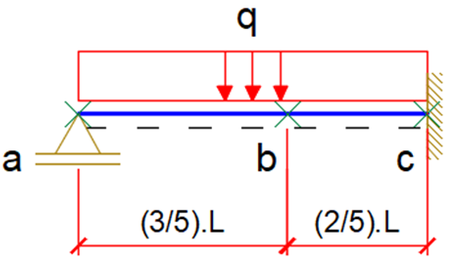
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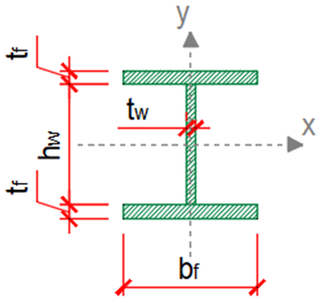
Considerando somente a verificação FLT, calcule a razão momento resistente / momento solicitante para o modelo de viga esboçado ao lado. Em seguida proceda a verificação de flecha e calcule a razão entre flecha limite / flecha calculada.



Perfil I Soldado em aço AR-415 com as seguintes dimensões:

$bf := 200\ mm$ $tf := 8\ mm$ $L := 9\ m$

$hw := 400\ mm$ $tw := 6,3\ mm$



- Combinação normal em ELU e quase-permanente em ELS sendo a viga parte de um edificação residencial de acesso restrito compondo um piso;
- Viga travada lateralmente nos pontos "a", "b" e "c";

- Cargas distribuídas incidentes na viga:

- peso próprio de estrutura metálica

$q1 := 5\ \frac{kN}{m}$ $\gamma 1 := 1,25$

- acidental de ocupação

$q2 := 15\ \frac{kN}{m}$ $\gamma 2 := 1,50$ $\psi 2 := 0,3$

$E := 200\ GPa$ $fy := 41,5\ \frac{kN}{cm^2}$ $\gamma a1 := 1,1$

Q01 - Qual o valor do fator Cb para o trecho "ab" do modelo de viga? [adim.]
Q02 - Qual o valor do fator Cb para o trecho "bc" do modelo de viga? [adim.]
Q03 - Qual o momento fletor resistente FLT do trecho mais desfavorável da viga "abc"? [em kNm]
Q04 - Qual o valor da razão momento resistente FLT / momento solicitante na viga "abc"? [adim.]
Q05 - Qual o valor da razão flecha limite / flecha calculada na viga "abc"? [adim.]

Propriedades Geométricas:

$d := 2 \cdot tf + hw = 416\ mm$ $Ag := 2 \cdot bf \cdot tf + hw \cdot tw = 57,2\ cm^2$

$Ix := \frac{bf \cdot d^3}{12} - \frac{(bf - tw) \cdot hw^3}{12} = 16679\ cm^4$ $Wx := \frac{Ix}{0,5 \cdot d} = 801,87\ cm^3$ $rx := \sqrt{\frac{Ix}{Ag}} = 17,076\ cm$

$Iy := \frac{2 \cdot tf \cdot bf^3}{12} + \frac{hw \cdot tw^3}{12} = 1067,5\ cm^4$ $Wy := \frac{Iy}{0,5 \cdot bf} = 106,75\ cm^3$ $ry := \sqrt{\frac{Iy}{Ag}} = 4,3200\ cm$

$Zx := 2 \cdot \left(bf \cdot tf \cdot \frac{(hw + tf)}{2} + \frac{hw}{2} \cdot tw \cdot \frac{hw}{4} \right) = 904,80\ cm^3$ $Cw := \frac{Iy \cdot (d - tf)^2}{4} = 4,4425 \cdot 10^5\ cm^6$

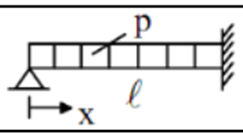
$J := \frac{1}{3} \cdot \left(2 \cdot bf \cdot tf^3 + hw \cdot tw^3 \right) = 10,161\ cm^4$ $\beta 1 := \frac{0,7 \cdot fy \cdot Wx}{E \cdot J} = 0,11463\ \frac{1}{cm}$

Combinações de Ações:

