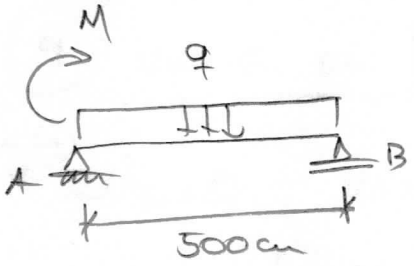
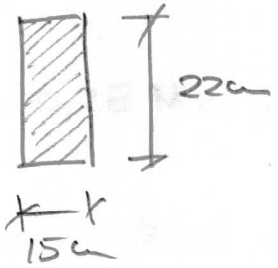
B4AM15ANA

- MADEIRA DICOTILEDÔNEA C30;
- AMBIENTE CLASSE 2 DE UMIDADE;
- CARREG. DE LONGA DURAÇÃO;
- A ESTRUTURA É UMA BIBLIOTECA;
- MADEIRA DE 1ª CATEGORIA;
- TRAVAMENTO LATERAIS SOMENTE NOS APOIOS;
- CARGAS: $q_1 = 3\ kN/m$ (PERM.)
  $M_1 = 27.7\ kNm$ (ACIDENTAL)





QO1) MÁXIMO VÃO "L" P/ QUE A VIGA AINDA NÃO SOFRA INSTABILIDADE LATERAL [cm]

QO2) MÁXIMO "Mk" POSSÍVEL DE SER APLICADO DE MODO A QUE A VERIF. DE MOMENTOS AINDA SEJA ATENDIDA [kNm]

(1) PROP. DA MADEIRA: $k_{mod} = 0,7 \times 1,0 \times 1,0 = 0,70$

$f_{cod} = 0,7 \times 3\ kN/cm^2 / 1,4 = 1,5\ kN/cm^2$

$E_{cod} = 0,7 \times 1450\ kN/cm^2 = 1015\ kN/cm^2$

(2) COMB. DE AÇÕES: $Sd_{ELU} = 1,4 \times 3\ kN/m + 1,4\ Mk$

$Sd_{ELU} = 4,2\ kN/m + 1,4\ Mk$

(3) MÁXIMO VÃO (COMP. DESTRAVADO)

$$L = \frac{E_{cod} \times b}{\beta_M \times f_{cod}}$$

$$\beta_M = \frac{1}{0,2GTT} \times \frac{4,0}{1,4} \times \frac{\left(\frac{22}{15}\right)^{3/2}}{\left(\frac{22}{15} - 0,63\right)^{1/2}} = 6,7925$$

$$L = \frac{1015\ kN/cm^2 \times 15\ cm}{6,7925 \times 1,5\ kN/cm^2} = \boxed{1494,3\ cm}$$

(4) VERIF. DE FLEXÃO:

$$\circlearrowright^{(+)} \Sigma M_B = 0 \qquad V_A \times L + M_{sd} - q_{sd} L^2/2 = 0$$

$$V_A = -\frac{M_{sd}}{L} + q_{sd} L/2 = \frac{-1,4\ MK}{5m} + \frac{4,2\ kN/m \times 5\ m}{2}$$

$$V_A = -0,28\ MK + 10,5\ kN$$

$$M_{AB}(x) = M_{sd} + V_A x - q_{sd} x^2/2$$

$$M_{AB}(x) = 1,4\ MK + (-0,28\ MK + 10,5)x - 2,1x^2$$

$$\frac{dM_{AB}(x)}{dx} = -0,28\ MK + 10,5 - 4,2x = 0$$

$$x = \frac{-0,28\ MK + 10,5}{4,2} = -6,666 \times 10^{-2}\ MK + 2,5$$

$$M_{MAX} = 1,4\ MK + (-0,28\ MK + 10,5)(-6,666 \times 10^{-2}\ MK + 2,5) - 2,1(-6,666 \times 10^{-2}\ MK + 2,5)^2$$

$$M_{MAX} = 9,3333 \times 10^{-3}\ MK^2 + 0,7\ MK + 13,125$$

$$M_{Rd} = 1,5\ kN/cm^2 \times 15\ cm \times (22\ cm)^2/6 = 1815\ kN\,cm = 18,15\ kN\,m$$

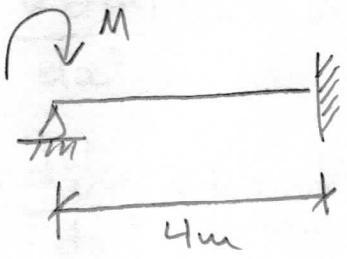
$$M_{MÁX} = M_{Rd}: \quad 9,3333 \times 10^{-3}\ MK^2 + 0,7\ MK - 5,025$$

