STEEL BUILDINGS IN EUROPE

Multi-Storey Steel Buildings
Part 8: Design software – Section Capacity

Multi-Storey Steel Buildings
Part 1: Design software – Section Capacity

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: Design software – section capacity
Part 9: Design software – simple connections
Part 10: Software specification for 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.

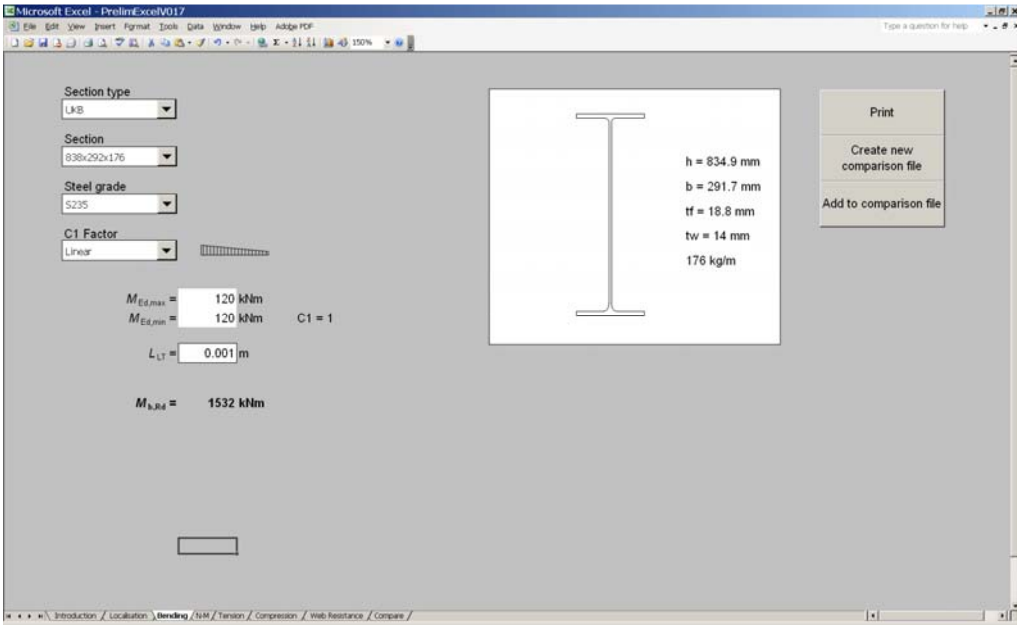


Figure 3.3 Bending worksheet

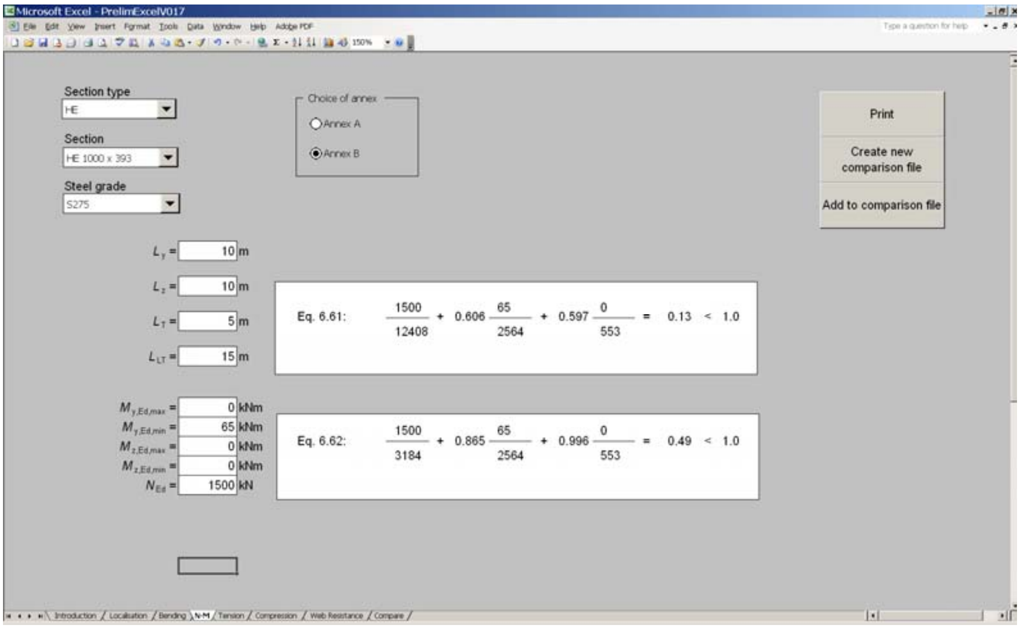


Figure 3.4 N-M worksheet

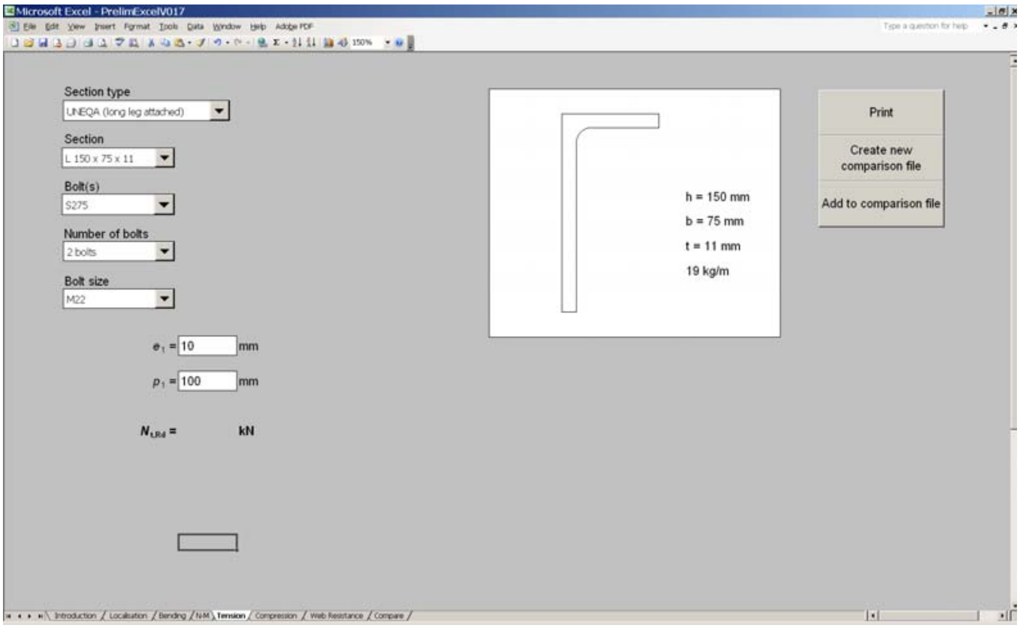


Figure 3.5 Tension worksheet

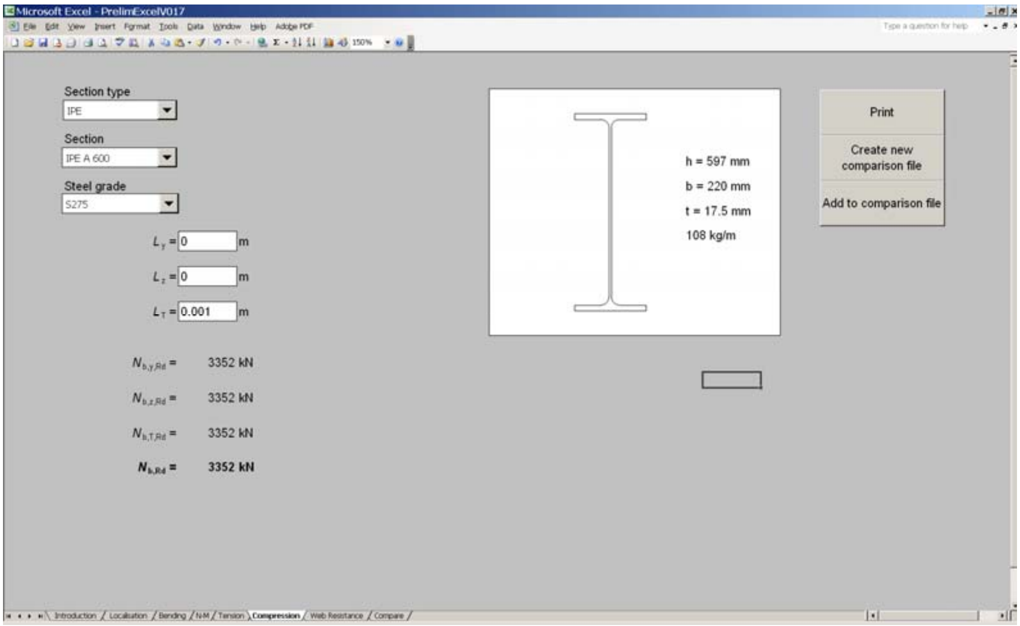


Figure 3.6 Compression worksheet

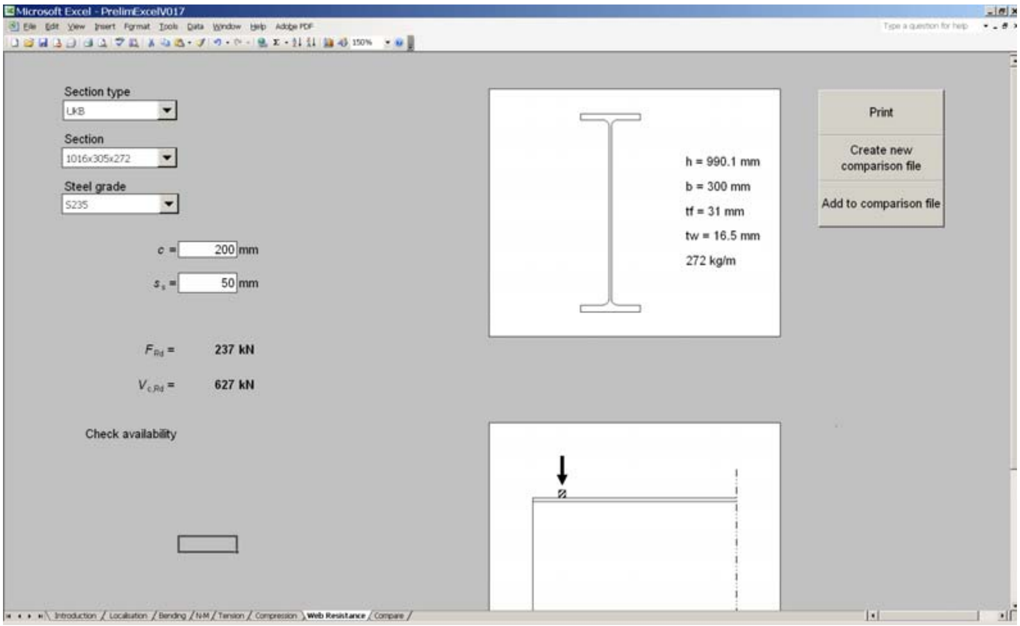


Figure 3.7 Web resistance worksheet

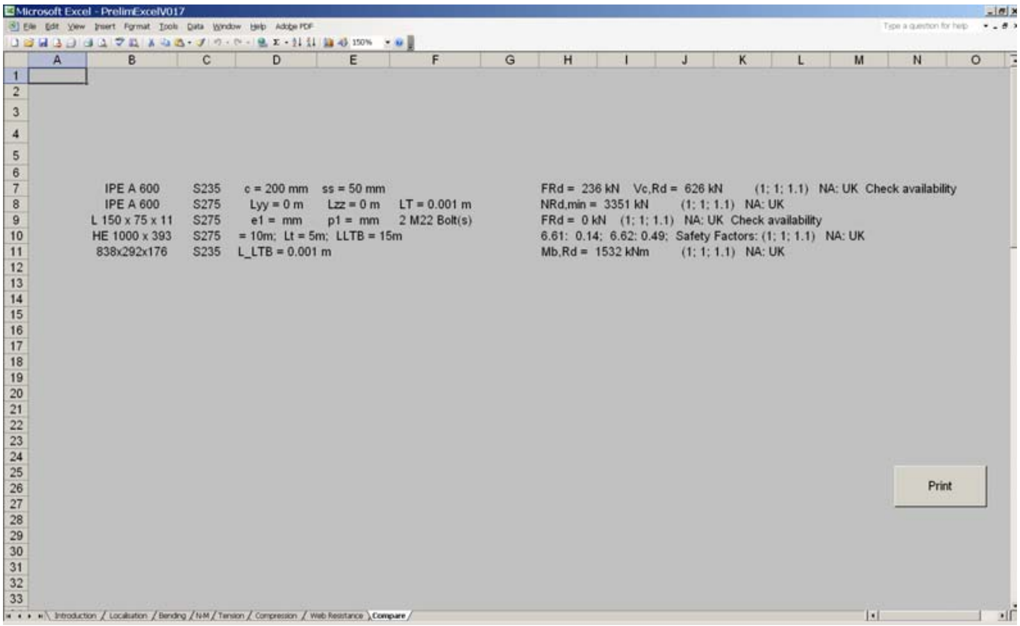


Figure 3.8 Compare worksheet

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
