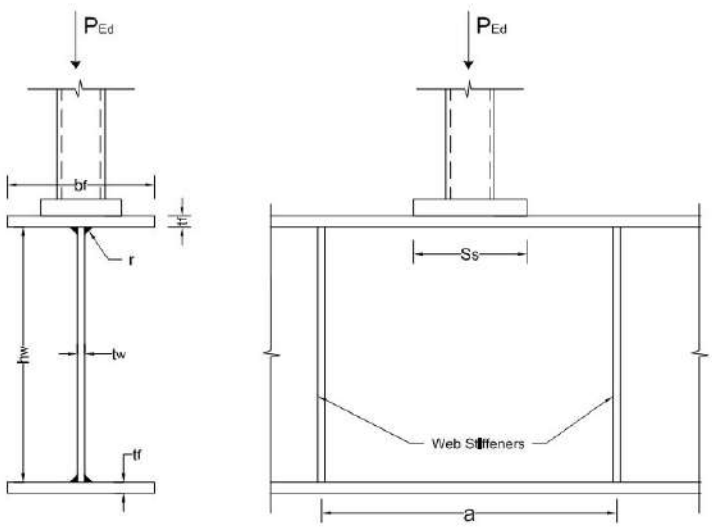
Created by Antoni Yiapani 22/12/2018

Beam web under concentrated load according to Eurocode 3/1.5

INPUT DATA

COMPUTED OUTPUT

DATA TO BE CHECKED



Characteristic Yield strength of structural steel of the beam: $f_{yk} := 275\ MPa$

Characteristic Yield strength of structural steel for the plate: $f_{yf} := f_{yk} = 275\ MPa$

Characteristic Yield strength of structural steel of the web: $f_{yw} := f_{yk} = 275\ MPa$

Safety factors $\gamma_{M1} := 1$ $\gamma_{M0} := 1$

Design axial compression force of the beam at the examined location $N_{Ed} := 15\ kN$

Design Bending Moment of the beam at the examined location $M_{Ed} := 232\ kN \cdot m$

Transverse force on the beam (downwards) $P_{Ed} := 500\ kN$

Main beam flange width $b_{flange} := 280\ mm$

Flange thickness $t_f := 13\ mm$

Main beam web thickness $t_w := 8\ mm$

Radius of fillet between flange and web $r := 24\ mm$

Beam web height $h_w := 400\ mm$

Length of stiff bearing $S_s := 400\ mm$ Figure.(6.2)

Modulus of Elasticity of steel $E_s := 210000\ MPa$

$S_s := min(S_s, h_w) = 400\ mm$

The length of stiff bearing Ss on the flange should be taken as the distance over which the applied load is effectively distributed at a slope of 1:1, see Figure 6.2. However, ss should not be taken as larger than hw.

Distance between adjacent transverse stiffeners $a := 500\ mm$

$$\varepsilon := \sqrt{\frac{235 \cdot MPa}{f_{yf}}} = 0.924$$

$b_f := min(b_{flange}, 2 \cdot 15 \cdot \varepsilon \cdot t_f) = 280\ mm$

1. Resistance against concentrated vertical load

1.1 Effective loaded length

$$m_1 := \frac{f_{yf} \cdot b_f}{f_{yw} \cdot t_w} = 35$$ Eq.(6.8)

Assume that λF>0.5

$$m_2 := 0.02 \cdot \left(\frac{h_w}{t_f}\right)^2 = 18.935$$ Eq.(6.9)

Therefore

$$l_y := min\left(\left(S_s + 2 \cdot t_f \cdot \left(1 + \sqrt{m_1 + m_2}\right)\right), a\right) = 50\ cm$$ effective loaded length Eq.(6.10)

1.2 kF coefficient

$$k_F := 6 + 2 \cdot \left(\frac{h_w}{a}\right)^2 = 7.28$$ Figure.(6.1)

Critical Buckling Load

$$F_{cr} := 0.90 \cdot k_F \cdot E_s \cdot \frac{{t_w}^3}{h_w} = 1761\ kN$$ Eq.(6.5)

$$\lambda_F := \sqrt{\frac{l_y \cdot t_w \cdot f_{yw}}{F_{cr}}} = 0.79$$

```
result := if (λF > 0.5)
              m2 ← 0.02 · (hw / tf)^2
          else
              m2 ← 0
          return m2
```

$m_2 := result = 18.935$

$l_y := min\left(\left(S_s + 2 \cdot t_f \cdot \left(1 + \sqrt{m_1 + m_2}\right)\right), a\right) = 50\ cm$

