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BUCKLING RESISTANCE OF MEMBER [EN 1993.1−1(6.3)]

The buckling resistance of the member is sufficient if the following conditions are fullfilled.

(No bending moment about weak axis, $M_{z,Ed}=0, \Delta M_z=0$)

$N_{Ed}=98.9\ kN$, $M_{y,Ed}=209.7\ kN\ m$

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}}+k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} \quad (6.61)$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}}+k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} \quad (6.62)$$

The k_{yy} *and* k_{zy} *factors will be calculated using the Annex B of EN* $1993-1-1$.

Design Summary

Check	Reference	Ratio
Compression and biaxial bending	6.61	0.74
Compression and biaxial bending	6.62	0.40
Torsional flexural buckling under compression	6.3.1.4	0.05

Loading

Axial Force $N_{Ed}=98.9\ kN$

Bending Moment of Major Axis $M_{y,Ed}=209.7\ kN\ m$

Bending Moment of Minor Axis $M_{z,Ed}=0.0\ kN\ m$

Combination Name

1.35xD+1.35xSF+1.35xPU+1.35xSH+1.5xS

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Cross-Section Properties

Section : HEA300 (Hot Rolled)

h : 290 mm

b : 300 mm

t_w : 8.5 mm

t_f : 14 mm

r : 27 mm

A : 109.35 cm^2

I_{yy} : 17779.6 cm^4

i_y : 12.8 cm

I_{zz} : 6304.01 cm^4

i_z : 7.59 cm

$W_{el,y}$: 420.27 cm^3

$W_{el,z}$: 420.27 cm^3

$W_{pl,y}$: 1344.1 cm^3

$W_{pl,z}$: 637.36 cm^3

$W_{eff,y}$: 1192.04 cm^3

$W_{eff,z}$: 420 cm^3

Steel Grade : S275

Material Properties

Modulus of Elasticity , $E = 2.100E+8\ kN/m^2$

Shear Modulus, $G = 8.077E+7\ kN/m^2$

Yield Strength , $f_y = 275000\ kN/m^2$

– Buckling curves definiation: [EN 1993.1.1(Table6.2)]

h/b : 0.97

Imperfaction factor or strong axis buckling : $\alpha_y = 0.34$

Imperfaction factor or strong axis buckling : $\alpha_z = 0.49$

– Reduction factor for Major axis [EN 1993.1.1(6.3.1.2)]

$$N_{cr,y} = \frac{\pi^2 \times E \times I_{yy}}{L_{cr,y}^2} = \frac{\pi^2 \times 2.100E+8 \times 0.000178}{6^2} = 18197.68\ kN$$

$$\frac{N_{Ed}}{N_{cr,y}} = \frac{98.9}{18197.68} = 0.00543 \leq 0.04 \quad thus \quad \chi_y = 1.000 \ [EN\ 1993.1.1(6.3.1.2(4))]$$

– Reduction factor for Minor axis [EN 1993.1.1(6.3.1.2)]

$$N_{} = \frac{\pi^2 \times E \times I_{zz}}{} = \frac{\pi^2 \times 2.100E+8 \times 6.3E-05}{} = 14517.56\ kN$$

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$$\frac{N_{Ed}}{N_{cr,z}}=\frac{98.9}{14517.56}=0.00681\leq 0.04 \quad thus \quad \chi_z=1.000 \quad [EN\,1993.1.1(6.3.1.2(4))]$$

– Auxilary Terms [EN 1993.1.1(Annex A)]

$$\mu_y=\frac{1-\frac{N_{ed}}{N_{cr,y}}}{1-\chi_y\frac{N_{ed}}{N_{cr,y}}}=\frac{1-\frac{98.9}{18197.68}}{1-0.923\times\frac{98.9}{18197.68}}=1$$

$$\mu_z=\frac{1-\frac{N_{ed}}{N_{cr,z}}}{1-\chi_z\frac{N_{ed}}{N_{cr,z}}}=\frac{1-\frac{98.9}{14517.56}}{1-0.868\times\frac{98.9}{14517.56}}=0.999$$

$$w_y=\frac{W_{pl,y}}{W_{el,y}}\leq 1.5=min\left\{\frac{0.00134}{0.00042}=3.2,1.5\right\}=1.1$$

$$w_z=\frac{W_{pl,z}}{W_{el,z}}\leq 1.5=min\left\{\frac{0.000637}{0.00042}=1.52,1.5\right\}=1.5$$

