{10,2} = 41,8$$

The limit between Class 3 and Class 4 is : $42\varepsilon = 42 \times 1,0 = 42$

Then : $\frac{c}{t_w} = 41,8 < 42$

→ The web is class 3.

1.1.2. The flange

Table 5.2 (Sheet 2)

$$\frac{c}{t_f} = \frac{73,9}{16} = 4,6$$

The limit between Class 1 and Class 2 is : $9\varepsilon = 9 \times 1,0 = 9$

Then : $\frac{c}{t_f} = 4,6 < 9$

→ The flange is Class 1.

Therefore the section is Class 3.

1.2. Flexural buckling resistance about the major axis, $N_{b,y,Rd}$

$L_y = 3,8$ m

$$\frac{h}{b} = \frac{500}{200} = 2,5$$

$t_f = 16$ mm

Buckling about y-y axis:

→ Curve **a** for hot rolled I sections	Table 6.2
→ $\alpha_y = 0{,}21$	Table 6.1
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}} = \pi \sqrt{\frac{210000}{235}} = 93{,}9$	§6.3.1.3
$\bar{\lambda}_y = \frac{L_{cr}}{i_z} \frac{1}{\lambda_1} = \frac{3800}{204} \times \frac{1}{93{,}9^2} = 0{,}198$	
$\phi_y = 0{,}5\left[1 + \alpha_y \left(\bar{\lambda}_y - 0{,}2\right) + \bar{\lambda}_y{}^2\right]$	§6.3.1.2
$\phi_y = 0{,}5\left[1 + 0{,}21\left(0{,}198 - 0{,}2\right) + 0{,}198^2\right] = 0{,}519$	
$\chi_y = \frac{1}{\phi_y + \sqrt{\phi_y{}^2 - \bar{\lambda}_y{}^2}} = \frac{1}{0{,}519 + \sqrt{0{,}519^2 - 0{,}198^2}} = 1{,}0$	
$N_{b,y,Rd} = \frac{\chi_y A f_y}{\gamma_{M1}} = \frac{1{,}0 \times 11600 \times 235}{1{,}0} \times 10^{-3} = 2726 \text{ kN}$	
1.3. Flexural buckling resistance about the minor axis, $N_{b,z,Rd}$	
$L_z = 3{,}8$ m	
$\frac{h}{b} = \frac{500}{200} = 2{,}5$	
$t_f = 16$ mm	
Buckling about z-z axis:	
→ Curve **b** for hot rolled I sections	Table 6.1 Table 6.2
→ $\alpha_z = 0{,}21$	
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}} = \pi \sqrt{\frac{210000}{235}} = 93{,}9$	§6.3.1.3
$\bar{\lambda}_y = \frac{L_{cr}}{i_z} \frac{1}{\lambda_1} = \frac{3800}{43{,}1} \times \frac{1}{93{,}9} = 0{,}94$	
$\phi_z = 0{,}5\left[1 + \alpha_z \left(\bar{\lambda}_z - 0{,}2\right) + \bar{\lambda}_z{}^2\right]$	§6.3.1.2
$\phi_z = 0{,}5\left[1 + 0{,}34\left(0{,}94 - 0{,}2\right) + 0{,}94^2\right] = 1{,}07$	
$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z{}^2 - \bar{\lambda}_z{}^2}} = \frac{1}{1{,}07 + \sqrt{1{,}07^2 - 0{,}94^2}} = 0{,}632$	
$N_{b,z,Rd} = \frac{\chi_z A f_y}{\gamma_{M1}} = \frac{0{,}632 \times 11600 \times 235}{1{,}0} \times 10^{-3} = 1723 \text{ kN}$	

1.4. Torsional buckling $N_{b,T,Rd}$

L_T = 3,8 m

$$N_{crT} = \frac{1}{i_0^{\ z}}\left(\frac{\pi^2 \ EI_w}{L_T^2} + GI_T\right)$$

$$i_0^{\ 2} = i_y^{\ 2} + i_z^{\ 2} = 204^2 + 43{,}1^2 = 43474$$

$$N_{crT} = \frac{1}{43474}\left(\frac{\pi^2 \times 210000 \times 1249 \times 10^9}{3800^2} + 81000 \times 89{,}3 \times 10^4\right) \times 10^{-3} = 5787 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \ f_y}{N_{crT}}} = \sqrt{\frac{11600 \times 235}{5787 \times 10^3}} = 0{,}686$$

$$\phi_T = 0{,}5 \ [1 + \alpha_T \ (\lambda_T - 0{,}2) + \bar{\lambda}_T^2 \ ]$$

The buckling curve for torsional buckling is the same as for minor axis buckling, therefore choose buckling curve **b**

$\alpha_z = 0{,}34$

$$\phi_T = 0{,}5 \ (1 + 0{,}34 \ (0{,}686 - 0{,}2) + 0{,}686^2] = 0{,}818$$

$$\chi_T = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_T^2}} = \frac{1}{0{,}818 + \sqrt{0{,}818^2 - 0{,}686^2}} = 0{,}791$$

$$N_{b,T,Rd} = \frac{\chi_T A f_y}{\gamma_{M1}} = \frac{0{,}791 \times 11600 \times 235}{1{,}0} \times 10^{-3} = 2156 \text{ kN}$$

1. Web Resistance

This example presents the method used in the member resistance calculator for calculating the web resistance and the shear resistance, adopting the recommended values of the EN 1993-1-5 and EN 1993-1-1.

