STEEL MEMBER DESIGN FOR FIRE SAFETY

Design member **54**

Nodes: **8-20**

Code: **Eurocode-H**

MSZ EN 1993-1-1:2009 + AC:2009, MSZ EN 1993-1-5:2007, EN 1993-1-2:2005

Material: **S 235**

Cross-section: **IPE 240**

Load case: **Linear,(ULS (accidental)) Critical**

Coefficient for seismic forces: **1,0**

1. Axial force-Bending-Shear (strength interaction):

EN 1993-1-2: 4.2.3, EN 1993-1-1: 6.2.1, 6.2.8, 6.2.9

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$N_{Ed_{11}}$ = 0,01 kN $V_{y,Ed_{11}}$ = 0 kN $V_{z,Ed_{11}}$ = 6,34 kN $M_{y,Ed_{11}}$ = 701,61 kNcm = 7,02 kNm $M_{z,Ed_{11}}$ = 1,28 kNcm = 0,01 kNm

$$\eta_{NMV_{el}fi} = \frac{N_{Ed_{11}}}{A \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} + \frac{M_{y,Ed_{11}}}{W_{el,y} \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} + \frac{M_{z,Ed_{11}}}{W_{el,z} \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} = \frac{0{,}01}{39{,}12 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} + \frac{701{,}61}{324{,}30 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} + \frac{1{,}28}{47{,}27 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} = 25{,}2\ \%$$

Critical temperature θ_{cr} = 834,00 °C

passed

2. Axial force-Bending-Flexural buckling (stability interaction):

EN 1993-1-2: 4.2.3.5

Critical combination: **[Self weight] {FIRE} {0,5*Wind}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

β_{My} = 1,44 Fig. 4.2

β_{Mz} = 1,8 Fig. 4.2

$$\mu_y = (2 \cdot \beta_{My} - 5) \cdot \lambda_{y,\theta}{}^* + 0.44 \cdot \beta_{My} + 0.29 = (2 \cdot 1{,}44 - 5) \cdot 0{,}82 + 0.44 \cdot 1{,}44 + 0.29 = -0{,}81$$

$$\mu_z = (1.2 \cdot \beta_{Mz} - 3) \cdot \lambda_{z,\theta}{}^* + 0.71 \cdot \beta_{Mz} - 0.29 = (1.2 \cdot 1{,}8 - 3) \cdot 3{,}02 + 0.71 \cdot 1{,}8 - 0.29 = -1{,}55$$

$$k_{yy} = 1 - \left(\frac{\mu_y \cdot \left| N_{Ed_{11}} \right|}{\frac{\chi_{y,fi} \cdot A \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} \right) = 1 - \left(\frac{(-0{,}81) \cdot |(-1{,}80)|}{\frac{0{,}55 \cdot 39{,}12 \cdot 23{,}50 \cdot 0{,}37}{1}} \right) = 1{,}01$$

$$k_{zz} = 1 - \left(\frac{\mu_z \cdot \left| N_{Ed_{11}} \right|}{\frac{\chi_{z,fi} \cdot A \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} \right) = 1 - \left(\frac{(-1{,}55) \cdot |(-1{,}80)|}{\frac{0{,}09 \cdot 39{,}12 \cdot 23{,}50 \cdot 0{,}37}{1}} \right) = 1{,}09$$

$$\eta_{NMB,fi} = \frac{N_{Ed_{11}}}{\frac{\chi_{min,fi} \cdot A \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} \pm k_{yy} \cdot \frac{M_{y,Ed_{11}}}{\frac{W_{el,y} \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} \pm k_{zz} \cdot \frac{M_{z,Ed_{11}}}{\frac{W_{el,z} \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} =$$

$$= \frac{(-1{,}80)}{\frac{0{,}09 \cdot 39{,}12 \cdot 23{,}50 \cdot 0{,}37}{1}} \pm 1{,}01 \cdot \frac{530{,}15}{\frac{324{,}30 \cdot 23{,}50 \cdot 0{,}37}{1}} \pm 1{,}09 \cdot \frac{(-6{,}14)}{\frac{47{,}27 \cdot 23{,}50 \cdot 0{,}37}{1}} = 26{,}6\ \% \quad (4.21)$$