Combinação Normal ELU: $q_elu := \gamma 1 \cdot q1 + \gamma 2 \cdot q2 = 28,750 \ \frac{kN}{m}$

Combinação Quase-Permanente ELS: $q_els := q1 + \psi 2 \cdot q2 = 9,5 \ \frac{kN}{m}$

Solicitações Máximas (ELU)

	$\frac{3}{554}\frac{pL^4}{EI}$	0,422 L	$\frac{pL^4}{48EI}(-2\alpha^4 + 3\alpha^3 - \alpha)$

$$\delta(x) := \frac{q_els \cdot L^4}{48 \cdot E \cdot Ix} \cdot \left[-2 \cdot \left(\frac{x}{L}\right)^4 + 3 \cdot \left(\frac{x}{L}\right)^3 - \left(\frac{x}{L}\right) \right] \qquad L = 9 \ m$$

$$\theta(x) := \frac{d}{dx}\delta(x) \quad ===> \quad \theta(x) := \frac{q_els \cdot L^4}{48 \cdot E \cdot Ix} \cdot \left[-8 \cdot \frac{x^3}{L^4} + 9 \cdot \frac{x^2}{L^3} - \frac{1}{L} \right]$$

$$M(x) := E \cdot Ix \cdot \frac{d}{dx}\theta(x) \quad ===> \quad M(x) := \frac{q_elu \cdot L^4}{48} \cdot \left[-24 \cdot \frac{x^2}{L^4} + 18 \cdot \frac{x}{L^3} \right]$$

$$V(x) := \frac{d}{dx}M(x) \quad ===> \quad V(x) := \frac{q_elu \cdot L^4}{48} \cdot \left[-48 \cdot \frac{x}{L^4} + 18 \cdot \frac{1}{L^3} \right]$$

* Momentos nas extremidades da viga:

$M_0 := M(0) = 0$ $\qquad M_L := M(L) = -291,09 \ kN\,m$

* Valor extremo de momento no meio do intervalo:

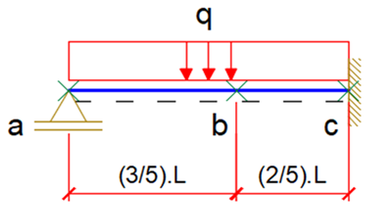
'M(x) = 0 $\qquad x_ext := \frac{3}{8} \cdot L = 3,375 \ m$ $\qquad M_{ext} := M(x_ext) = 163,74 \ kN\,m$

* Cortantes nas extremidades da viga:

$V_0 := V(0) = 97,031 \ kN$ $\qquad V_L := V(L) = -161,72 \ kN$

$Msd := \max\left(\left[\left|M_0\right| \left|M_L\right| \left|M_{ext}\right|\right]\right) = 291,09 \ kN\,m$ $\qquad Vsd := \max\left(\left[\left|V_0\right| \left|V_L\right|\right]\right) = 161,72 \ kN$

Fator Cb do trecho "ab":



$xab_ini := 0$ $\qquad xab_final := \frac{3}{5} \cdot L = 5,4 \ m$

$Lab := xab_final - xab_ini = 5,4 \ m$

$R := 1$ * dupla simetria do perfil

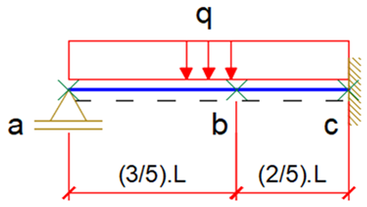
$Ma_ab := \left|M\left(\frac{1}{4} \cdot Lab\right)\right| = 104,79 \ kN\,m$ $\qquad M_0 = 0$ $\qquad M_1 := \left|M\left(\frac{4}{4} \cdot Lab\right)\right| = 104,79 \ kN\,m$

$Mb_ab := \left|M\left(\frac{2}{4} \cdot Lab\right)\right| = 157,19 \ kN\,m$ $\qquad M_{ext} = 163,74 \ kN\,m$

$Mc_ab := \left|M\left(\frac{3}{4} \cdot Lab\right)\right| = 157,19 \ kN\,m$ $\qquad Mmax_ab := \left|M_{ext}\right| = 163,74 \ kN\,m$

