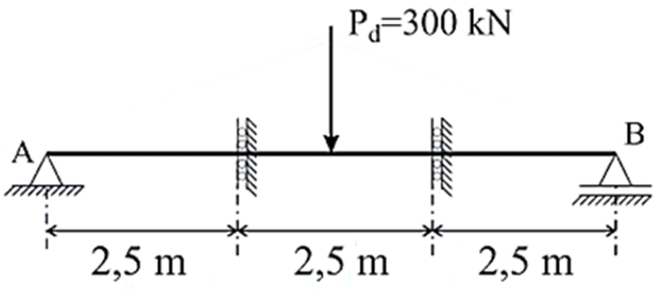
## SE1_E08-04

Verifique se o perfil Ip 550x106 laminado, selecionado para a viga da figura é adequado. A viga tem travamento lateral intermediário a cada terço do vão.




- A carga está aplicada no meio do vão;
- Aço A36;
- Viga de piso com carga Pd em valor de cálculo onde 50% é permanente e 50% é acidental. (Yg= Yq=1,4)
- Considerar combinação quase-permanente para ELS com ψ2 = 0,3
- Desprezar o peso próprio da viga;

Dados do perfil :

$bf := 210\ mm$ $tf := 17,8\ mm$ $tw := 11,1\ mm$ $d := 550\ mm$

$Zx := 2780\ cm^3$ $Wx := 2440\ cm^3$ $ry := 4,45\ cm$ $Iy := 2670\ cm^4$

$Cw := 1884000\ cm^6$ $J := 123\ cm^4$ $L := 7,5\ m$

$E := 200\ GPa$ $fy := 25\ \frac{kN}{cm^2}$ $Pd := 300\ kN$

$\gamma g := 1,4$ $\gamma q := 1,4$

$\gamma a1 := 1,1$ $\psi 2 := 0,3$

### Combinações de Ações:

Combinação Normal ELU: P_elu =Pd

$P_elu := Pd = 300\ kN$

$Pk := \frac{Pd}{1,4} = 214,29\ kN$

Combinação Quase-Permanente ELS: P_els = Pk_perm + ψ2.Pk_acid

$P_els := 0,5 \cdot Pk + \psi 2 \cdot 0,5 \cdot Pk$

$P_els = 139,29\ kN$

### Solicitações Máximas (ELU)

Msd_max = P.a.b/ L = P.(L/2).(L/2) / L = P.L/4

$Msd_max := \frac{P_elu \cdot L}{4} = 562,50\ kN\ m$

Vsd_max = P / 2

$Vsd_max := \frac{P_elu}{2} = 150\ kN$

### Verificação de Momentos Resistentes - FLA, FLM e FLT:

| FLA | $f_y W$ | Viga de alma esbelta (Anexo H) | $\frac{h_w}{t_w}$ | $3,76\sqrt{\frac{E}{f_y}}$ | $5,70\sqrt{\frac{E}{f_y}}$ |
|---|---|---|---|---|---|

$hw := d - 2 \cdot tf = 514,40\ mm$

$\lambda_{FLA} := \frac{hw}{tw} = 46,3423$

$\lambda_{pFLA} := 3,76 \cdot \sqrt{\frac{E}{fy}} = 106,3489$

$\lambda_{rFLA} := 5,70 \cdot \sqrt{\frac{E}{fy}} = 161,2203$

| FLA / FLM | | |
|---|---|---|
| **Tipo de Seção** | **Relação de Parâmetros** | **Expressão de Cálculo** |
| **Compacta** | $\lambda \le \lambda_p$ | $M_{Rd} = \frac{M_{pl}}{\gamma_{a1}}$ |
| **Semi-compacta** | $\lambda_p < \lambda \le \lambda_r$ | $M_{Rd} = \frac{1}{\gamma_{a1}}\left[M_{pl} - (M_{pl} - M_r)\frac{(\lambda - \lambda_p)}{(\lambda_r - \lambda_p)}\right] \le \frac{M_{pl}}{\gamma_{a1}}$ |
| **Esbelta** | $\lambda_r < \lambda$ | $M_{Rd} = \frac{M_{cr}}{\gamma_{a1}}$ Não aplicável à FLA (vide anexo H) |