$\eta_{NMBuckl,fi} = \eta_{NMB,fi} = 26{,}6 = 26{,}6\ \%$

Critical temperature θ_{cr} = 832,00 °C

passed

3. Axial force-Bending-Lateral-torsional buckling (stability interaction):

EN 1993-1-2: 4.2.3.5

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**
Section class: **3** (Elastic design)
Fire curve: **ISO fire curve**
Design temperature θ = 641,63 °C
Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm
$N_{Ed_{11}}$ = 0,01 kN (Beam in tension)

$$M_{mod,y,Ed} = \max \left(W_{y,com} \cdot \left(\frac{M_{y,Ed_{11}}}{W_{y,com}} - 0{,}8 \cdot \frac{N_{Ed_{11}}}{A} \right) ; 0 \right) = \max \left(324{,}30 \cdot \left(\frac{701{,}61}{324{,}30} - 0{,}8 \cdot \frac{0{,}01}{39{,}12} \right) ; 0 \right) = 701{,}53 \text{ kNcm} \quad (5.50)$$

$$\eta_{NMLTBuckl,fi} = \frac{M_{mod,y,Ed}}{M_{b,Rd,fi}} + \frac{M_{z,Ed_{11}}}{\frac{W_{el,z} \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} = \frac{701{,}53}{1017{,}14} + \frac{1{,}28}{\frac{47{,}27 \cdot 23{,}50 \cdot 0{,}37}{1}} = 69{,}3\ \%$$

Critical temperature θ_{cr} = 685,00 °C

passed

4. Shear(y) (strength check):

EN 1993-1-1: 6.2.6, EN 1993-1-2: 4.2.3.3, 4.2.3.4

Critical combination: **[Self weight] {FIRE} {0,5*Wind}**
Section class: **3** (Elastic design)
Fire curve: **ISO fire curve**
Design temperature θ = 641,63 °C
Critical section: $x = 0{,}00 \cdot L = 0{,}00 \cdot 609{,}60 = 0$ cm

$$V_{el,fi,Rd,y} = \frac{\frac{I \cdot t}{S} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}} = \frac{A_{V,el,y} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}}$$

$$\rho_I = \frac{I_{z,1}}{I_{z,1} + I_{z,2}} = 0{,}5$$

$$A_{V,el,y} = \frac{I_{z,1} \cdot t_{f,1}}{\frac{b_1^2 \cdot t_{f,1}}{8} \cdot \rho_I} = 15{,}68 \text{ cm}^2$$

$$V_{el,fi,Rd,y} = \frac{A_{V,el,y} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}} = \frac{15{,}68 \cdot 23{,}50 \cdot 0{,}37}{\sqrt{3} \cdot 1} = 78{,}73 \text{ kN}$$

$$\eta_{V_{y,fi}} = \frac{\left|V_{y,Ed_1}\right|}{V_{el,fi,Rd,y}} = \frac{|0{,}01|}{78{,}73} = 0 \text{ \%}$$

Critical temperature > 1000 °C

passed

5. Web shear buckling (stability check):

EN 1993-1-5: 5.1, 5.2, 5.3, 5.5, Annex A: A.3, EN 1993-1-2

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

η_w = 1,2 5.2 (2) NOTE 2

$h_w = h - 2 \cdot t_f = 24{,}00 - 2 \cdot 0{,}98 = 22{,}04$ cm

ε = 0,85 (EN 1993-1-2, 4.2)

No stiffener $\rightarrow k_\tau$ = 0 (A.5)

$$\frac{h_w}{t_w} \le \frac{31 \cdot \varepsilon \cdot \sqrt{k_\tau}}{\eta_w} \rightarrow V_{b,fi,Rd} = V_{el,fi,Rd,z} = 70{,}03 = 70{,}03 \text{ kN} \quad (5.1\ (2))$$

$$\eta_{V_{w,fi}} = \frac{\left|V_{z,Ed_{11}}\right|}{V_{z,fi,Rd}} = \frac{|6{,}34|}{70{,}03} = 9{,}0 \text{ \%} \quad (5.10)$$

Critical temperature > 1000 °C

passed

6. Web shear buckling-Bending-Axial force (strength interaction):

EN 1993-1-2: 4.2.3, EN 1993-1-1: 6.2.9; EN 1993-1-5: 7.1

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$M_{f,fi,Rd} = b \cdot t_f \cdot f_y \cdot k_{y,\theta} \cdot (h - t_f) = 12{,}00 \cdot 0{,}98 \cdot 23{,}50 \cdot 0{,}37 \cdot (24{,}00 - 0{,}98) = 2354{,}45$ kNcm $= 23{,}54$ kNm

$N_{Ed_{11}} < 0.25 \cdot N_{pl,fi,Rd}$; $N_{Ed_{11}} < \dfrac{0.5 \cdot (A_x - 2 \cdot b \cdot t_f) \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}}$

