

Group A, Maximum of group members

Maximum of load combinations

S 355

$$E = 210000 \text{ N/mm}^2$$

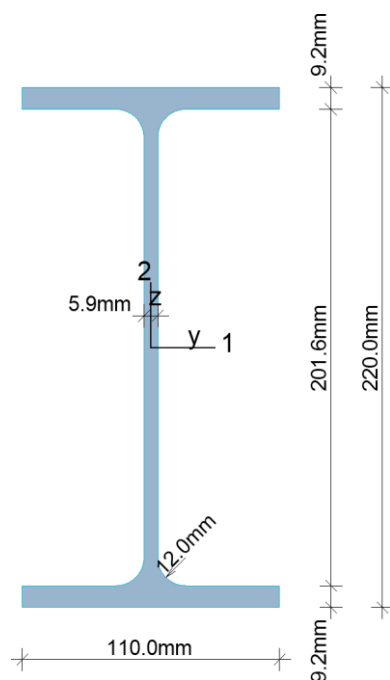
$$G = 80769 \text{ N/mm}^2$$

$$\gamma_{M0,ult} = 1.00 \quad \gamma_{M0,acc/seis} = 1.00$$

$$\gamma_{M1,ult} = 1.00 \quad \gamma_{M1,acc/seis} = 1.00$$

$$\gamma_{M2,ult} = 1.25 \quad \gamma_{M2,acc/seis} = 1.00$$

IPE 220



$$P = 848 \text{ mm} \quad f_y = 355 \text{ N/mm}^2$$

$$A = 3337 \text{ mm}^2 \quad \varepsilon = 0.81$$

$$I_y = 2.772e+07 \text{ mm}^4 \quad \lambda_1 = 76.40$$

$$I_z = 2.049e+06 \text{ mm}^4$$

$$I_1 = 2.772e+07 \text{ mm}^4$$

$$I_2 = 2.049e+06 \text{ mm}^4$$

$$W_{pl,1} = 2.854e+05 \text{ mm}^3$$

$$W_{pl,2} = 5.814e+04 \text{ mm}^3$$

$$W_{el,min,1} = 2.520e+05 \text{ mm}^3$$

$$W_{el,min,2} = 3.725e+04 \text{ mm}^3$$

$$i_1 = 91 \text{ mm}$$

$$i_2 = 25 \text{ mm}$$

$$I_t = 8.982e+04 \text{ mm}^4$$

$$I_w = 2.231e+10 \text{ mm}^6$$

Shear resistance, 1-1 - Part 1-1: 6.2.6, 6.2.8

Bar: B.204.1, LC: 'ULS elementi', $x = 0 \text{ mm}$

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$V_{1,pl,Rd} = \frac{A_{1,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{2148 \cdot 355}{\sqrt{3} \cdot 1.00} = 440.17 \text{ kN} \quad (6.18)$$

$$V_{1,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 (f_y/\sqrt{3})/\gamma_{M0}}} \cdot V_{1,pl,Rd} = \sqrt{1 - \frac{0.00}{1.25 (355/\sqrt{3})/1.00}} \cdot 440.17 = 440.17 \text{ kN} \quad (6.26)$$

$$\frac{V_{1,Ed}}{V_{1,pl,T,Rd}} = \frac{0.00}{440.17} = 0.00 \leq 1.00 \quad (6.25) - \text{OK}$$

Shear resistance, 2-2 - Part 1-1: 6.2.6, 6.2.8

Bar: B.204.1, LC: 'ULS elementi', $x = 0 \text{ mm}$

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$V_{2,pl,Rd} = \frac{A_{2,v} \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = \frac{1588 \cdot 355}{\sqrt{3} \cdot 1.00} = 325.50 \text{ kN} \quad (6.18)$$

$$V_{2,pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1.25 (f_y/\sqrt{3})/\gamma_{M0}}} \cdot V_{2,pl,Rd} = \sqrt{1 - \frac{0.00}{1.25 (355/\sqrt{3})/1.00}} \cdot 325.50 = 325.50 \text{ kN} \quad (6.26)$$

$$\frac{V_{2,Ed}}{V_{2,pl,T,Rd}} = \frac{146.77}{325.50} = 0.45 \leq 1.00 \quad (6.25) - \text{OK}$$

Torsional resistance - Part 1-1: 6.2.7

Bar: B.204.1, LC: '6.10 a Y+ wind down ', $x = 0$ mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$\tau_{\max, \text{unit}} = 162.80 \frac{\text{N/mm}^2}{\text{kNm}}$ is calculated by FEM analysis.