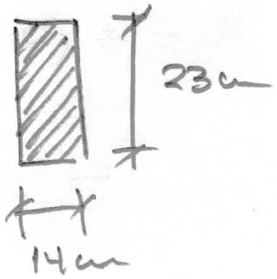
$$MK' = -81,598\ kN\,m$$

$$MK'' = \boxed{6,598\ kN\,m}$$

B4AM16AMA

→ MAD DICOTILEDÔNEA C40
→ $k_{mod} = 0{,}56$
→ ELU COMB. NORMAL;
→ ELUti COMB. LONGA DURAÇÃO;
→ $\delta_{LIM} = L/200$
→ M: PERMANENTE ($\gamma = 1{,}4$)





PEDE-SE: MÁXIMO M_K POSSÍVEL DE MODO A ATENDER

Q01) VERIF. DE CISALHAMENTO;
Q02) " " MOMENTO FLETOR;
Q03) " " FLECHA;

- PROPRIEDADES DA MADEIRA;

$f_{cod} = 0{,}56 \times 4\,kN/cm^2 / 1{,}4 = 1{,}6\,kN/cm^2$

$f_{vd} = 0{,}56 \times 0{,}6\,kN/cm^2 / 1{,}8 = 0{,}18667\,kN/cm^2$

$E_{coef} = 0{,}56 \times 1950\,kN/cm^2 = 1092\,kN/cm^2$

- VERIF. DE FLECHA: $\delta_{calc} = \dfrac{M_K L^2}{27EI} = \dfrac{L}{200}$

$$M_K = \frac{27EI}{200L} = \frac{27 \times 1092\,kN/cm^2 \times 14195\,cm^4}{200 \times 400\,cm} = 5231{,}6\,kNcm$$

$I = 14 \times 23^3/12 = 14195\,cm^4$

$M_{K\,FLECHA} = 52{,}316\,kNm$ (Q03)

- VERIF. DE FLEXÃO:

$$\delta(x) = \frac{ML^2}{4EI}\left(\left(\frac{x}{L}\right)^3 - 2\left(\frac{x}{L}\right)^2 + \frac{x}{L}\right)$$

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$$\frac{d\delta(x)}{dx} = \theta(x) = \frac{ML^2}{4EI}\left(3x^2/L^3 - 4x/L^2 + 1/L\right)$$

$$\frac{d^2\delta(x)}{dx^2} EI = M(x) = \frac{ML^2}{4}\left(6x/L^3 - 4/L^2\right)$$

$$\frac{d^3\delta(x)}{dx^3} EI = V(x) = \frac{ML^2}{4}\left(6/L^3\right) = \frac{6M}{4L}$$

* CORTANTE CTE $M_{MÁX}$ / $M_{MÍN}$ NOS EXTREMOS DA VIGA

$$M(x=0) = -M$$

$$M(x=L) = \frac{ML^2}{4}\left(\frac{6L}{L^3} - 4/L^2\right) = \frac{ML^2}{4}\left(\frac{2}{L^2}\right) = \frac{M}{2}$$

* MÁXIMO EM MÓDULO OCORRE EM $x=0$

$$\frac{6M_{sd}}{bh^2} = f_{cod} \rightarrow \frac{6 \times 1{,}4 \times M_K}{bh^2} = f_{cod}$$

$$M_K = \frac{bh^2 f_{cod}}{6 \times 1{,}4} = \frac{14\,cm \times (23\,cm)^2 \times 1{,}6\,kN/cm^2}{6 \times 1{,}4} = 1410{,}7\,kN.cm$$

$$M_{K_{FLEX}} = 14{,}107\,kN.m \quad (Q02)$$

• VERIF. DE CORTANTES:

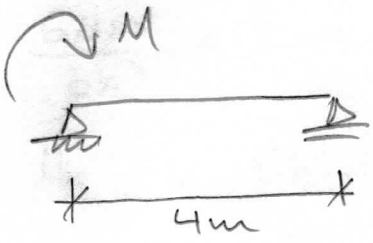
$$\frac{3}{2}\frac{V_{sd}}{bh} = f_{vd} \rightarrow \frac{3}{2}\frac{1{,}4 M_K}{4Lbh} = f_{vd}$$

$$M_K = \frac{8Lbh\,f_{vd}}{18 \times 1{,}4} = \frac{8 \times 400\,cm \times 14\,cm \times 23\,cm \times 0{,}18667\,kN/cm^2}{18 \times 1{,}4}$$

$$M_K = 7632{,}7\,kN.cm \qquad M_{K_{CS}} = 76{,}327\,kN.m \quad (Q01)$$

B4AM16ANA

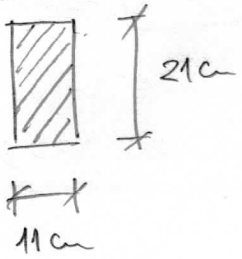
- MAD. DICOTILEDÔNEA C30;
- $k_{mod} = 0,7$;
- ELU COMB. NORMAL;
- ELUti COMB. DE LONGA DURAÇÃO;



M: PERMANENTE ($\gamma_g = 1,4$)

$f_{LIM} = L/200$

SEÇÃO TRANSV.



Qual o máximo valor de M (com termos característicos) possível de ser aplicada de modo que a condição seja atendida:

Q01) VERIF. DE CORTANTES;
Q02) VERIF DE FLEXÃO;
Q03) VERIF DE FLECHA;

① PROP. DA MADEIRA: $f_{cod} = 0,7 \times 3\,kN/cm^2 / 1,4 = 1,5\,kN/cm^2$

$f_{vd} = 0,7 \times 0,5\,kN/cm^2 / 1,8 = 0,1944\,kN/cm^2$

$E_{cod} = 0,7 \times 1450\,kN/cm^2 = 1015\,kN/cm^2$

② VERIF. DE CORTE: $V_{sd} = 1,4 \times M_k / 400cm = 0,0035\,M_k$

$\frac{3}{2}\frac{V_{sd}}{bh} = f_{vd} \rightarrow \frac{3}{2}\frac{0,35\,M_k}{bh} = f_{vd}$

$M_{k_{cis}} = \frac{2bh\,f_{vd}}{3 \times 0,35} = \frac{2 \times 11 \times 21}{3 \times 0,0035} \times 0,1944\,kN/cm^2$

$M_{k_{cis}} = 8553,6\,kN.cm = \underline{85,536\,kN.m}$ (Q01)

(3) VERIF. DE FLEXÃO $\quad M_{sd} = 1{,}4\,M_k$

$$\frac{6M_{sd}}{bh^2} = f_{cod} \Rightarrow \frac{6 \times 1{,}4 M_k}{b\,h^2} = f_{cod}$$

$$M_{k_{FLEX}} = \frac{b\,h^2 f_{cod}}{6 \times 1{,}4} = \frac{11 \times 21^2 \times 1{,}5\,kN/cm^2}{6 \times 1{,}4} = 866{,}25\,kNcm$$

$$M_{K_{FLEX}} = 8{,}6625\,kNm \quad (Q02)$$

(4) VERIF DE FLECHA $\quad \delta_{LIM} = L/200 = 400cm/200 = 2cm$

$$I = 11 \times 21^3/12 = 8489{,}3\,cm^4$$

$$\delta_{CALC} = \frac{1}{9\sqrt{3}} \frac{M_k L^2}{EI} = \delta_{LIM}$$

$$M_k = \frac{9\sqrt{3}\,EI\,\delta_{LIM}}{L^2} = \frac{9\sqrt{3} \times 1015\,kN/cm^2 \times 8489{,}3cm^4 \times 2cm}{(400cm)^2}$$

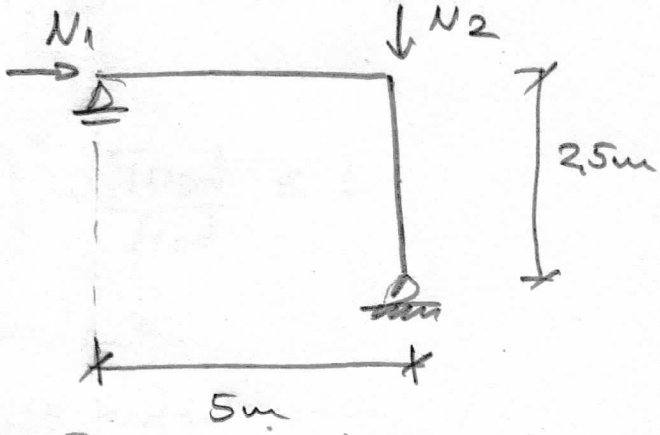
$$M_k = 1679{,}0\,kNcm = 16{,}79\,kNm \quad (Q03)$$

