## Input

| | | |
|---|---|---|
| Section | : 406x178x67UB | $f_y$ = 275 N/mm$^2$. |
| $N_{Ed}$ | = 1500.00 kN. | *Compression* |
| $M_{yEd}$ | = 25.00 kN.m. | *Vertical moment* |
| $L_{cry}$ | = 2.00 m. | *Y axis buckling length* |
| $L_{crz}$ | = 2.00 m. | *Z axis buckling length* |
| $L_{crt}$ | = 2.00 m. | *For torsional buckling* |
| L | = 8.00 m. | *for lateral-torsional buckling* |

## Classification - Axial

| | | |
|---|---|---|
| ε | = 0.924 | |
| Flange | = Class 1 | *Part subject to compression c/t=5.23 limit=8.32* |
| Web | = Class 4 | *Uniform stress c/t=40.95 Class 3 limit=38.83* |
| Section | = Class 4 | |

## Classification - Y axis bending

| | | |
|---|---|---|
| ε | = 0.924 | |
| Flange | = Class 1 | *Part subject to compression c/t=5.23 limit=8.32* |
| Web | = Class 4 | ψ = 3.00 *Non-uniform stress c/t=40.95 Class 3 limit=23.38* |
| Section | = Class 4 | |

## Properties

Use effective section properties *EN 1993-1-5, 5.2.2.*

$A_{eff}$ = 83.02 cm$^2$.

$W_{eff,y,min}$ = 1189 cm$^3$. *(6.15)*

Shift in centroidal axis *6.2.2.5(4) and 6.2.9.3(2) Compression only*

$e_{Ny}$ = 0.0 mm.

$e_{Nz}$ = 0.0 mm.

## Compression

$N_{c,Rd} = A_{eff} f_y/\gamma_{M0}$ = 2282.99 kN. *(6.11)*

$\frac{N_{Ed}}{N_{c,Rd}}$ = 0.66 **Pass** *(6.9)*

## Moment capacity - Y axis

$M_{y,Rd} = W_{eff,y,min} f_y / \gamma_{M0}$ *(6.15)*

= 326.87 kN.m.

$\frac{M_{y,Ed}}{M_{y,Rd}}$ = 0.08 **Pass** *(6.12)*

## Combined capacity *6.2.9.3.(2) (6.44)*

$$\frac{N_{Ed}}{A_{eff}\, f_y/\gamma_{M0}} + \frac{M_{y,Ed} + N_{Ed}\, e_{Ny}}{W_{eff,y,min}\, f_y/\gamma_{M0}} + \frac{M_{z,Ed} + N_{Ed}\, e_{Nz}}{W_{eff,z,min}\, f_y/\gamma_{M0}} < 1.00$$

$$\frac{1500.00}{83.02 \times 275 \times 0.1 / 1.00} = 0.66$$

$$\frac{25.00 + 1500.00 \times 0.0000}{1189 \times 275 \times 0.001 / 1.00} = 0.08$$

$$\frac{0.00 + 1500.00 \times 0.0000}{152.7 \times 275 \times 0.001 / 1.00} = 0.00$$

= 0.73 **Pass**

## Flexural buckling - Y axis *6.3.1.3*

$N_{cr} = \pi^2 E.I/L_{cr}^2 = \pi^2\ 210 \times\ 24330 \times 10^4/\ 2000^2$ = 126071.68 kN.

$\bar{\lambda} = \sqrt{(A_{eff}.f_y/N_{cr})} = \sqrt{(\ 83.0 \times\ 275 \times 0.1 / 126071.68)}$ = 0.13

From Figure 6.4 using: $\bar{\lambda}$ = 0.13 and buckling curve 'b' *(see Table 6.2)*

$\chi$ = 1.000

$N_{b,Rd} = \chi\, A_{eff}.f_y/\gamma_{M1} = 1.000 \times\ 83.0 \times\ 275 \times 0.1 / \gamma_{M1}$ = 2282.99 kN

$\frac{N_{Ed}}{N_{b,Rd}}$ = 0.66 **Pass** *(6.46)*

## Flexural buckling - Z axis *6.3.1.3*

$N_{cr} = \pi^2 E.I/L_{cr}^2 = \pi^2\ 210 \times\ 1365 \times 10^4/\ 2000^2$ = 7072.49 kN.