$Cb_ab := \min\left(\left[\frac{12,5 \cdot Mmax_ab}{2,5 \cdot Mmax_ab + 3 \cdot Ma_ab + 4 \cdot Mb_ab + 3 \cdot Mc_ab} \cdot R \;\; 3\right]\right) = 1,1221$ $\qquad Q01 := Cb_ab = 1,1221$

Fator Cb do trecho "bc":



$xbc_ini := xab_final = 5,4\ m$ $\qquad xbc_final := L = 9\ m$

$Lbc := xbc_final - xbc_ini = 3,6\ m$

$R := 1$ * dupla simetria do perfil

$Ma_bc := \left|M\left(xbc_ini + \frac{1}{4} \cdot Lbc\right)\right| = 40,753\ kN\ m$ $\qquad M_b := \left|M\left(xbc_ini\right)\right| = 104,79\ kN\ m$

$Mb_bc := \left|M\left(xbc_ini + \frac{2}{4} \cdot Lbc\right)\right| = 46,575\ kN\ m$ $\qquad M_c := \left|M\left(L\right)\right| = 291,09\ kN\ m$

$Mc_bc := \left|M\left(xbc_ini + \frac{3}{4} \cdot Lbc\right)\right| = 157,19\ kN\ m$ $\qquad Mmax_bc := \left|M_c\right| = 291,09\ kN\ m$

$Cb_bc := \min\left(\left[\frac{12,5 \cdot Mmax_bc}{2,5 \cdot Mmax_bc + 3 \cdot Ma_bc + 4 \cdot Mb_bc + 3 \cdot Mc_bc} \cdot R \;\; 3\right]\right) = 2,4131$ $\qquad Q02 := Cb_bc = 2,4131$

Verificação de Momentos Resistentes FLT - Trecho "ab":

FLT	$(f_y - \sigma_r)W$ Ver Nota 5	Ver Nota 1	$\frac{L_b}{r_y}$	$1,76\sqrt{\frac{E}{f_y}}$	Ver Nota 1

$I_x = \frac{b_f(2*t_f+h_w)^3}{12} - \frac{(b_f-t_w)h_w^3}{12}$ $\quad I_y = 2\frac{t_f b_f^3}{12} + \frac{h_w t_w^3}{12}$ $\quad W_x = \frac{I_x}{0,5d}$ $\quad W_y = \frac{I_y}{0,5b_f}$ $\quad Z_x = 2\left(b_f t_f\left(\frac{h_w}{2} + \frac{t_f}{2}\right) + \frac{h_w^2}{8} t_w\right)$ $\quad M_{pl} = Z_x f_y$

Nota 1 :

$\lambda_r = \frac{1,38\sqrt{Iy.J}}{ry.J\beta_1}\sqrt{1 + \sqrt{1 + \frac{27 C_w \beta_1^2}{Iy}}}$ $\quad M_{cr} = \frac{C_b \pi^2 E I_y}{L_b^2}\sqrt{\frac{C_w}{I_y}\left(1 + 0,039\frac{J L_b^2}{C_w}\right)}$ $\quad \beta_1 = \frac{(f_y - \sigma_r)W_x}{E\,J}$ $\quad C_w = \frac{I_y(d-t_f)^2}{4}$ $\quad J = \frac{1}{3}(2b_f t_f^3 + h_w t_w^3)$

Trecho "ab":

$ry = 4,32\ cm$ $\qquad Lb_ab := \frac{3}{5} \cdot L = 540\ cm$

FLT		
Tipo de Viga	**Relação de Parâmetros**	**Expressão de Cálculo**
Curta	$\lambda \le \lambda_p$	$M_{Rd} = \frac{M_{pl}}{\gamma_{a1}}$
Intermediária	$\lambda_p < \lambda \le \lambda_r$	$M_{Rd} = \frac{C_b}{\gamma_{a1}}\left[M_{pl} - (M_{pl} - M_r)\frac{(\lambda - \lambda_p)}{(\lambda_r - \lambda_p)}\right] \le \frac{M_{pl}}{\gamma_{a1}}$
Longa	$\lambda_r < \lambda$	$M_{Rd} = \frac{M_{cr}}{\gamma_{a1}} \le \frac{M_{pl}}{\gamma_{a1}}$

