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CALCULATION SHEET

Job No.	OSM 466	Sheet	1 of 4	Rev	B
Job Title	ECSC Stainless Steel Valorisation Project				
Subject	Design Example 2 – Welded I-section Beam-column with lateral restraints				
Client		Made by	HS	Date	Jul 2002
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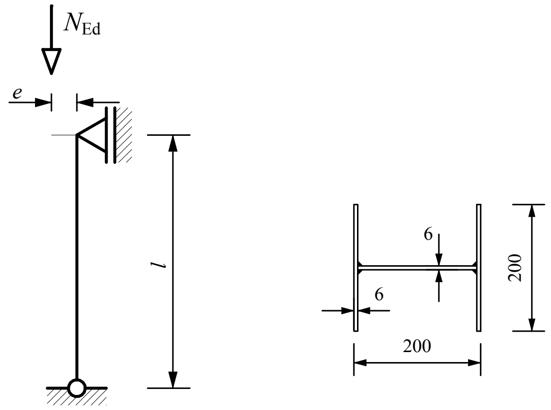
DESIGN EXAMPLE 2 – WELDED I-SECTION BEAM-COLUMN WITH LATERAL RESTRAINTS

The beam-column to be designed is a welded I-section, simply supported at its ends. Minor axis buckling is prevented by lateral restraints. The inter-storey height is equal to 3,50 m. The column is loaded by a vertical single load with an eccentricity.



Structure

Simply supported column, length between supports:

l = 3,50 m

Eccentricity of the load:

e = 20 cm

Actions

Permanent and variable actions result in a vertical design compression force equal to:

N_{Ed} = 120 kN

Structural analysis

Maximum bending moment occurs at the top of the column:

$M_{y,max\ Ed} = 120 \times 0{,}20 = 24$ kNm

Cross section properties

Try a bi-symmetric welded I-section 200 × 200, thickness = 6 mm, grade 1.4401

Geometric properties

b = 200 mm	t_f = 6 mm	$W_{el,y}$ = 259,1 cm^3
h_w = 188 mm	t_w = 6 mm	$W_{pl,y}$ = 285,8 cm^3
a = 3 mm (weld thickness)	I_y = 2591,1 cm^4	
A_g = 35,3 cm²	i_y = 8,6 cm	

Material properties

0,2% proof stress = 220 N/mm^2. Take f_y = 220 N/mm^2 — Table 3.1

E = 200 000 N/mm^2 and G = 76 900 N/mm^2 — Section 3.2.4

Classification of the cross-section

$\varepsilon = 1{,}01$ — Table 4.2

Web subject to compression: $\dfrac{c}{t} = \dfrac{188-3-3}{6} = 30{,}3$ — Table 4.2

For Class 3, $\dfrac{c}{t} \leq 30{,}7\varepsilon$, therefore web is Class 3 (at least)

Outstand flange subject to compression: $\dfrac{c}{t} = \dfrac{200/2-6/2-3}{6} = \dfrac{94}{6} = 15{,}7$ — Table 4.2

For Class 3, $\dfrac{c}{t} \leq 11{,}0\varepsilon$, therefore outstand flange is Class 4

Therefore, overall classification of cross-section is Class 4

Effective section properties

Calculate reduction factor ρ for welded outstand elements

$$\rho = \frac{1}{\bar{\lambda}_p} - \frac{0{,}242}{\bar{\lambda}_p^{\,2}} \leq 1$$ Eq. 4.1c

$$\bar{\lambda}_p = \frac{\bar{b}/t}{28{,}4\varepsilon\sqrt{k_\sigma}} \quad \text{where } \bar{b} = c = 94 \text{ mm}$$ Eq. 4.2

Assuming uniform stress distribution within the compression flange,

$$\psi = \frac{\sigma_2}{\sigma_1} = 1$$ Table 4.4

$\Rightarrow k_\sigma = 0{,}43$ — Table 4.4

$$\bar{\lambda}_p = \frac{94/6}{28{,}4 \times 1{,}01 \times \sqrt{0{,}43}} = 0{,}833$$

$$\rho = \frac{1}{\bar{\lambda}_p} - \frac{0{,}242}{\bar{\lambda}_p^{\,2}} = \frac{1}{0{,}833} - \frac{0{,}242}{0{,}833^2} = 0{,}852$$

b_{eff} = 0,852 × 94 — Table 4.4

= 80,1 mm

Calculate effective cross-section for compression only

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$A_{\mathrm{eff}} \;=\; A_g - 4\times(1-\rho)ct \;=\; 35{,}3 - 4\times(1-0{,}852)\times 94\times 6\times 10^{-2} \;=\; 31{,}9\ \mathrm{cm}^2$

Calculate effective cross-section for major axis bending

$A_{\mathrm{eff}} \;=\; A_{\mathrm{g}} - 2\times(1-\rho)ct \;=\; 35{,}3 - 2\times(1-0{,}852)\times 94\times 6\times 10^{-2} \;=\; 33{,}6\ \mathrm{cm}^2$