$\bar{\lambda} = \sqrt{(A_{eff}.f_y/N_{cr})} = \sqrt{(\ 83.0 \times\ 275 \times 0.1 /\ 7072.49)}$ = 0.57

From Figure 6.4 using: $\bar{\lambda}$ = 0.57 and buckling curve 'c' *(see Table 6.2)*

$\chi$ = 0.804

$N_{b,Rd} = \chi\, A_{eff}.f_y/\gamma_{M1} = 0.804 \times\ 83.0 \times\ 275 \times 0.1 / \gamma_{M1}$ = 1835.74 kN

$\frac{N_{Ed}}{N_{b,Rd}}$ = 0.82 **Pass** *(6.46)*

## Torsional and torsional-flexural buckling *6.3.1.4*

**Torsional buckling**

$N_{cr,T}$ = $1/i_0^2\ (G.I_T + \pi^2\ E.I_w\ /\ L_{cr,T}^2)$

$i_0^2$ = $i_y^2 + i_z^2 + y_0^2 + z_0^2 = 169^2 + 39.9^2 + 0.000^2 + 0.000^2$ = 30039 $mm^2$

$N_{cr,T}$ = $1/\ 30039\ (\ 81 \times\ 46.11 \times 10^4 + \pi^2 \times\ 210 \times\ 0.5327 \times 10^{12} /\ 2000^2)$

= 10431.65 kN.

**Torsional-flexural buckling**

$$N_{cr,TF} = \frac{N_{cr,y}}{2\beta}\left( 1 + N_{cr,T} / N_{cr,y} - \sqrt{( ( 1 - N_{cr,T} / N_{cr,y})^2 + 4(y_0/i_0)^2 N_{cr,T} / N_{cr,y} )} \right)$$

$N_{cr,T} / N_{cr,y}$ = 10431.65 /126071.68 = 0.08

$(y_0/i_0)^2$ = $(0.000 /\ 173)^2$ = 0.00

$\beta$ = $1 - (y_0/i_0)^2$ = 1.00

$$N_{cr,TF} = \frac{126071.68}{2 \times\ 1.00}( 1 + 0.08 - \sqrt{( ( 1 - 0.08)^2 + 4 \times 0.00 \times 0.08)} )$$

= 10431.65 kN.

Torsional buckling governs $N_{cr} = N_{cr,T}$

$\bar{\lambda}$ = $\sqrt{(A_{eff}.f_y / N_{cr})}$ = $\sqrt{(\ 83.0 \times\ 275 \times 0.1 /\ 10431.65)}$ = 0.47

From Figure 6.4 using: $\bar{\lambda}$ = 0.47 and buckling curve 'c' *(see Table 6.2)*

$\chi$ = 0.861

$N_{b,Rd}$ = $\chi\ A_{eff}.f_y/\gamma_{M1}$ = $0.861 \times\ 83.0 \times\ 275 \times 0.1 / \gamma_{M1}$ = 1965.23 kN

$$\frac{N_{Ed}}{N_{b,Rd}} = 0.76$$ **Pass** *(6.46)*

**Calculate the elastic critical moment for lateral-torsional buckling**
**Use formula for doubly symmetrical sections.** *See Access Steel SN003a-EN-EU*

| | | | | |
|---|---|---|---|---|
| L | = | 8.000 | m. | *Length between restraints* |
| $C_1$ | = | 1.000 | | *Factor depending upon bending diagram shape* |
| $C_2$ | = | 1.000 | | *Factor depending upon bending diagram shape* |
| $k_z$ | = | 1.00 | | *Factor covering end rotation on plan* |
| $k_w$ | = | 1.00 | | *Factor refers to end warping* |
| $z_a$ | = | 0.0 | mm. | *Distance from load application to centroid. +ve above, -ve below* |
| $I_z$ | = | 1365 | $cm^4$. | *Second moment of are about minor axis* |