$\lambda_{VIGA_ab} := \frac{Lb_ab}{ry} = 125,0$

$\lambda_{pFLT} := 1,76 \cdot \sqrt{\frac{E}{fy}} = 38,64$

$\lambda_{rFLT} := \frac{1,38 \cdot \sqrt{Iy \cdot J}}{ry \cdot J \cdot \beta 1} \cdot \sqrt{1 + \sqrt{1 + \frac{27 \cdot Cw \cdot \beta 1^2}{Iy}}} = 103,7$

```
Tipo_de_Viga_ab := if λ_VIGA_ab ≤ λ_pFLT = "Longa"
                     "Curta"
                   else
                     if λ_VIGA_ab ≤ λ_rFLT
                       "Intermediária"
                     else
                       "Longa"
```

$Mpl := Zx \cdot fy = 375,49\ kN\ m$ $\qquad Mr := Wx \cdot 0,7 \cdot fy = 232,9\ kN\ m$

$Mrd_FLT_ab := \text{if } \lambda_{VIGA_ab} \le \lambda_{pFLT} \quad = 168{,}80 \text{ kN m}$

$\quad \frac{Mpl}{\gamma a1}$

$\quad \text{else}$

$\quad\quad \text{if } \lambda_{VIGA_ab} \le \lambda_{rFLT}$

$\quad\quad\quad \min\left(\left[\frac{Cb_ab}{\gamma a1}\cdot\left[Mpl-(Mpl-Mr)\cdot\frac{\left(\lambda_{VIGA_ab}-\lambda_{pFLT}\right)}{\left(\lambda_{rFLT}-\lambda_{pFLT}\right)}\right]\ \frac{Mpl}{\gamma a1}\right]\right)$

$\quad\quad \text{else}$

$\quad\quad\quad \min\left(\left[\frac{Cb_ab\cdot\pi^2\cdot E\cdot Iy}{Lb_ab^2\cdot\gamma a1}\cdot\sqrt{\frac{Cw}{Iy}\cdot\left(1+\frac{0{,}039\cdot J\cdot Lb_ab^2}{Cw}\right)}\ \frac{Mpl}{\gamma a1}\right]\right)$

$\frac{Cb_ab}{\gamma a1}\cdot\left[Mpl-(Mpl-Mr)\cdot\frac{\left(\lambda_{VIGA_ab}-\lambda_{pFLT}\right)}{\left(\lambda_{rFLT}-\lambda_{pFLT}\right)}\right] = 190{,}1547 \text{ kN m}$ $\qquad \frac{Mpl}{\gamma a1} = 341{,}3564 \text{ kN m}$

$\frac{Cb_ab\cdot\pi^2\cdot E\cdot Iy}{Lb_ab^2\cdot\gamma a1}\cdot\sqrt{\frac{Cw}{Iy}\cdot\left(1+\frac{0{,}039\cdot J\cdot Lb_ab^2}{Cw}\right)} = 168{,}8011 \text{ kN m}$

Verificação de Momentos Resistentes FLT - Trecho "bc":

FLT	$(f_y-\sigma_r)W$ Ver Nota 5	Ver Nota 1	$\frac{L_b}{r_y}$	$1{,}76\sqrt{\frac{E}{f_y}}$	Ver Nota 1

Trecho "bc":

$Lb_bc := \frac{2}{5}\cdot L = 360 \text{ cm}$

$\lambda_{VIGA_bc} := \frac{Lb_bc}{ry} = 83{,}33$

FLT		
Tipo de Viga	**Relação de Parâmetros**	**Expressão de Cálculo**
Curta	$\lambda \le \lambda_p$	$M_{Rd}=\frac{M_{pl}}{\gamma_{a1}}$
Intermediária	$\lambda_p < \lambda \le \lambda_r$	$M_{Rd}=\frac{C_b}{\gamma_{a1}}\left[M_{pl}-(M_{pl}-M_r)\frac{(\lambda-\lambda_p)}{(\lambda_r-\lambda_p)}\right]\le\frac{M_{pl}}{\gamma_{a1}}$
Longa	$\lambda_r < \lambda$	$M_{Rd}=\frac{M_{cr}}{\gamma_{a1}}\le\frac{M_{pl}}{\gamma_{a1}}$