$V_{z,Ed_{11}} < 0.5 \cdot V_{bw,Rd}$;

$\left|M_{y,Ed_{11}}\right| \le M_{f,fi,Rd} \cdot \rho_{Nf} \rightarrow \eta_{V_w MN,fi} = \dfrac{\left|M_{y,Ed_{11}}\right|}{M_{pl,fi,Rd,y}} = \dfrac{|701{,}61|}{3009{,}29} = 23{,}3$ %

Critical temperature θ_{cr} = 848,00 °C

passed

Partial results

8. Axial force (strength check):

EN 1993-1-2: 4.2.3.1

Critical combination: **[Self weight] {FIRE} {0,5*Wind}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 0{,}00 \cdot L = 0{,}00 \cdot 609{,}60 = 0$ cm

$N_{pl,fi,Rd} = \dfrac{A \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}} = \dfrac{39{,}12 \cdot 23{,}50 \cdot 0{,}37}{1} = 340{,}23$ kN (4.3)

$\eta_{N,fi} = \dfrac{\left|N_{Ed_1}\right|}{N_{pl,fi,Rd}} = \dfrac{|(-1{,}80)|}{340{,}23} = 0{,}5$ %

Critical temperature > 1000 °C

passed

9. Bending(y) (strength check):

EN 1993-1-2: 4.2.3.3, 4.2.3.4

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$M_{el,fi,Rd,y} = \dfrac{W_{el,y} \cdot f_y \cdot k_{y,\theta}}{\kappa_1 \cdot \kappa_2 \cdot \gamma_{MFi}} = \dfrac{324{,}30 \cdot 23{,}50 \cdot 0{,}37}{1 \cdot 1 \cdot 1} = 2820{,}50$ kNcm $= 28{,}21$ kNm (6.14)

$\eta_{M_{y,el,fi}} = \dfrac{\left|M_{y,Ed_{11}}\right|}{M_{el,fi,Rd,y}} = \dfrac{|701{,}61|}{2820{,}50} = 24{,}9$ % (6.12)

Critical temperature θ_{cr} = 836,00 °C

passed

10. Bending(z) (strength check):

EN 1993-1-2: 4.2.3.3, 4.2.3.4

Critical combination: **[Self weight] {FIRE} {0,5*Wind}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$$M_{el,fi,Rd,z} = \frac{W_{el,z} \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}} = \frac{47{,}27 \cdot 23{,}50 \cdot 0{,}37}{1} = 411{,}13 \text{ kNcm} = 4{,}11 \text{ kNm} \quad (6.13)$$

$$\eta_{M_{z,el,fi}} = \frac{\left|M_{z,Ed_{11}}\right|}{M_{el,fi,Rd,z}} = \frac{|(-6{,}14)|}{411{,}13} = 1{,}5\ \% \quad (6.12)$$

Critical temperature > 1000 °C

passed

11. Shear(z) (strength check):

EN 1993-1-1: 6.2.6, EN 1993-1-2: 4.2.3.3, 4.2.3.4

Critical combination: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$$V_{el,fi,Rd,z} = \frac{\frac{I \cdot t}{S} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}} = \frac{A_{V,el,z} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}}$$

$$A_{V,el,z} = \frac{I_y \cdot t_w}{(b \cdot t_f) \cdot \left(h - z_c - \frac{t_f}{2}\right) + (h - z_c - t_f)^2 \cdot \frac{t_w}{2}} = 13{,}95 \text{ cm}^2$$

$$V_{el,fi,Rd,z} = \frac{A_{V,el,z} \cdot f_y \cdot k_{y,\theta}}{\sqrt{3} \cdot \gamma_{MFi}} = \frac{13{,}95 \cdot 23{,}50 \cdot 0{,}37}{\sqrt{3} \cdot 1} = 70{,}03 \text{ kN}$$

$$\eta_{V_{z,fi}} = \frac{\left|V_{z,Ed_{11}}\right|}{V_{el,fi,Rd,z}} = \frac{|6{,}34|}{70{,}03} = 9{,}0\ \%$$