$k_F := 6 + 2 \cdot \left(\frac{h_w}{a}\right)^2 = 7.28$

$F_{cr} := 0.90 \cdot k_F \cdot E_s \cdot \frac{t_w^{\ 3}}{h_w} = 1761\ kN$

$\lambda_F := \sqrt{\frac{l_y \cdot t_w \cdot f_{yw}}{F_{cr}}} = 0.79$

$x_F := min\left(\frac{0.5}{\lambda_F}, 1\right) = 0.633$ Reduction fuction Eq.(6.3)

$L_{eff} := x_F \cdot l_y = 31.633\ cm$ effective length for resistance to transverse forces Eq.(6.2)

1.3 Design Resistance to local buckling under transverse forces

$F_{Rd} := \frac{f_{yw} \cdot L_{eff} \cdot t_w}{\gamma_{M1}} = 695.9\ kN$ Eq.(6.1)

$\text{if}\left(F_{Rd} > P_{Ed}, \text{“SAFE”}, \text{“NOT SAFE”}\right) = \text{“SAFE”}$

$n_2 := \frac{P_{Ed}}{F_{Rd}} = 0.718$ Eq.(6.14)

2. Check against normal stresses due to Bending and Axial Force acting on the beam

Flange Classification

EC3/1.1

Table 5.2 (sheet 2 of 3)

```
classification_flange :=
    c_over_t ← ((b_flange − t_w)/2 − r·√2) / t_f
    if (c_over_t ≤ 9·ε)
        “Category 1”
    else if (c_over_t > 9·ε) ∧ (c_over_t ≤ 10·ε)
        “Category 2”
    else if (c_over_t > 10·ε) ∧ (c_over_t ≤ 14·ε)
        “Category 3”
    else
        “Category 4”
```

$classification\_flange = \text{“Category 1”}$

If classification of flange is "4", it is advisable to change the design section

Web Classification for bending

$$classification\_web\_bending := \left\| \begin{array}{l} c\_over\_t \leftarrow \dfrac{\left(h_w - 2 \cdot r \cdot \sqrt{2}\right)}{t_w} \\ \text{if } \left(c\_over\_t \le 72 \cdot \varepsilon\right) \\ \quad \| \text{"Category 1"} \\ \text{else if } \left(c\_over\_t > 72 \cdot \varepsilon\right) \land \left(c\_over\_t \le 83 \cdot \varepsilon\right) \\ \quad \| \text{"Category 2"} \\ \text{else if } \left(c\_over\_t > 83 \cdot \varepsilon\right) \land \left(c\_over\_t \le 124 \cdot \varepsilon\right) \\ \quad \| \text{"Category 3"} \\ \text{else} \\ \quad \| \text{"Category 4"} \end{array} \right.$$

Table 5.2 (sheet 1 of 3)

$$classification\_web\_bending = \text{"Category 1"}$$

If classification of web bending is "4", it is advisable to change the design section

Web Classification for compression

$$classification\_web\_compression := \left\| \begin{array}{l} c\_over\_t \leftarrow \dfrac{\left(h_w - 2 \cdot r \cdot \sqrt{2}\right)}{t_w} \\ \text{if } \left(c\_over\_t \le 33 \cdot \varepsilon\right) \\ \quad \| \text{"Category 1"} \\ \text{else if } \left(c\_over\_t > 33 \cdot \varepsilon\right) \land \left(c\_over\_t \le 38 \cdot \varepsilon\right) \\ \quad \| \text{"Category 2"} \\ \text{else if } \left(c\_over\_t > 38 \cdot \varepsilon\right) \land \left(c\_over\_t \le 42 \cdot \varepsilon\right) \\ \quad \| \text{"Category 3"} \\ \text{else} \\ \quad \| \text{"Category 4"} \end{array} \right.$$

Table 5.2 (sheet 1 of 3)

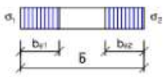
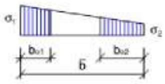
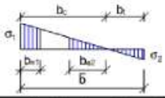
$$classification\_web\_compression = \text{"Category 4"}$$

Plate elements without longitudinal stiffeners | EC3/1.5 4.4

$k_\sigma := 4$ buckling factor corresponding to the stress ratio ψ and boundary conditions. For long plates kσ is given in Table 4.1 or Table 4.2

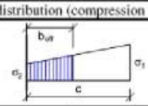
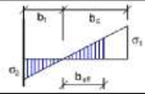
$\psi := 1$ stress ratio determined in accordance with 4.4(3) and 4.4(4)

Table 4.1: Internal compression elements

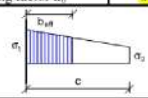
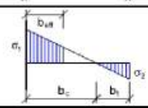
Stress distribution (compression positive)	Effective[1] width b_{eff}
	$\psi = 1$: $b_{eff} = \rho \bar{b}$; $b_{e1} = 0,5\, b_{eff}$ $b_{e2} = 0,5\, b_{eff}$
	$1 > \psi \geq 0$: $b_{eff} = \rho \bar{b}$; $b_{e1} = \frac{2}{5-\psi} b_{eff}$ $b_{e2} = b_{eff} - b_{e1}$
	$\psi < 0$: $b_{eff} = \rho\, b_c = \rho\, \bar{b} / (1-\psi)$; $b_{e1} = 0,4\, b_{eff}$ $b_{e2} = 0,6\, b_{eff}$