$I_t$ = 46.11 $cm^4$. *Torsional constant*
$I_w$ = 0.5327 $dm^6$. *Warping constant*
$z_g$ = 0.0 mm. *Distance from load application to shear centre. +ve above.*
***Note:*** *Shear centre and centroid coincide*

$$M_{cr} = C_1 \frac{\pi^2.E.I_z}{(k_z.L)^2} \left( \sqrt{ (k_z/k_w)^2.I_w/I_z + (k_z.L)^2.G.I_t/(\pi^2.E.I_z) + (C_2.z_g)^2 } - (C_2.z_g) \right)$$

$M_{cr}$ = 155.35 kN.m.

**Lateral torsional buckling**

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$W_y$ = $W_{eff,y}$ *Class 4 cross section*

$M_{cr}$ = 155.35 kN.m. *Access Steel SN003a-EN-EU*

$\bar{\lambda}_{LT} = \sqrt{(W_y.f_y/M_{cr})} = \sqrt{( 1189 \times 275 \times 0.001 / 155.35)} = 1.451$

Using Equation (6.57) : $\bar{\lambda}_{LT}$ = 1.451 and buckling curve 'c' *Rolled sections or equivalent welded*

$\chi_{LT}$ = 0.408

$M_{b,Rd} = \chi_{LT} W_y.f_y/\gamma_{M1}$ = 0.408 x 1189 x 275 x 0.001 /$\gamma_{M1}$ = 133.51 kN.

$\frac{M_{Ed}}{M_{b,Rd}}$ = 0.19 **Pass** *(6.54)*

**Combined bending and axial compression**
**Method 1 - Calculate interaction factors $k_{ij}$** *Annex A*

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Elastic cross-section properties class 3, class 4

**Equivalent uniform moment factor - $C_{my,0}$** *Table A.2*

Case 1 - $M_1$ = 0.00 $M_2$ = 0.00 Therefore $\psi_y$ = 1.000

$N_{Ed}/N_{cr,y}$ = 1500.00 /126071.68 = 0.012

$C_{my,0} = 0.79 + 0.21\psi_y + 0.36 (\psi_y - 0.33) N_{Ed}/N_{cr,y}$ = 1.003

**Equivalent uniform moment factor - $C_{mz,0}$** *Table A.2*

Case 1 - $M_1$ = 0.00 $M_2$ = 0.00 Therefore $\psi_z$ = 1.000

$N_{Ed}/N_{cr,z}$ = 1500.00 / 7072.49 = 0.212

$C_{mz,0} = 0.79 + 0.21\psi_z + 0.36 (\psi_z - 0.33) N_{Ed}/N_{cr,z}$ = 1.051

**Susceptability to torsional deformations**

$\bar{\lambda}_{LT}$ = 1.451

$C_1$ = 1.000

$N_{Ed}/N_{cr,TF}$ = 1500.00 / 10431.65 = 0.144

$\bar{\lambda}_{0,lim} = 0.2\sqrt{C_1} \times \sqrt[4]{((1 - N_{Ed}/N_{cr,z})(1 - N_{Ed}/N_{cr,TF}))}$ = 0.181