Critical temperature > 1000 °C

passed

13. Axial force-Bending (strength interaction):

EN 1993-1-2: 4.2.3, EN 1993-1-1: 6.2.1, 6.2.8, 6.2.9

Critical combination for N-M-V strength interaction: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$$\eta_{MN,fi} = \frac{N_{Ed_{11}}}{A \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} + \frac{M_{y,Ed_{11}}}{W_{el,y} \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} + \frac{M_{z,Ed_{11}}}{W_{el,z} \cdot \frac{f_y \cdot k_{y,\theta}}{\gamma_{MFi}}} = \frac{0{,}01}{39{,}12 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} + \frac{701{,}61}{324{,}30 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} + \frac{1{,}28}{47{,}27 \cdot \frac{23{,}50 \cdot 0{,}37}{1}} = 25{,}2\ \%$$

Critical temperature θ_{cr} = 834,00 °C

passed

14. Flexural buckling (stability check):

EN 1993-1-1: 6.3.1, EN 1993-1-2: 4.2.3.2

Critical combination for N-M-Buckling interaction: **[Self weight] {FIRE} {0,5*Wind}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00 \cdot L = 1{,}00 \cdot 609{,}60 = 609{,}60$ cm

$K_{y,fi}$ = 1

$K_{z,fi}$ = 1

$L_{y,fi} = K_{y,fi} \cdot L = 1 \cdot 609{,}60 = 609{,}60$ cm

$L_{z,fi} = K_{z,fi} \cdot L = 1 \cdot 609{,}60 = 609{,}60$ cm

$$\lambda_y{}^* = \sqrt{\frac{A \cdot f_y}{N_{cr,y,fi}}} = \sqrt{\frac{39{,}12 \cdot 23{,}50}{2170{,}49}} = 0{,}65 \quad (6.50)$$

$$\lambda_z{}^* = \sqrt{\frac{A \cdot f_y}{N_{cr,z,fi}}} = \sqrt{\frac{39{,}12 \cdot 23{,}50}{158{,}19}} = 2{,}41 \quad (6.50)$$

$$\lambda_{y,\theta}{}^* = \lambda_y{}^* \cdot \sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} = 0{,}65 \cdot \sqrt{\frac{0{,}37}{0{,}235}} = 0{,}82 \quad (4.7)$$

$$\lambda_{z,\theta}{}^* = \lambda_z{}^* \cdot \sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} = 2{,}41 \cdot \sqrt{\frac{0{,}37}{0{,}235}} = 3{,}02 \quad (4.7)$$

$$\alpha_\theta = 0.65 \cdot \sqrt{\frac{235}{f_y}} = 0.65 \cdot \sqrt{\frac{23{,}50}{23{,}50}} = 0{,}65$$

$$\phi_{y,\theta} = \frac{1 + \alpha_\theta \cdot \lambda_{y,\theta}{}^* + \lambda_{y,\theta}{}^{*2}}{2} = \frac{1 + 0{,}65 \cdot 0{,}82 + 0{,}82^2}{2} = 0{,}8583$$

$$\phi_{z,\theta} = \frac{1 + \alpha_\theta \cdot \lambda_{z,\theta}{}^* + \lambda_{z,\theta}{}^{*2}}{2} = \frac{1 + 0{,}65 \cdot 3{,}02 + 3{,}02^2}{2} = 4{,}1242$$

$$\chi_{y,fi} = \min\left(\frac{1}{\phi_{y,\theta} + \sqrt{\phi_{y,\theta}^2 - \lambda_{y,\theta}{}^{*2}}}\ ;\ 1\right) = \min\left(\frac{1}{0{,}8583 + \sqrt{0{,}8583^2 - 0{,}82^2}}\ ;\ 1\right) = 0{,}55 \quad (4.6)$$

$$\chi_{z,fi} = \min\left(\frac{1}{\phi_{z,\theta} + \sqrt{\phi_{z,\theta}^2 - \lambda_{z,\theta}{}^{*2}}}\,;1\right) = \min\left(\frac{1}{4{,}1242 + \sqrt{4{,}1242^2 - 3{,}02^2}}\,;1\right) = 0{,}09 \quad (4.6)$$

$$\chi_{fi} = \min\left(\chi_{y,fi}\,;\chi_{z,fi}\right) = \min\left(0{,}55\,;0{,}09\right) = 0{,}09 \le 1{,}0$$

$$N_{b,fi,Rd} = \frac{\chi_{fi}\cdot A\cdot f_y\cdot k_{y,\theta}}{\gamma_{MFi}} = \frac{0{,}09\cdot 39{,}12\cdot 23{,}50\cdot 0{,}37}{1} = 30{,}09 \text{ kN} \quad (4.5)$$

$$\eta_{N_{b,fi}} = \frac{\left|N_{Ed_{11}}\right|}{N_{b,fi,Rd}} = \frac{|(-1{,}80)|}{30{,}09} = 6{,}0\ \% \quad (6.46)$$