$$T_{Rd} = \frac{f_y}{\sqrt{3} \cdot \tau_{\max, \text{unit}} \cdot \gamma_{M0}} = \frac{355}{\sqrt{3} \cdot 162.80 \cdot 1.00} = 1.26 \text{ kNm}$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0.00}{1.26} = 0.00 \leq 1.00 \quad (6.23) - \text{OK}$$

Shear stress - Part 1-1: 6.2.6

Not relevant

Normal stress - Part 1-1: 6.2.1

Not relevant

Pure normal resistance - Part 1-1: 6.2.3, 6.2.4

Not relevant

Normal capacity - Part 1-1: 6.2

Bar: B.204.1, LC: 'ULS element', $x = 500$ mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$V_{1,Ed} = 0.00 \text{ kN} \leq 0.5 \cdot V_{1,pl,T,Rd} = 0.5 \cdot 440.17 = 220.09 \text{ kN} \rightarrow \rho_1 = 0.00$$

$$V_{2,Ed} = 146.60 \text{ kN} \leq 0.5 \cdot V_{2,pl,T,Rd} = 0.5 \cdot 325.50 = 162.75 \text{ kN} \rightarrow \rho_2 = 0.00$$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{1,Ed}}{M_{1,Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} = \frac{0.00}{1184.65} + \frac{73.34}{101.32} + \frac{0.00}{20.64} = 0.72 \leq 1.00 \quad (6.2) - \text{OK}$$

Flexural buckling, 1-1 - Part 1-1: 6.3.1

Bar: B.204.1, LC: '6.10 a Y+ wind down ', $x = 0$ mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$\bar{\lambda}_1 = \frac{L_{cr,1}}{i_1 \cdot \lambda_1} = \frac{1500}{91 \cdot 76.40} = 0.22 \quad (6.50)$$

$$\alpha_1 = 0.21 \quad (\text{Buckling curve: a})$$

$$\varphi_1 = 0.5 \left[1 + \alpha_1 \cdot (\bar{\lambda}_1 - 0.2) + \bar{\lambda}_1^2 \right] = 0.5 \left[1 + 0.21 \cdot (0.22 - 0.2) + 0.22^2 \right] = 0.52$$

$$\chi_1 = \min \left(\frac{1}{\varphi_1 + \sqrt{\varphi_1^2 - \bar{\lambda}_1^2}}, 1.0 \right) = \min \left(\frac{1}{0.52 + \sqrt{0.52^2 - 0.22^2}}, 1.0 \right) = 1.00 \quad (6.49)$$

$$N_{b,Rd,1} = \frac{\chi_1 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{1.00 \cdot 3337 \cdot 355}{1.00} = 1180.64 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,1}} = \frac{0.00}{1180.64} = 0.00 \leq 1.00 \quad (6.46) - \text{OK}$$

Flexural buckling, 2-2 - Part 1-1: 6.3.1

Bar: B.204.1, LC: '6.10 a Y+ wind down ', $x = 0$ mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$\bar{\lambda}_2 = \frac{L_{cr,2}}{i_2 \cdot \lambda_1} = \frac{1500}{25 \cdot 76.40} = 0.79 \quad (6.50)$$

$$\alpha_2 = 0.34 \quad (\text{Buckling curve: b})$$

$$\varphi_2 = 0.5 \left[1 + \alpha_2 \cdot (\bar{\lambda}_2 - 0.2) + \bar{\lambda}_2^2 \right] = 0.5 \left[1 + 0.34 \cdot (0.79 - 0.2) + 0.79^2 \right] = 0.91$$

$$\chi_2 = \min \left(\frac{1}{\varphi_2 + \sqrt{\varphi_2^2 - \bar{\lambda}_2^2}}, 1.0 \right) = \min \left(\frac{1}{0.91 + \sqrt{0.91^2 - 0.79^2}}, 1.0 \right) = 0.73 \quad (6.49)$$

$$N_{b,Rd,2} = \frac{\chi_2 \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.73 \cdot 3337 \cdot 355}{1.00} = 863.79 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,2}} = \frac{0.00}{863.79} = 0.00 \leq 1.00 \quad (6.46) - \text{OK}$$