$\bar{\lambda}_0 = \sqrt{C_1} \times \bar{\lambda}_{LT}$ = 1.451

$\bar{\lambda}_0 > \bar{\lambda}_{0,lim}$ susceptible to torsional deformations

$$\varepsilon_y = \frac{M_{y,Ed}}{N_{Ed}} \frac{A_{eff}}{W_{eff,y}} = 0.116$$

$a_{LT} = 1 - I_t / I_y$ but $\geq 0.0$ = 0.998

$$C_{my} = C_{my,0} + (1 - C_{my,0}) \frac{\sqrt{(\varepsilon_y)}\, a_{LT}}{1 + \sqrt{(\varepsilon_y)}\, a_{LT}} = 1.002$$

$C_{mz} = C_{mz,0}$ = 1.051

$N_{Ed}/N_{cr,T}$ = 1500.00 / 10431.65 = 0.144

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

but $\geq 1.0$ = 1.220

**Calculate auxiliary terms**

$\chi_y$ = 1.000

$\chi_z$ = 0.804

$$\mu_y = \frac{1 - N_{Ed}/N_{cr,y}}{1 - \chi_y N_{Ed}/N_{cr,y}} = 1.000$$

$$\mu_z = \frac{1 - N_{Ed}/N_{cr,z}}{1 - \chi_z N_{Ed}/N_{cr,z}} = 0.950$$

**Calculate interaction factors $k_{ij}$**

$$k_{yy} = C_{my} C_{mLT} \frac{\mu_y}{(1 - N_{Ed}/N_{cr,y})} = 1.238$$

$$k_{yz} = C_{mz} \frac{\mu_y}{(1 - N_{Ed}/N_{cr,z})} = 0.828$$

$\mu_z$

$k_{zy} = C_{my} C_{mLT} \dfrac{}{(1 - N_{Ed}/N_{cr,y})}$ = 1.176

$k_{zz} = C_{mz} \dfrac{\mu_z}{(1 - N_{Ed}/N_{cr,z})}$ = 1.267

**Combined bending and axial compression**

$$\frac{N_{Ed}}{\chi_y . N_{rk} / \gamma_{M1}} + k_{yy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} . M_{y.Rk} / \gamma_{M1}} + k_{yz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z.Rk} / \gamma_{M1}} < 1.00 \quad \textit{(6.61)}$$

$$\frac{N_{Ed}}{\chi_z . N_{rk} / \gamma_{M1}} + k_{zy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} . M_{y.Rk} / \gamma_{M1}} + k_{zz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z.Rk} / \gamma_{M1}} < 1.00 \quad \textit{(6.62)}$$

Where:

$N_{Ed}$ = 1500.00 kN.
$M_{y,Ed} + N_{Ed}\, e_{Ny}$ = 25.00 + 1500.00 x 0.0000 = 25.00 kN.m.
$M_{z,Ed} + N_{Ed}\, e_{Nz}$ = 0.00 + 1500.00 x 0.0000 = 0.00 kN.m.
$N_{Rk}$ = $A_{eff}\, f_y$ = 83.02 x 275 x 0.1 = 2282.99 kN.
$M_{y,Rk}$ = $W_{eff,y,min}\, f_y$ = 1189 x 275 x 0.001 = 326.87 kN.m.
$M_{z,Rk}$ = $W_{pl,z}\, f_y$ = 236.6 x 275 x 0.001 = 65.05 kN.m.
$\chi_y$ = 1.000
$\chi_z$ = 0.804
$\chi_{LT}$ = 0.408

From Annex A *Use Factors $K_{ij}$ button*

$k_{yy}$ = 1.238
$k_{yz}$ = 0.828
$k_{zy}$ = 1.176
$k_{zz}$ = 1.267

$$\frac{1500.00}{1.00 \times 2282.99 / 1.00} + 1.24 \frac{25.00}{0.41 \times 326.87 / 1.00} + 0.83 \frac{0.00}{65.05 / 1.00} = 0.89$$ **Pass**

$$\frac{1500.00}{0.80 \times 2282.99 / 1.00} + 1.18 \frac{25.00}{0.41 \times 326.87 / 1.00} + 1.27 \frac{0.00}{65.05 / 1.00} = 1.04$$ **Fail**