$Tipo_de_Alma_Flex := \text{if } \lambda_{FLA} \le \lambda_{pFLA} = \text{"Compacta"}$
"Compacta"
else
if $\lambda_{FLA} \le \lambda_{rFLA}$
"Semicompacta"
else
"Esbelta"

$Mpl := Zx \cdot fy = 695,00$ kN m

$My := Wx \cdot fy = 610$ kN m

$Mrd_FLA := \text{if } \lambda_{FLA} \le \lambda_{pFLA} = 631,82$ kN m
$\frac{Mpl}{\gamma a1}$
else
$\frac{1}{\gamma a1} \cdot \left[Mpl - (Mpl - My) \cdot \frac{(\lambda_{FLA} - \lambda_{pFLA})}{(\lambda_{rFLA} - \lambda_{pFLA})}\right]$

| | | | | | |
|---|---|---|---|---|---|
| FLM | $(f_y - \sigma_r)W$ Ver Nota 5 | Ver Nota 6 | $b/t$ ver Nota 8 | $0,38\sqrt{\frac{E}{f_y}}$ | Ver Nota 6 |

$\lambda_{FLM} := \frac{0,5 \cdot bf}{tf} = 5,8989$

$\lambda_{pFLM} := 0,38 \cdot \sqrt{\frac{E}{fy}} = 10,748$

$\lambda_{rFLM} := 0,83 \cdot \sqrt{\frac{E}{fy - 0,30 \cdot fy}} = 28,0591$

$Mr := (fy - 0,3 \cdot fy) \cdot Wx = 42700$ kN cm

| FLA / FLM | | |
|---|---|---|
| **Tipo de Seção** | **Relação de Parâmetros** | **Expressão de Cálculo** |
| **Compacta** | $\lambda \le \lambda_p$ | $M_{Rd} = \frac{M_{pl}}{\gamma_{a1}}$ |
| **Semi-compacta** | $\lambda_p < \lambda \le \lambda_r$ | $M_{Rd} = \frac{1}{\gamma_{a1}}\left[M_{pl} - (M_{pl} - M_r)\frac{(\lambda - \lambda_p)}{(\lambda_r - \lambda_p)}\right] \le \frac{M_{pl}}{\gamma_{a1}}$ |
| **Esbelta** | $\lambda_r < \lambda$ | $M_{Rd} = \frac{M_{cr}}{\gamma_{a1}}$ Não aplicável à FLA (vide anexo H) |

Para perfis laminados: $M_{cr} = \frac{0,69E}{\lambda^2} W_c$ , $\lambda_r = 0,83\sqrt{\frac{E}{(f_y - \sigma_r)}}$

*** Perfil simétrico em relação ao eixo horizontal logo: $Wc := Wx$

$Tipo_de_Mesa := \text{if } \lambda_{FLM} \le \lambda_{pFLM} = \text{"Compacta"}$
"Compacta"
else
if $\lambda_{FLM} \le \lambda_{rFLM}$
"Semicompacta"
else
"Esbelta"

$Mrd_FLM := \text{if } \lambda_{FLM} \le \lambda_{pFLM} = 631,82$ kN m
$\frac{Mpl}{\gamma a1}$
else
if $\lambda_{FLM} \le \lambda_{rFLM}$
$\frac{1}{\gamma a1} \cdot \left[Mpl - (Mpl - Mr) \cdot \frac{(\lambda_{FLM} - \lambda_{pFLM})}{(\lambda_{rFLM} - \lambda_{pFLM})}\right]$
else
$\frac{1}{\gamma a1} \cdot \frac{0,69 \cdot E}{\lambda_{FLM}^2} \cdot Wc$

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

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

Nota 1 :

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

$Lb := 2{,}5\ \text{m}$

$\lambda_{VIGA} := \frac{Lb}{ry} = 56{,}180$

$\lambda_{pFLT} := 1{,}76\cdot\sqrt{\frac{E}{fy}} = 49{,}7803$

| 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** | $\lambda_r < \lambda$ | $M_{Rd} = \frac{M_{cr}}{\gamma_{a1}} \le \frac{M_{pl}}{\gamma_{a1}}$ |

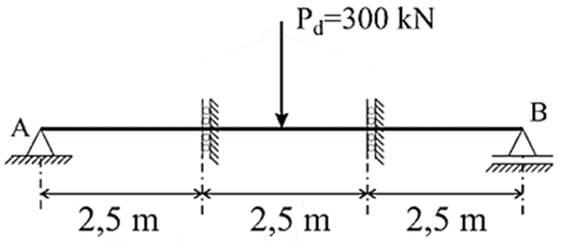
$J = 123\ \text{cm}^4$ $ry = 4{,}45\ \text{cm}$