Torsional-flexural buckling - Part 1-1: 6.3.1

Bar: B.204.1, LC: '6.10 a Y+ wind down ', $x = 0 \text{ mm}$

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$i_0 = \sqrt{i_1^2 + i_2^2 + y_0^2 + z_0^2} = \sqrt{91^2 + 25^2 + 0^2 + 0^2} = 94 \text{ mm}$$

$$N_{cr,1} = \frac{\pi^2 \cdot E \cdot I_1}{L_{cr,1}^2} = \frac{\pi^2 \cdot 210000 \cdot 27718396}{1500^2} = 25533.16 \text{ kN}$$

$$N_{cr,2} = \frac{\pi^2 \cdot E \cdot I_2}{L_{cr,2}^2} = \frac{\pi^2 \cdot 210000 \cdot 2048861}{1500^2} = 1887.34 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_0^2} \left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{L_t^2} \right) = \frac{1}{94^2} \left(80769 \cdot 8.982e + 04 + \frac{\pi^2 \cdot 210000 \cdot 2.231e + 10}{1500^2} \right) = 3117.19 \text{ kN}$$

$$\begin{aligned} i_0^2 (N - N_{cr,1}) (N - N_{cr,2}) (N - N_{cr,T}) - N^2 y_0^2 (N - N_{cr,2}) - N^2 z_0^2 (N - N_{cr,1}) \\ = 94^2 (N - 25533.16) (N - 1887.34) (N - 3117.19) - N^2 0^2 (N - 1887.34) \\ - N^2 0^2 (N - 25533.16) = 0 \end{aligned}$$

Smallest root of the above equation related to the torsional-flexural buckling:

$$N_{cr,TF} = 3117.19 \text{ kN}$$

$$N_{cr} = \min(N_{cr,T}, N_{cr,TF}) = \min(3117.19, 3117.19) = 3117.19 \text{ kN}$$

$$\bar{\lambda}_T = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \sqrt{\frac{3337 \cdot 355}{3117.19}} = 0.62 \quad (6.53)$$

$$\alpha_T = 0.34 \quad (\text{Buckling curve: b})$$

$$\varphi_T = 0.5 \left[1 + \alpha_T \cdot (\bar{\lambda}_T - 0.2) + \bar{\lambda}_T^2 \right] = 0.5 \left[1 + 0.34 \cdot (0.62 - 0.2) + 0.62^2 \right] = 0.76$$

$$\chi_T = \min \left(\frac{1}{\varphi_T + \sqrt{\varphi_T^2 - \bar{\lambda}_T^2}}, 1.0 \right) = \min \left(\frac{1}{0.76 + \sqrt{0.76^2 - 0.62^2}}, 1.0 \right) = 0.83 \quad (6.49)$$

$$N_{b,Rd,T} = \frac{\chi_T \cdot A \cdot f_y}{\gamma_{M1}} = \frac{0.83 \cdot 3337 \cdot 355}{1.00} = 981.73 \text{ kN} \quad (6.47)$$

$$\frac{N_{Ed}}{N_{b,Rd,T}} = \frac{0.00}{981.73} = 0.00 \leq 1.00 - \text{OK}$$

Lateral torsional buckling, top flange - Part 1-1: 6.3.2.2

Bar: B.204.1, LC: 'ULS elementi', $x = 500 \text{ mm}$

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e + 05 \cdot 2.049e + 06}{(1.00 \cdot 1500)^2} = 1887.34 \text{ kN}$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 110 - 0.52 \cdot 0) = 49.50 \text{ mm}$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left(\left[\left(\frac{k_z}{k_w} \right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right)$$

$$= 1.13 \cdot 1.887e + 06 \cdot \left(\left[\left(\frac{1.00}{1.00} \right)^2 \cdot \frac{2.231e + 10}{2.049e + 06} + \frac{8.077e + 04 \cdot 8.982e + 04}{1.887e + 06} + 49.50^2 \right]^{0.5} - 49.50 \right)$$

$$= 173.99 \text{ kNm}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{285406 \cdot 355}{1.740e + 08}} = 0.76$$

$$\alpha_{LT} = 0.21 \quad (\text{Buckling curve: a})$$

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right] = 0.5 \left[1 + 0.21 \cdot (0.76 - 0.2) + 0.76^2 \right] = 0.85$$

$$\chi_{LT} = \min \left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0 \right) = \min \left(\frac{1}{0.85 + \sqrt{0.85^2 - 0.76^2}}, 1.0 \right) = 0.82 \quad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.82 \cdot 285406 \cdot 355}{1.00} = 82.69 \text{ kNm} \quad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{73.34}{82.69} = 0.89 \leq 1.00 \quad (6.54) - \text{OK}$$

Lateral torsional buckling, bottom flange - Part 1-1: 6.3.2.2

Bar: B.204.1, LC: '6.10 a Y+ wind down ', x = 0 mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

$$N_{cr,LT} = \frac{\pi^2 \cdot E \cdot I_z}{(k_z \cdot L_{cr})^2} = \frac{\pi^2 \cdot 2.100e + 05 \cdot 2.049e + 06}{(1.00 \cdot 1500)^2} = 1887.34 \text{ kN}$$

Loaded on top edge.