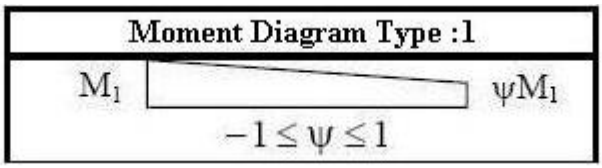
– Equivalent uniform momemt factor for major axis ($C_{m,y,0}$)

[EN 1993.1.1(Table A.2)]

Moment Diagram Type : Type 1

$$C_{m,y,0}=0.79+0.21\psi_y+0.36(\psi_y-0.33)\frac{N_{Ed}}{N_{cr,y}}$$

$$C_{m,y,0}=0.79+0.21\times 0.803+0.36(0.803-0.33)\frac{98.9}{18197.68}=0.96$$



– Equivalent uniform momemt factor for minor axis ($C_{m,z,0}$)

[EN 1993.1.1(Table A.2)]

Moment Diagram Type : Type 1

$$C_{m,z,0}=0.79+0.21\psi_z+0.36(\psi_z-0.33)\frac{N_{Ed}}{N_{cr,z}}$$

$$C_{m,z,0}=0.79+0.21\times 0.803+0.36(0.803-0.33)\frac{98.9}{14517.56}=1$$

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– Resistance to lateral torsional buckling

Section Class of Major Axis : 2

$C_1 = 1.29 \quad C_2 = 0 \quad C_3 = 1$

$z_j = 0 \rightarrow$

$$s_{q,0} = \sqrt{\frac{I_w}{I_{zz}} + \frac{L^2}{\pi^2} \times \frac{G \times I_t}{E \times I_{zz}}} = \sqrt{\frac{1.2E\text{-}06}{6.3E\text{-}05} + \frac{6000^2}{\pi^2} \times \frac{8.077E+7 \times 8.52E\text{-}07}{2.100E+8 \times 6.3E\text{-}05}} = 0.195$$

$$M_{cr,0} = C_1 \times \frac{\pi^2 \times E \times I_{zz}}{L^2} \times s_{q,0} = 1.29 \times \frac{\pi^2 \times 2.100E+8 \times 6.3E\text{-}05}{6000^2} \times 0.195 = 909.12\, kN\, m$$

$$\bar{\lambda}_0 = \sqrt{\frac{W_{ply} \times f_y}{M_{cr,0}}} = \sqrt{\frac{0.00134 \times 275000}{909.12}} = 0.723$$

The elastic torsional buckling force ($N_{cr,T}$):

$$i_s^2 = i_y^2 + i_z^2 + a^2 = 0.128^2 + 0.0759^2 + 0.0^2 = 0.022\, kN^2$$

where

a is the distance between the centroid of the member and the centroid of the restraining members

L_t *is the distance between the torsional restraints*

$$N_{cr,T} = \frac{1}{i_s^2}\left(\frac{\pi^2 \times E \times I_w}{L_t^2} + G \times I_t\right)$$

$$= \frac{1}{0.022}\left(\frac{\pi^2 \times 2.100E+8 \times 1.2E\text{-}06}{6000^2} + 8.077E+7 \times 8.52E\text{-}07\right) = 6261.79\, kN$$

$$N_{cr,TF} = min(N_{cr,T}; N_{cr,y}; N_{cr,z}) = 6261.79\, kN \; (Doubly\, Symmetrical\, Section)$$

$$\bar{\lambda}_{0,lim} = 0.2\sqrt{C_1}\sqrt[4]{\left(1 - \frac{N_{Ed}}{N_{cr,z}}\right)\left(1 - \frac{N_{Ed}}{N_{cr,TF}}\right)}$$

$$\bar{\lambda}_{0,lim} = 0.2\sqrt{1.29}\sqrt[4]{\left(1 - \frac{98.9}{14517.56}\right)\left(1 - \frac{98.9}{6261.79}\right)} = 0.225$$