Estruturas de Aço e Madeira

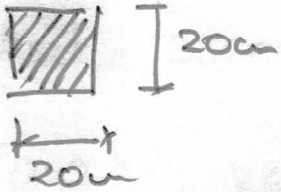
B4AM16ANB valor 1,0 ponto

→ PROCEDER À VERIFICAÇÃO DE RESISTÊNCIA E À VERIFICAÇÃO DE ESTABILIDADE DA COLUNA BC;

- MADEIRA DICOTILEDÔNEA C40
- $k_{mod} = 0{,}56$
- $N_1 = 10\,kN$ (ACIDENTAL)
- $N_2 = 120\,kN$ (PERM.)



SEÇÃO



* VINCULAÇÕES VÁLIDAS P/ AMBOS EIXOS PRINCIPAIS;
* PROBLEMA DE FLEXOCOMP. RETA;

PEDE-SE: Q01) F.S. RES. Q02) F.S. ESTAB.

(1) PROP. MAD. $f_{cod} = 0{,}56 \times 4\,kN/cm^2 / 1{,}4 = 1{,}6\,kN/cm^2$

$E_{cod} = 0{,}56 \times 1950\,kN/cm^2 = 1092\,kN/cm^2$

(2) COMB. DEFLEXÕES E SOLICITAÇÕES

$S_d = 1{,}4 \times 120\,kN + 1{,}4 \times 10\,kN = 168\,kN + 14\,kN$

$N_2 \quad N_1$

$N_{sd} = 168\,kN \qquad M_{sd} = 14\,kN \times 250\,cm = 3500\,kN\,cm$

(3) PROP. GEOM. $A = (20\,cm)^2 = 400\,cm^2$

$I = 20 \times 20^3/12 = 13333\,cm^4$

$W = 20 \times 20^2/6 = 1333{,}3\,cm^3$

Teoria das Estruturas

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{13333}{400}} = 5{,}773 \text{ cm}$$

$$\lambda = L_0/r = 250\text{cm}/5{,}773\text{cm} = 43{,}305 \quad \text{MED. ESB.}$$

(4) VERIF. DE RESIST. $\left(\frac{\sigma_{Nsd}}{f_{cod}}\right)^2 + \frac{\sigma_{Msd}}{f_{cod}} \leq 1$.

$\sigma_{Nsd} = 168\text{kN}/400\text{cm}^2 = 0{,}42 \text{ kN/cm}^2$

$\sigma_{Msd} = 3500\text{kNcm}/13333{,}3\text{cm}^3 = 2{,}625 \text{ kN/cm}^2$.

$\left(\frac{0{,}42}{1{,}6}\right)^2 + \frac{2{,}625}{1{,}6} = 1{,}7095 > 1{,}0$ NÃO VERIFICA!

F.S. RES = $1/1{,}7095 = \underline{0{,}58497}$ Q01)

(5) VERIF. DE ESTAB.

$e_a = 250\text{cm}/300 = 0{,}8333\text{cm} > h/30 = 20/30 = 0{,}6667\text{cm}$

$e_i = \frac{3500\text{kNcm}}{168\text{kN}} = 20{,}833\text{cm} > h/30$

$e_1 = 20{,}833 + 0{,}833 = 21{,}667 \text{ cm}$

$F_E = \pi^2 \times 1092 \text{ kN/cm}^2 \times 13333 \text{ cm}^4/(250\text{cm})^2 = 2299{,}2 \text{ kN}$

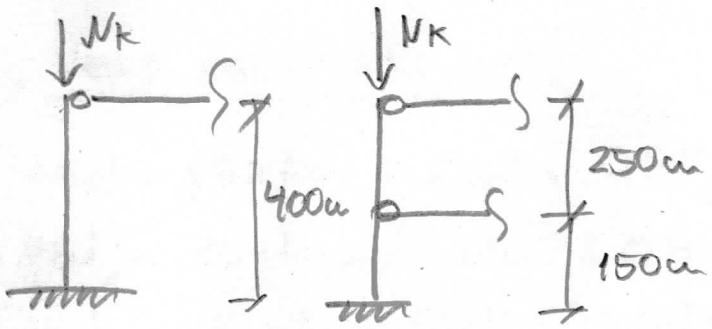
$N_{sd\,FINAL} = 168 \times 21{,}667 \times \left(\frac{2299{,}2}{2299{,}2 - 168}\right) = 3927 \text{ kNcm}$