$$Z = (C_2 \cdot z_g - C_3 \cdot z_j) = (0.45 \cdot 110 - 0.52 \cdot 0) = 49.50 \text{ mm}$$

$$M_{cr} = C_1 \cdot N_{cr,LT} \cdot \left(\left[\left(\frac{k_z}{k_w} \right)^2 \cdot \frac{I_w}{I_z} + \frac{G \cdot I_t}{N_{cr,LT}} + Z^2 \right]^{0.5} - Z \right)$$

$$= 1.13 \cdot 1.887e + 06 \cdot \left(\left[\left(\frac{1.00}{1.00} \right)^2 \cdot \frac{2.231e + 10}{2.049e + 06} + \frac{8.077e + 04 \cdot 8.982e + 04}{1.887e + 06} + 49.50^2 \right]^{0.5} - 49.50 \right)$$

$$= 173.99 \text{ kNm}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} = \sqrt{\frac{285406 \cdot 355}{1.740e + 08}} = 0.76$$

$$\alpha_{LT} = 0.21 \quad (\text{Buckling curve: a})$$

$$\varphi_{LT} = 0.5 \left[1 + \alpha_{LT} \cdot (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right] = 0.5 \left[1 + 0.21 \cdot (0.76 - 0.2) + 0.76^2 \right] = 0.85$$

$$\chi_{LT} = \min \left(\frac{1}{\varphi_{LT} + \sqrt{\varphi_{LT}^2 - \bar{\lambda}_{LT}^2}}, 1.0 \right) = \min \left(\frac{1}{0.85 + \sqrt{0.85^2 - 0.76^2}}, 1.0 \right) = 0.82 \quad (6.56)$$

$$M_{y,b,Rd} = \frac{\chi_{LT} \cdot W_y \cdot f_y}{\gamma_{M1}} = \frac{0.82 \cdot 285406 \cdot 355}{1.00} = 82.69 \text{ kNm} \quad (6.55)$$

$$\frac{M_{1,Ed}}{M_{y,b,Rd}} = \frac{0.00}{82.69} = 0.00 \leq 1.00 \quad (6.54) - \text{OK}$$

Interaction between normal force and bending 1. - Part 1-1: 6.3.3

Bar: B.204.1, LC: 'ULS element', x = 500 mm

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

k_{ij} factors are calculated according to Method 1

$$C_{my} = 1.00 \quad C_{yy} = 1.00$$

$$C_{mz} = 1.00 \quad C_{yz} = 0.64$$

$$C_{mLT} = 1.00 \quad C_{zy} = 1.00$$

$$C_{zz} = 0.64$$

$$M_{2,Rk} = f_y \cdot W_{pl,2} = 355 \cdot 58145 = 20.64 \text{ kNm}$$

$$\frac{N_{Ed}^{comp}}{N_{b,Rd,1}} + k_{11} \cdot \frac{M_{1,Ed}}{M_{y,b,Rd}} + k_{12} \cdot \frac{M_{2,Ed}}{M_{2,Rk}} = \frac{0.00}{1180.64} + 1.00 \cdot \frac{73.34}{82.69} + 1.08 \cdot \frac{0.00}{\frac{20.64}{1.00}} = 0.89 \leq 1.00 \quad (6.61) - \text{OK}$$

Interaction between normal force and bending 2. - Part 1-1: 6.3.3

Bar: B.204.1, LC: 'ULS elementi', $x = 500 \text{ mm}$

Class_N = 2, Class_{M1} = 1, Class_{M2} = 1

k_{ij} factors are calculated according to Method 1

$$C_{my} = 1.00 \quad C_{yy} = 1.00$$

$$C_{mz} = 1.00 \quad C_{yz} = 0.64$$

$$C_{mLT} = 1.00 \quad C_{zy} = 1.00$$

$$C_{zz} = 0.64$$

$$M_{2,Rk} = f_y \cdot W_{pl,2} = 355 \cdot 58145 = 20.64 \text{ kNm}$$

$$\frac{N_{Ed}^{comp}}{N_{b,Rd,2}} + k_{21} \cdot \frac{M_{1,Ed}}{M_{y,b,Rd}} + k_{22} \cdot \frac{M_{2,Ed}}{M_{2,Rk}} = \frac{0.00}{863.79} + 0.52 \cdot \frac{73.34}{82.69} + 1.56 \cdot \frac{0.00}{\frac{20.64}{1.00}} = 0.46 \leq 1.00 \quad (6.62) - \text{OK}$$

Interaction between normal force and bending, 2nd order - Part 1-1: 6.3.3

Not relevant

Shear buckling - Part 1-5: 5

$$\frac{h_w}{t} = \frac{202}{6} = 34.2 \leq \frac{72}{\eta} \cdot \varepsilon = \frac{72}{1.20} \cdot 0.81 = 48.8 \rightarrow \text{Not relevant}$$

Summary