2. Combined axial force and bending moment (N-M interaction)
3. Tension resistance
4. Compression resistance
5. Web resistance

1. Bending moment 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 bending moment resistance, adopting the recommended values of EN 1993-1-1.

Section: IPE 500

Steel grade: S355

L = 3,8 m

1.1. Cross-section classification

1.1.1. The web

Table 5.2 (Sheet 1)

$$\frac{c}{t_{\mathrm{w}}} = \frac{426}{10,2} = 41,8$$

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

Then : $\frac{c}{t_{\mathrm{w}}} = 41,8 < 58,3$

→ The web is class 1.

1.1.2. The flange

Table 5.2 (Sheet 2)

$$\frac{c}{t_{\mathrm{f}}} = \frac{73,9}{16} = 4,6$$

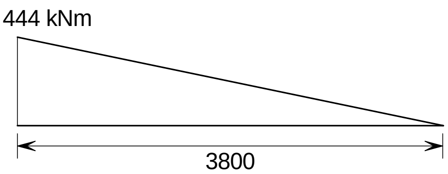
The limit for Class 1 is : $9\varepsilon = 9 \times 0,81 = 7,3$

Then : $\frac{c}{t_{\mathrm{f}}} = 4,6 < 8,3$

→ 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, $M_{\mathrm{b,Rd}}$



Appendix C of Single-Storey Steel Building, Part 4

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

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

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

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

Appendix C of Single-Storey Steel Building, Part 4

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

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

§6.3.2.2

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

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

→ $\alpha_{LT} = 0,49$

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

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

§6.3.2.3

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

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

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

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

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

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

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

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

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

$N_{Ed} = 127$ kN

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

$M_{z,Ed} = 0$ kNm

$L_y = L_z = L_{LT} = L_{cr} = 1{,}7$ m

1.1. Cross-section classification

1.1.1. The web

Table 5.2 (Sheet 1)

$$\frac{c}{t_w} = \frac{378{,}8}{9{,}4} = 40{,}3$$

$$d_N = \frac{N_{Ed}}{t_w f_y} = \frac{127000}{9{,}4 \times 355} = 38$$

$$\alpha = \frac{d_w + d_N}{2 d_w} = \frac{378{,}8 + 38}{2 \times 378{,}8} = 0{,}55 \ > \ 0{,}50$$

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 : $\dfrac{c}{t_w} = 40{,}3 < 52{,}1$

→ The web is class 1.