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– Reduction factor for Lateral Buckling χ_{LT} [EN 1993.1.1(6.3.2.2)]

$C_1 = 1.29 \quad C_2 = 1.56 \quad C_3 = 0.753$

$Section = HEA300\ (Hot\ Rolled)$

$Section\ Class = 2$

$h/b = 0.967$

$$\alpha_{LT} = 1 - \frac{I_t}{I_{yy}} \geq 0 = Max\left(1 - \frac{8.52E\text{-}07}{0.000178}, 0\right) \rightarrow \alpha_{LT} = 0.995$$

$$s_q = \sqrt{\frac{I_w}{I_{zz}} + \frac{L^2}{\pi^2} \times \frac{G \times I_t}{E \times I_{zz}} + (C_2 \times z_g - C_3 \times z_j)^2}$$

$$s_q = \sqrt{\frac{1.2E\text{-}06}{6.3E\text{-}05} + \frac{6^2}{\pi^2} \times \frac{8.077E+7 \times 8.52E\text{-}07}{2.100E+8 \times 6.3E\text{-}05} + (1.56 \times 0.0 - 0.753 \times 0.0)^2} = 0.195$$

$$M_{cr} = C_1 \times \frac{\pi^2 \times E \times I_{zz}}{L^2}(s_q(C_2 \times z_g - C_3 \times z_j))$$

$$M_{cr} = 1.29 \times \frac{\pi^2 \times 2.100E+8 \times 6.3E\text{-}05}{6^2} \times (0.195 \times (1.56 \times 0.0 - 0.753 \times 0.0))$$

$M_{cr} = 909.12 \quad kN\ m$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{ply} \times f_y}{M_{cr}}} = \sqrt{\frac{0.00134 \times 275000}{909.12}} = 0.638$$

$$\Phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0.2\right) + \bar{\lambda}_{LT}^{\ 2}\right] = 0.5[1 + 0.995 \times (0.638 - 0.2) + 0.638^2] = 0.749$$

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^{\ 2} - \bar{\lambda}_{LT}^{\ 2}}} \leq 1 = min\left(\frac{1}{0.749 + \sqrt{0.749^2 - 0.638^2}}, 1\right) = 0.875$$

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$\lambda_0 > \lambda_{0,lim} \rightarrow$

$$C_{my} = C_{my,0} + (1 - C_{my,0}) \frac{\sqrt{\varepsilon_y a_{LT}}}{1 + \sqrt{\varepsilon_y a_{LT}}} = 0.96 + (1 - 0.96) \frac{\sqrt{18.9 \times 0.995}}{1 + \sqrt{18.9 \times 0.995}} = 0.992$$

$$C_{mz} = C_{mz,0} = 1$$

$$C_{mLT} = C_{my}^2 \frac{a_{LT}}{\sqrt{\left(1 - \frac{N_{Ed}}{N_{cr,z}}\right)\left(1 - \frac{N_{Ed}}{N_{cr,T}}\right)}} \geq 1$$

$$C_{mLT} = max\left(0.992^2 \frac{0.995}{\sqrt{\left(1 - \frac{98.9}{14517.56}\right)\left(1 - \frac{98.9}{6261.79}\right)}}, 1\right) = 1$$

$-\ Cij\ Factors\ [EN\ 1993.1.1(Table\ A.1)]$

$Section\ class = 2$

$$N_{Rk} = A \times f_y = 0.0109 \times 275000 = 3007.13\ kN$$

$$n_{pl} = \frac{N_{Ed}}{N_{Rk}/\gamma_{M1}} = \frac{98.9}{3007.13/1.10} = 0.0362$$

$$a_{LT} = max\left(1 - \frac{I_T}{I_{yy}}, 0\right) = max\left(1 - \frac{8.52E\text{-}07}{0.000178}, 0\right) = 0.995$$