Taking area moments about the neutral axis of the gross cross-section, calculate the shift in the position of the neutral axis:

$$\bar{z}' \;=\; \frac{2\times(1-\rho)ct\times(h_{\mathrm{w}}+t_{\mathrm{f}})/2}{A_{\mathrm{eff}}} \;=\; \frac{2\times(1-0{,}852)\times 94\times 6\times(188+6)/2}{33{,}6\times 10^2}$$

$= 4{,}8$ mm shifted in the direction away from the compression flange

Calculate effective 2nd moment of inertia for major axis bending

$$I_{\mathrm{y,eff}} \;=\; I_{\mathrm{y}} \;-\; 2\times(1-\rho)ct\times\left[\frac{t^2}{12}+\frac{(h_{\mathrm{w}}+t_{\mathrm{f}})^2}{4}\right] \;-\; \bar{z}'^{\,2} A_{\mathrm{eff}}$$

$$= 2591{,}1 - 2\times(1-0{,}852)\times 94\times 6\times\left[\frac{6^2}{12}+\frac{(188+6)^2}{4}\right]\times 10^{-4} - (4{,}8)^2\times 33{,}6\times 10^{-2}$$

$= 2426{,}2\ \mathrm{cm}^4$

And

$$W_{\mathrm{eff,y}} \;=\; \frac{I_{\mathrm{y,\,eff}}}{h_{\mathrm{w}}/2 + t_{\mathrm{f}} + \bar{z}'} \;=\; \frac{2426{,}2}{18{,}8/2+0{,}6+0{,}48} \;=\; 231{,}5\ \mathrm{cm}^3$$

Resistance to major axis flexural buckling

$N_{\mathrm{b,Rd}} \;=\; \chi A_{\mathrm{eff}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}$ Eq. 5.2b

$A_{\mathrm{eff}} \;=\; 31{,}9\ \mathrm{cm}^2$ for Class 4 cross-section subject to compression

$$\chi \;=\; \frac{1}{\varphi + \left[\varphi^2 - \bar{\lambda}^2\right]^{0,5}} \le 1$$ Eq. 5.3

$$\varphi \;=\; 0{,}5\left(1+\alpha(\bar{\lambda}-\bar{\lambda}_0)+\bar{\lambda}^2\right)$$ Eq. 5.4

$$\bar{\lambda} \;=\; \sqrt{\frac{A_{\mathrm{eff}} f_{\mathrm{y}}}{N_{\mathrm{cr}}}}$$

$l \;=\; 350$ cm (buckling length is equal to actual length)

$$N_{\mathrm{cr}} \;=\; \frac{\pi^2 EI}{l^2} \;=\; \frac{\pi^2\times 200000\times 2591{,}1\times 10^4}{350^2\times 10^2}\times 10^{-3} \;=\; 4175{,}2\ \mathrm{kN}$$

$$\bar{\lambda} \;=\; \sqrt{\frac{31{,}9\times 10^2\times 220}{4175{,}2\times 10^3}} \;=\; 0{,}410$$

Using imperfection factor $\alpha = 0{,}49$ and initial slenderness $\bar{\lambda}_0 = 0{,}2$ for welded open sections, major axis bending — Table 5.1

$$\varphi = 0{,}5\left(1 + 0{,}49(0{,}410 - 0{,}2) + 0{,}410^2\right) = 0{,}636$$

$$\chi = \frac{1}{0{,}636 + \left[0{,}636^2 - 0{,}410^2\right]^{0,5}} = 0{,}891$$

$$N_{\mathrm{b,y,Rd}} = 0{,}891 \times 31{,}9 \times 10^2 \times 220 \times 10^{-3}/ 1{,}1$$

$$= 568{,}46 \text{ kN}$$

Resistance to axial compression and uniaxial major axis moment — Section 5.5.2

Eq. 5.40

$$\frac{N_{\mathrm{Ed}}}{\left(N_{\mathrm{b,Rd}}\right)_{\min}} + k_y \frac{M_{\mathrm{y,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Ny}}}{\beta_{\mathrm{W,y}}\, W_{\mathrm{pl,y}}\, f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \leq 1$$

$\beta_{\mathrm{W,y}} = W_{\mathrm{eff}} / W_{\mathrm{pl,y}}$ for a Class 4 cross -section

$= 231{,}5 / 285{,}8 = 0{,}810$

e_{Ny} is zero, due to the symmetry of the cross-section

$$k_{\mathrm{y}} = 1{,}0 + 2(\bar{\lambda}_y - 0{,}5)\frac{N_{\mathrm{Ed}}}{N_{\mathrm{b,Rd,y}}} = 1{,}0 + 2(0{,}410 - 0{,}5)\frac{120{,}0}{568{,}46} = 0{,}962$$

$$1{,}2 + \frac{2N_{\mathrm{Ed}}}{N_{\mathrm{b,Rd.y}}} = 1{,}2 + \frac{2 \times 120}{568{,}46} = 1{,}62$$

but $1{,}2 \leq k_{\mathrm{y}} \leq 1{,}62$

$\therefore k_{\mathrm{y}} = 1{,}2$

$$\frac{120{,}0}{568{,}46} + 1{,}2\frac{24{,}0 \times 10^6}{0{,}81 \times 285{,}8 \times 10^3 \times 220/1{,}1} = 0{,}833 \leq 1$$

Thus the member has adequate resistance.