1.1.2. The flange

Table 5.2 (Sheet 2)

$$\frac{c}{t_f} = \frac{69{,}3}{14{,}6} = 4{,}7$$

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

Then : $\dfrac{c}{t_f} = 4{,}7 < 7{,}3$

→ 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)

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

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

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:

Appendix C of Single-Storey Steel Building, Part 4

$\rightarrow C_1 = 1{,}0$

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:

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

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:

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

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

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

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

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

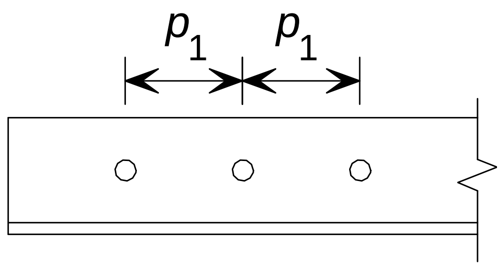
= max (0,997, 0,994) = 0,997

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

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

1. Tension Resistance

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
$\bar{\lambda}_y = \frac{L_{cr}}{i_z}\frac{1}{\lambda_1} = \frac{3800}{204} \times \frac{1}{93{,}9} = 0{,}198$	
$\phi_y = 0{,}5\left[1 + \alpha_y\left(\bar{\lambda}_y - 0{,}2\right) + \bar{\lambda}_y^{\,2}\right]$	§6.3.1.2
$\phi_y = 0{,}5\left[1 + 0{,}21(0{,}198 - 0{,}2) + 0{,}198^2\right] = 0{,}519$	
$\chi_y = \frac{1}{\phi_y + \sqrt{\phi_y^{\,2} - \bar{\lambda}_y^{\,2}}} = \frac{1}{0{,}519 + \sqrt{0{,}519^2 - 0{,}198^2}} = 1{,}0$	
$N_{b,y,Rd} = \frac{\chi_y A f_y}{\gamma_{M1}} = \frac{1{,}0 \times 11600 \times 235}{1{,}0} \times 10^{-3} = 2726 \text{ kN}$	

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
$\phi_z = 0{,}5\left[1 + 0{,}34(0{,}94 - 0{,}2) + 0{,}94^2\right] = 1{,}07$	
$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z^{\,2} - \bar{\lambda}_z^{\,2}}} = \frac{1}{1{,}07 + \sqrt{1{,}07^2 - 0{,}94^2}} = 0{,}632$	
$N_{b,z,Rd} = \frac{\chi_z A f_y}{\gamma_{M1}} = \frac{0{,}632 \times 11600 \times 235}{1{,}0} \times 10^{-3} = 1723 \text{ kN}$	

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)

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

$$V_{pl,Rd} = 1237 \text{ kN}$$

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

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

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

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

$k_F \quad = 3,41 < 6$

$$\ell_e = \frac{k_F \, E \, t_w^{\,2}}{2 \, f_y \, h_w} \qquad \text{but} \le s_s + c$$

EN 1993-1-5 Eq (6.13)

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

therefore $\ell_e = 110$

$$\ell_{y1} = s_s + 2\, t_f \left(1 + \sqrt{m_1 + m_2}\right) = 100 + 2 \times 16 \left(1 + \sqrt{19,6 + 17,11}\right) = 325 \text{ mm}$$

EN 1993-1-5 Eq (6.10)

$$\ell_{y2} = \ell_e + t_f \sqrt{\frac{m_1}{2} + \left(\frac{\ell_e}{t_f}\right)^2 + m_2} = 110 + 16 \sqrt{\frac{19,6}{2} + \left(\frac{110}{16}\right)^2 + 17,11}$$

EN 1993-1-5 Eq (6.11)

$= 248$ mm

$$\ell_{y3} = \ell_e + t_f \sqrt{m_1 + m_2} = 110 + 16 \sqrt{19,6 + 17,22} = 207 \text{ mm}$$

EN 1993-1-5 Eq (6.12)

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

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

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

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

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

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

$\chi_F \quad = 0,69$

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

$L_{eff} \quad = 0,69 \times 207 = 143$ mm

$$F_{Rd} = \frac{f_y \, L_{eff} \, t_w}{\gamma_{M1}} = \frac{355 \times 143 \times 10,2}{1,0} = 518 \text{ kN}$$

EN 1993-1-5 § 6.2 (1)