$Cw = 1{,}884\cdot10^6\ \text{cm}^6$ $Wx = 2440\ \text{cm}^3$ $\beta1 := \frac{0{,}7\cdot fy\cdot Wx}{E\cdot J} = 0{,}0174\ \frac{1}{\text{cm}}$

$Iy = 2670\ \text{cm}^4$

$\lambda_{rFLT} := \frac{1{,}38\cdot\sqrt{Iy\cdot J}}{ry\cdot J\cdot\beta1}\cdot\sqrt{1+\sqrt{1+\frac{27\cdot Cw\cdot\beta1^2}{Iy}}} = 157{,}85$

```
Tipo_de_Viga := if λ_VIGA ≤ λ_pFLT        = "Intermediária"
                  "Curta"
                else
                  if λ_VIGA ≤ λ_rFLT
                    "Intermediária"
                  else
                    "Longa"
```




Cálculo do Fator Cb:

$RVa := \frac{P_elu}{2} = 150{,}00\ \text{kN}$ $MaP(x) := RVa\cdot x$ $MPb(x) := RVa\cdot x - Pd\cdot\left(x - \frac{L}{2}\right)$

Cb para o trecho 1:

$Ma1 := |MaP(0{,}25\cdot Lb)| = 93{,}750\ \text{kN m}$ $Mb1 := |MaP(0{,}50\cdot Lb)| = 187{,}5\ \text{kN m}$

$Mc1 := |MaP(0{,}75\cdot Lb)| = 281{,}25\ \text{kN m}$ $M_max1 := |MaP(Lb)| = 375\ \text{kN m}$

$Cb1 := \min\left(\left[\frac{12{,}5\cdot M_max1}{2{,}5\cdot M_max1 + 3\cdot Ma1 + 4\cdot Mb1 + 3\cdot Mc1}\ \ 3\right]\right) = 1{,}6667$

Cb para o trecho 2:

$Ma2 := |MaP(Lb + 0{,}25\cdot Lb)| = 468{,}75\ \text{kN m}$ $Mb2 := |MaP(Lb + 0{,}5\cdot Lb)| = 562{,}5\ \text{kN m}$

$Mc2 := |MPb(Lb + 0{,}75\cdot Lb)| = 468{,}75\ \text{kN m}$ $M_max2 := |MPb(Lb + 0{,}50\cdot Lb)| = 562{,}5\ \text{kN m}$

$Cb2 := \min\left(\left[\frac{12{,}5\cdot M_max2}{2{,}5\cdot M_max2 + 3\cdot Ma2 + 4\cdot Mb2 + 3\cdot Mc2}\ \ 3\right]\right) = 1{,}087$

Conclusão: a verificação FLT deve ser feita no trecho 2 (entre os travamentos nos terços da viga) porque nele encontra-se o valor do máximo momento que ocorre na viga e também é o trecho que apresenta o menor fator Cb.

$$\frac{Cb2}{\gamma a1}\cdot\left(Mpl-(Mpl-Mr)\cdot\frac{(\lambda_{VIGA}-\lambda_{pFLT})}{(\lambda_{rFLT}-\lambda_{pFLT})}\right)=671,08\ \text{kN m}\qquad\frac{Mpl}{\gamma a1}=631,82\ \text{kN m}$$

$$Mrd_FLT:=\text{if}\ \lambda_{VIGA}\le\lambda_{pFLT}\quad=631,82\ \text{kN m}$$
$$\frac{Mpl}{\gamma a1}$$
$$\text{else}$$
$$\text{if}\ \lambda_{VIGA}\le\lambda_{rFLT}$$
$$\min\left(\left[\frac{Cb2}{\gamma a1}\cdot\left(Mpl-(Mpl-Mr)\cdot\frac{(\lambda_{VIGA}-\lambda_{pFLT})}{(\lambda_{rFLT}-\lambda_{pFLT})}\right)\ \frac{Mpl}{\gamma a1}\right]\right)$$
$$\text{else}$$
$$\min\left(\left[\frac{1}{\gamma a1}\cdot\frac{Cb2\cdot\pi^2\cdot E\cdot Iy}{Lb^2}\cdot\sqrt{\frac{Cw}{Iy}\cdot\left(1+\frac{0,039\cdot J\cdot Lb^2}{Cw}\right)}\ \frac{Mpl}{\gamma a1}\right]\right)$$