$Tipo_de_Viga_bc := \text{if } \lambda_{VIGA_bc} \le \lambda_{pFLT} \quad = \text{"Intermediária"}$

$\quad \text{"Curta"}$

$\quad \text{else}$

$\quad\quad \text{if } \lambda_{VIGA_bc} \le \lambda_{rFLT}$

$\quad\quad\quad \text{"Intermediária"}$

$\quad\quad \text{else}$

$\quad\quad\quad \text{"Longa"}$

$Mrd_FLT_bc := \text{if } \lambda_{VIGA_bc} \le \lambda_{pFLT} \quad = 341{,}36 \text{ kN m}$

$\quad \frac{Mpl}{\gamma a1}$

$\quad \text{else}$

$\quad\quad \text{if } \lambda_{VIGA_bc} \le \lambda_{rFLT}$

$\quad\quad\quad \min\left(\left[\frac{Cb_bc}{\gamma a1}\cdot\left[Mpl-(Mpl-Mr)\cdot\frac{\left(\lambda_{VIGA_bc}-\lambda_{pFLT}\right)}{\left(\lambda_{rFLT}-\lambda_{pFLT}\right)}\right]\ \frac{Mpl}{\gamma a1}\right]\right)$

$\quad\quad \text{else}$

$\quad\quad\quad \min\left(\left[\frac{Cb_bc\cdot\pi^2\cdot E\cdot Iy}{Lb_ab^2\cdot\gamma a1}\cdot\sqrt{\frac{Cw}{Iy}\cdot\left(1+\frac{0{,}039\cdot J\cdot Lb_bc^2}{Cw}\right)}\ \frac{Mpl}{\gamma a1}\right]\right)$

$$\frac{Cb_bc}{\gamma a1}\cdot\left[Mpl-\left(Mpl-Mr\right)\cdot\frac{\left(\lambda_{VIGA_bc}-\lambda_{pFLT}\right)}{\left(\lambda_{rFLT}-\lambda_{pFLT}\right)}\right]=609,0644\ \text{kN m}$$

$$\frac{Mpl}{\gamma a1}=341,3564\ \text{kN m}$$

$$\frac{Cb_bc\cdot\pi^{2}\cdot E\cdot Iy}{Lb_ab^{2}\cdot\gamma a1}\cdot\sqrt{\frac{Cw}{Iy}\cdot\left(1+\frac{0,039\cdot J\cdot Lb_bc^{2}}{Cw}\right)}=341,5721\ \text{kN m}$$

$$Mrd_desfav:=\min\left(\left[\,Mrd_FLT_ab\ \ Mrd_FLT_bc\,\right]\right)=168,80\ \text{kN m}$$

$$Q03:=Mrd_desfav$$

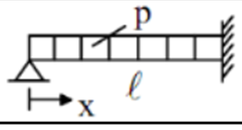
Razões momento resistente FLT / momento solicitante:

Trecho "ab": $\frac{Mrd_FLT_ab}{Mmax_ab}=1,0309$

Trecho "bc": $\frac{Mrd_FLT_bc}{Mmax_bc}=1,1727$

$$Q04:=\min\left(\left[\,\frac{Mrd_FLT_ab}{Mmax_ab}\ \ \frac{Mrd_FLT_bc}{Mmax_bc}\,\right]\right)=1,0309$$

Verificação de Deslocamentos Máximos:

	$\frac{3}{554}\frac{pL^4}{EI}$	0,422 L	$\frac{pL^4}{48EI}(-2\alpha^4+3\alpha^3-\alpha)$

$$\delta calc:=\frac{3\cdot q_els\cdot L^{4}}{554\cdot E\cdot Ix}=1,0118\ \text{cm}$$

$$\delta lim:=\frac{L}{350}=2,5714\ \text{cm}$$

$$Q05:=\frac{\delta lim}{\delta calc}=2,5414$$

$Q01=1,1221$

$Q02=2,4131$

$Q03=168,80\ \text{kN m}$

$Q04=1,0309$

$Q05=2,5414$