$\psi = \sigma_2/\sigma_1$	1	$1 > \psi > 0$	0	$0 > \psi > -1$	-1	$-1 > \psi > -3$
Buckling factor k_σ	4,0	$8,2 / (1,05 + \psi)$	7,81	$7,81 - 6,29\psi + 9,78\psi^2$	23,9	$5,98\,(1-\psi)^2$

Table 4.2: Outstand compression elements

Stress distribution (compression positive)	Effective[1] width b_{eff}
	$1 > \psi > 0$: $b_{eff} = \rho\, c$
	$\psi < 0$: $b_{eff} = \rho\, b_c = \rho\, c / (1-\psi)$

$\psi = \sigma_2/\sigma_1$	1	0	-1	$1 \geq \psi \geq -3$
Buckling factor k_σ	0,43	0,57	0,85	$0,57 - 0,21\psi + 0,07\psi^2$

Stress distribution (compression positive)	Effective[1] width b_{eff}
	$1 > \psi \geq 0$: $b_{eff} = \rho\, c$
	$\psi < 0$: $b_{eff} = \rho\, b_c = \rho\, c / (1-\psi)$

$\psi = \sigma_2/\sigma_1$	1	$1 > \psi > 0$	0	$0 > \psi > -1$	-1
Buckling factor k_σ	0,43	$0,578 / (\psi + 0,34)$	1,70	$1,7 - 5\psi + 17,1\psi^2$	23,8

$$\lambda_p := \frac{\left(\frac{h_w - 2 \cdot r \cdot \sqrt{2}}{t_w}\right)}{28.4 \cdot \varepsilon \cdot \sqrt{k_\sigma}} = 0.791$$

$$\rho := \begin{array}{l} \text{if } (\lambda_p > 0.673) \\ \quad \rho \leftarrow \frac{\lambda_p - 0.055 \cdot (3 + \psi)}{\lambda_p^2} \\ \text{else} \\ \quad \rho \leftarrow 1 \end{array}$$

Reduction factor ρ for internal compression elements | Eq.(4.2)

$\rho = 0.913$

Effective cross section

$$A_{eff} := 2 \cdot b_f \cdot t_f + \rho \cdot h_w \cdot t_w = 102.011\ cm^2$$

Moment of inertia of section

$$I_y := \frac{1}{12} \cdot t_w \cdot h_w^3 + 2 \cdot b_f \cdot t_f \cdot \left(\frac{(h_w + t_f)}{2}\right)^2 = 35310\ cm^4$$

Elastic Section Modulus

$$y_{max} := \left(\frac{h_w + t_f}{2} + \frac{t_f}{2}\right) = 21.3\ cm$$

$$W_{el.y} := \frac{I_y}{y_{max}} = 1658\ cm^3$$

$$W_{eff} := W_{el.y} = 1658\ cm^3$$

Verification

$$n_1 := \frac{N_{Ed}}{\frac{f_{yk} \cdot A_{eff}}{\gamma_{M0}}} + \frac{M_{Ed}}{\frac{f_{yk} \cdot W_{eff}}{\gamma_{M0}}} = 0.514$$

Eq.(4.15)

$$\text{if}\left(n_1 < 1, \text{"SAFE"}, \text{"NOT SAFE"}\right) = \text{"SAFE"}$$

3. Interaction between transverse force, bending moment and axial force

$$\text{if}\left(n_2 + 0.8 \cdot n_1 \le 1.4, \text{"SAFE"}, \text{"NOT SAFE"}\right) = \text{"SAFE"}$$

Eq.(7.2)

4. Flange induced buckling

$A_W := h_w \cdot t_w = 32\ cm^2$ is the cross section area of the web

$A_{fc} := b_f \cdot t_f = 36.4\ cm^2$ fc is the effective cross section area of the compression flange

$k := 0.4$ plastic moment resistance utilized for the beam resistance

To prevent the compression flange buckling in the plane of the web, the following criterion should be met:

$$\text{if}\left(\frac{h_w}{t_w} \le k \cdot \frac{E_s}{f_{yf}} \cdot \sqrt{\frac{A_W}{A_{fc}}}, \text{"SAFE"}, \text{"NOT SAFE"}\right) = \text{"SAFE"}$$

Eq.(8.1)

$$ratio := \frac{\frac{h_w}{t_w}}{k \cdot \frac{E_s}{f_{yf}} \cdot \sqrt{\frac{A_W}{A_{fc}}}} = 0.175$$