$M_{y,Ed} = 0\ \ veya\ \ M_{z,Ed} = 0 \rightarrow b_{LT} = 0$

$$C_{yy} = 1 + \left(w_y - 1\right) \times \left[\left(2 - \frac{1.6}{w_y} \times C_{my}^2 \times \bar{\lambda}_{max} - \frac{1.6}{w_y} \times C_{my}^2 \times \bar{\lambda}_{max}^2\right) n_{pl} - b_{LT}\right] \geq \frac{W_{el,y}}{W_{pl,y}}$$

$$\frac{W_{el,y}}{W_{pl,y}} = \frac{0.00042027}{0.0013441} = 0.31$$

$$C_{yy} = 1 + (1.1 - 1) \times \left[\left(2 - \frac{1.6}{1.1} \times 0.99^2 \times 0.46 - \frac{1.6}{1.1} \times 0.99^2 \times 0.46^2\right) \times 0.036 - 0.0\right] \geq 0.31$$

$C_{yy} = 1$

$M_{y,Ed} = 0\ \ or\ \ M_{z,Ed} = 0 \rightarrow d_{LT} = 0$

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$$C_{zy}=1+\left(w_y-1\right)\left[\left(2-14\frac{C_{my}^2\times\bar{\lambda}_{max}^{\,2}}{w_y^5}\right)\times n_{pl}-d_{LT}\right]\geq 0.6\times\sqrt{\frac{w_y}{w_z}}\times\frac{W_{el,y}}{W_{pl,y}}$$

$$0.6\times\sqrt{\frac{w_y}{w_z}}\times\frac{W_{el,y}}{W_{pl,y}}=0.6\times\sqrt{\frac{1.1}{1.5}}\times\frac{0.00042027}{0.0013441}=0.16$$

$$C_{zy}=1+\left(1.1-1\right)\left[\left(2-14\frac{0.99^2\times 0.46^2}{1.1^5}\right)\times 0.036-0.0\right]\geq 0.16$$

$$C_{zy}=1$$

– Interaction Factors (k_{ij}) (Table A.1)

$Section\ Class = 2$

$$k_{yy}=C_{my}\times C_{mLT}\times\frac{\mu_y}{1-\frac{N_{Ed}}{N_{cr,y}}}\times\frac{1}{C_{yy}}$$

$$=0.992\times 1\frac{1}{1-\frac{98.9}{18197.68}}\times\frac{1}{1}=0.994$$

$$k_{zy}=C_{my}\times C_{mLT}\times\frac{\mu_z}{1-\frac{N_{Ed}}{N_{cr,y}}}\times\frac{1}{C_{zy}}\times 0.6\sqrt{\frac{w_y}{w_z}}$$

$$=0.992\times 1\times\frac{0.999}{1-\frac{98.9}{18197.68}}\times\frac{1}{1}\times 0.6\sqrt{\frac{1.1}{1.5}}=0.511$$

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– *Capacity Ratios For Buckling* [*EN* 1993.1.1(6.3.3)]

$M_{z,Ed}=0$ *and* $\Delta M_{z,Ed}=0 \rightarrow$

$$\frac{|N_{Ed}|}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}}+k_{yy}\frac{|M_{y,Ed}|+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}}\leq 1 \quad (6.61)$$

$$\frac{|98.9|}{\frac{0.923\times 3007.13}{1.1}}+0.994\times\frac{|209.7|+|0.0|}{0.875\times\frac{369.63}{1.1}}=0.745\leq 1\rightarrow \textit{Satisfactory}$$

$$\frac{|N_{Ed}|}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}}+k_{zy}\frac{|M_{y,Ed}|+|\Delta M_{y,Ed}|}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}}\leq 1 \quad (6.62)$$

$$\frac{|98.9|}{\frac{0.868\times 3007.13}{1.1}}+0.511\times\frac{|209.7|+|0.0|}{0.875\times\frac{369.63}{1.1}}=0.401\leq 1\rightarrow \textit{Satisfactory}$$

So the buckling resistance of the member is Satisfactory .