Critical temperature > 1000 °C

passed

15. Lateral-torsional buckling (stability check):

EN 1993-1-1: 6.3.2, EN 1993-1-2: 4.2.3.3, 4.2.3.4

Critical combination for N-M-LTBuckling interaction: **[Self weight] {FIRE} {0,2*Snow}**

Section class: **3** (Elastic design)

Fire curve: **ISO fire curve**

Design temperature θ = 641,63 °C

Critical section: $x = 1{,}00\cdot L = 1{,}00\cdot 609{,}60 = 609{,}60$ cm

M_{cr} Analysis method: ENV 1993-1-1 Appendix F; C_1: Lopez formula;C_2 , C_3: User-defined values

$C_{1,fi}$ = 1,78, $C_{2,fi}$ = 0, $C_{3,fi}$ = 0

L = 609,60 cm, K_{fi} = 1, $K_{w,fi}$ = 1

z_g = 0 cm, z_j = 0 cm

$$M_{cr} = \frac{C_{1,fi}\cdot\pi^2\cdot E\cdot I_z}{(K_{fi}\cdot L)^2}\cdot\left[\sqrt{\left(\frac{K_{fi}}{K_{w,fi}}\right)^2\cdot\frac{I_w}{I_z} + \frac{(K_{fi}\cdot L)^2\cdot G\cdot I_t}{\pi^2\cdot E\cdot I_z} + (C_{2,fi}\cdot z_g + C_{3,fi}\cdot z_j)^2} - (C_{2,fi}\cdot z_g + C_{3,fi}\cdot z_j)\right] =$$

$$= \frac{1{,}78\cdot\pi^2\cdot 21000{,}00\cdot 283{,}63}{(1\cdot 609{,}60)^2}\cdot\left[\sqrt{\left(\frac{1}{1}\right)^2\cdot\frac{37575{,}33}{283{,}63} + \frac{(1\cdot 609{,}60)^2\cdot 8076{,}92\cdot 12{,}88}{\pi^2\cdot 21000{,}00\cdot 283{,}63} + (0\cdot 0 + 0\cdot 0)^2} - (0\cdot 0 + 0\cdot 0)\right] = 7895{,}26 \text{ kNcm}$$

$$= 78{,}95 \text{ kNm}$$

$$\lambda_{LT} = \sqrt{\frac{W_y\cdot f_y}{M_{cr}}} = \sqrt{\frac{324{,}30\cdot 23{,}50}{7895{,}26}} = 0{,}98$$

$$\lambda_{LT,\theta} = \lambda_{LT}\cdot\sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} = 0{,}98\cdot\sqrt{\frac{0{,}37}{0{,}235}} = 1{,}23 \quad (4.15)$$

$$\alpha_\theta = 0.65\cdot\sqrt{\frac{235}{f_y}} = 0.65\cdot\sqrt{\frac{23{,}50}{23{,}50}} = 0{,}65 \quad (4.14)$$

$$\phi_{LT,\theta} = \frac{1 + \alpha_\theta\cdot\lambda_{LT,\theta} + \lambda_{LT,\theta}^2}{2} = \frac{1 + 0{,}65\cdot 1{,}23 + 1{,}23^2}{2} = 1{,}3405 \quad (4.13)$$

$$\chi_{LT,fi} = \min\left(\frac{1}{\phi_{LT,\theta} + \sqrt{\phi_{LT,\theta}^2 - \lambda_{LT,\theta}^2}}\,;\,1\right) = \min\left(\frac{1}{1{,}3405 + \sqrt{1{,}3405^2 - 1{,}23^2}}\,;\,1\right) = 0{,}36 \quad (4.12)$$

$$M_{b,fi,Rd} = \frac{\chi_{LT,fi} \cdot W_y \cdot f_y \cdot k_{y,\theta}}{\gamma_{MFi}} = \frac{0{,}36 \cdot 324{,}30 \cdot 23{,}50 \cdot 0{,}37}{1} = 1017{,}14 \text{ kNcm} = 10{,}17 \text{ kNm} \quad (4.11, 4.19)$$

$$\eta_{M_{b,fi}} = \frac{\left|M_{y,Ed_{11}}\right|}{M_{b,fi,Rd}} = \frac{|701{,}61|}{1017{,}14} = 69{,}0\ \%$$

Critical temperature θ_{cr} = 685,00 °C

passed