Section: IPE 500

Steel grade: S355

c = 10 mm

s_s = 100 mm

1.1. Shear resistance

In the absence of torsion, the shear plastic resistance depends on the shear area, which is given by:

EN 1993-1-1 § 6.2.6 (3)

$A_v = A - 2\,b\,t_f + (t_w + 2\,r)\,t_f$

$A_v = 11600 - 2 \times 200 \times 16 + (10{,}2 + 2 \times 21) \times 16 = 6035\ \text{mm}^2$

EN 1993-1-1 § 6.2.6 (2)

$$V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}\gamma_{M0}} = \frac{6035 \times 355 \times 10^{-3}}{\sqrt{3} \times 1{,}0} = 1237\ \text{kN}$$

$V_{pl,Rd}$ = 1237 kN

1.2. Design resistance to local buckling

c = 10 mm

s_s = 100 mm

$$m_1 = \frac{b_f}{t_w} = \frac{200}{10{,}2} = 19{,}6$$

$$m_2 = 0{,}02\left(\frac{h_w}{t_f}\right)^2 \quad \text{if } \bar{\lambda}_F > 0{,}5$$

$$m_2 = 0 \quad \text{if } \bar{\lambda}_F < 0{,}5$$

First assume that $\bar{\lambda}_F > 0{,}5$

$$m_2 = 0{,}02\left(\frac{468}{16}\right)^2 = 17{,}11$$

$$k_F = 2 + 6\left(\frac{s_s + c}{h_w}\right)^2 \quad \text{but } k_F \le 6$$

$$k_F = 2 + 6\left(\frac{100 + 10}{468}\right)$$

k_F = 3,41 < 6

$\ell_e = \dfrac{k_F\ E\ t_w^{\ 2}}{2\ f_y\ h_w}$ but $\leq s_s + c$ — EN 1993-1-5 Eq (6.13)

$\ell_e = \dfrac{3{,}41 \times 210000 \times 10{,}2^2}{2 \times 355 \times 468} = 224 \leq 100 + 10 = 110$

therefore ℓ_e = 110

$\ell_{y1} = s_s + 2\ t_f \left(1 + \sqrt{m_1 + m_2}\right) = 100 + 2 \times 16\left(1 + \sqrt{19{,}6 + 17{,}11}\right) = 325$ mm — EN 1993-1-5 Eq (6.10)

$\ell_{y2} = \ell_e + t_f \sqrt{\dfrac{m_1}{2} + \left(\dfrac{\ell_e}{t_f}\right)^2 + m_2} = 110 + 16\sqrt{\dfrac{19{,}6}{2} + \left(\dfrac{110}{16}\right)^2 + 17{,}11}$ — EN 1993-1-5 Eq (6.11)

= 248 mm

$\ell_{y3} = \ell_e + t_f \sqrt{m_1 + m_2} = 110 + 16\sqrt{19{,}6 + 17{,}22} = 207$ mm — EN 1993-1-5 Eq (6.12)

$\ell_y = \min(\ell_{y1}; \ell_{y2}; \ell_{y3}) = \min(325; 248; 207) = 207$ mm

$F_{cr} = 0{,}9\ k_F\ E \dfrac{t_w^{\ 3}}{h_w} = 0.9 \times 3{,}41 \times 210000 \times \dfrac{10{,}2^3}{468} = 1461406$ N

$\bar{\lambda}_F = \sqrt{\dfrac{\ell_y t_w f_y}{F_{cr}}} = \sqrt{\dfrac{207 \times 10{,}2 \times 355}{1461406}} = 0{,}72$

$\bar{\lambda}_F = 0{,}72 > 0{,}5$

Therefore the initial assumption was correct and the web resistance can be calculated based on this value of λ_F. Should the calculated value of λ_F be less than 0,5 then the calculation would need to be carried out again, using the appropriate expression for M_2

$\chi_F = \dfrac{0{,}5}{\bar{\lambda}_F} = \dfrac{0{,}5}{0{,}72} = 0{,}69$

χ_F = 0,69

$L_{eff} = \chi_F\ \ell_y$

L_{eff} = 0,69 × 207 = 143 mm

$F_{Rd} = \dfrac{f_y\ L_{eff}\ t_w}{\gamma_{M1}} = \dfrac{355 \times 143 \times 10{,}2}{1{,}0} = 518$ kN — EN 1993-1-5 § 6.2 (1)