$$Mrd:=\min([\ Mrd_FLA\ \ Mrd_FLM\ \ Mrd_FLT\ ])=631,82\ \text{kN m}$$

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## Cortante Resistente:

| Tipo de Alma | Relação de Parâmetros | Expressão de Cálculo |
|---|---|---|
| Compacta | $\lambda \le \lambda_p$ | $V_{Rd}=\frac{V_{pl}}{\gamma_{a1}}$ |
| Semi-compacta | $\lambda_p < \lambda \le \lambda_r$ | $V_{Rd}=\frac{\lambda_p V_{pl}}{\lambda\,\gamma_{a1}}$ |
| Esbelta | $\lambda_r < \lambda$ | $V_{Rd}=1,24\left(\frac{\lambda_p}{\lambda}\right)^2\frac{V_{pl}}{\gamma_{a1}}$ |

$V_{pl}=0,60A_w f_y=0,60dt_w f_y$

$\lambda=\frac{h_w}{t_w}\qquad\lambda_p=1,10\sqrt{\frac{k_v E}{f_y}}\qquad\lambda_p=1,37\sqrt{\frac{k_v E}{f_y}}$

$k_v$ igual a 5,0 para almas sem enrijecedores transversais, para $\frac{a}{h_w}>3$ ou para $\frac{a}{h_w}>\left[\frac{260}{h_w/t_w}\right]^2$ e $5+\frac{5}{(a/h_w)^2}$ para os demais casos.

$$Aw:=d\cdot tw=61,05\ \text{cm}^2\qquad Vpl:=0,60\cdot Aw\cdot fy=915,75\ \text{kN}\qquad kv:=5,0$$

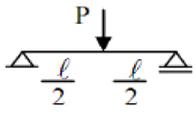
$$\lambda_{CIS}:=\frac{hw}{tw}=46,3423\qquad\lambda_{pCIS}:=1,10\cdot\sqrt{\frac{kv\cdot E}{fy}}=69,5701\qquad\lambda_{rCIS}:=1,37\cdot\sqrt{\frac{kv\cdot E}{fy}}=86,6464$$

$$Tipo_de_Alma_CIS:=\text{if}\ \lambda_{CIS}\le\lambda_{pCIS}\quad=\text{"Compacta"}$$
$$\text{"Compacta"}$$
$$\text{else}$$
$$\text{if}\ \lambda_{CIS}\le\lambda_{rCIS}$$
$$\text{"Semicompacta"}$$
$$\text{else}$$
$$\text{"Esbelta"}$$

$$Vrd:=\text{if}\ \lambda_{CIS}\le\lambda_{pCIS}\quad=832,5\ \text{kN}$$
$$\frac{Vpl}{\gamma a1}$$
$$\text{else}$$
$$\text{if}\ \lambda_{CIS}\le\lambda_{rCIS}$$
$$\frac{\lambda_{pCIS}\cdot Vpl}{\lambda_{CIS}\cdot\gamma a1}$$
$$\text{else}$$
$$1,24\cdot\left(\frac{\lambda_{pCIS}}{\lambda_{CIS}}\right)^2\cdot\frac{Vpl}{\gamma a1}$$

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## Verificação de Deslocamentos Máximos:




$\frac{1}{48}\frac{PL^3}{EI}$ | 0,5 L

$Wx = 2440\ cm^3$ $d = 55\ cm$ Wx= Ix / (0,5.d) $Ix := Wx \cdot 0,5 \cdot d = 67100\ cm^4$

δlim: $\delta lim := \frac{L}{350} = 2,1429\ cm$

δcalc: $\delta calc := \frac{1 \cdot P_els \cdot L^3}{48 \cdot E \cdot Ix} = 0,9122\ cm$

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## Razões entre resistências / solicitações

$R_mom := \frac{Mrd}{Msd_max} = 1,1232$ Ok! Verifica!

$R_cor := \frac{Vrd}{Vsd_max} = 5,55$ Ok! Verifica!

$R_des := \frac{\delta lim}{\delta calc} = 2,3491$ Ok! Verifica!

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