$\sigma_{Msd} = 3927\text{kNcm}/1333{,}3\text{cm}^3 = 2{,}9453 \text{ kN/cm}^2$

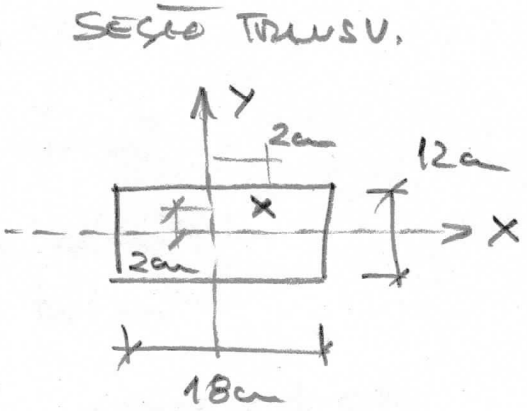
$\frac{0{,}42}{1{,}6} + \frac{2{,}9453}{1{,}6} = 2{,}1033$ F.S. EST. $\frac{1}{2{,}1033} = 0{,}47544$ Q02)

Teoria das Estruturas

BAAM16BNB VERIF. DA COLUNA ABC



PLANO XZ PLANO YZ



→ DICOTILEDÔNEA C40; AMBIENTE CLASSE 1 DE UMIDADE

PEÇA DE 1ª CATEGORIA

→ N_k = 130kN (CARAC. PERMANENTE)

Q01) FS RESIST. Q02) F.S. ESTAD. DO EIXO MAIS DESFAVORÁVEL;

① PROP. MAD: $f_{cod} = 0{,}6 \times 4\,kN/cm^2 / 1{,}4 = \underline{1{,}714\,kN/cm^2}$

$E_{cod} = 0{,}6 \times 1950\,kN/cm^2 = \underline{1170\,kN/cm^2}$

② SOLICITAÇÕES: $N_{sd} = 1{,}4 \times 130kN = 182kN$

$M_{sdx} = M_{sdy} = 182kN \times 2cm = 364kNcm$

③ PROP. GEOM. $A_g = 18 \times 12 = 216\,cm^2$

$I_x = 18 \times 12^3/12 = 2592\,cm^4$ $W_x = 18 \times 12^2/6 = 432\,cm^3$

$I_y = 12 \times 18^3/12 = 5832\,cm^4$ $W_y = 12 \times 18^2/6 = 648\,cm^3$

$r_x = \sqrt{\frac{2592}{216}} = 3{,}464cm$ $r_y = \sqrt{\frac{5832}{216}} = 5{,}196cm$

$\lambda_x = \frac{L_{ox}}{r_x} = \frac{250}{3{,}464} = 72{,}17$ $\lambda_y = \frac{400}{5196} = 76{,}98$

PEÇA MEDIANAMENTE ESB. P/ AMBOS EIXOS; COMO O MOM. SOLICITANTE É IGUAL BASTA A VERIF. DO EIXO Y;

(4) VERIF. DE RESIST.

$\sigma_{Nsd} = 182\,kN / 216\,cm^2 = 0{,}8426\,kN/cm^2$

$\sigma_{Msd_x} = 364\,kN.cm / 432\,cm^3 = 0{,}8426\,kN/cm^2$

$\sigma_{Msd_y} = 364\,kN.cm / 648\,cm^3 = 0{,}5617\,kN/cm^2$

$\left(\frac{0{,}8426}{1{,}714}\right)^2 + \frac{0{,}8426}{1{,}714} + 0{,}5 \times \frac{0{,}5617}{1{,}714} = 0{,}8971 < 1$ ok!

$\left(\frac{0{,}8426}{1{,}714}\right)^2 + 0{,}5 \times \frac{0{,}8426}{1{,}714} + \frac{0{,}5617}{1{,}714} = 0{,}8152 < 1$ ok!

F.S. $1/0{,}8971 = 1{,}115$ (Q01)

(5) VERIF. ESTAB. EIXO Y

$e_{a_y} = 400\,cm/300 = 1{,}333\,cm$

$e_{1y} = 364\,kN.cm/182\,kN = 2\,cm$

$e_1 = 2 + 1{,}333 = 3{,}333\,cm$

$F_{ey} = \frac{\pi^2 \times 1170 \times 5832}{400^2} = 420{,}9\,kN$

$M_{sd_{FINAL}} = 182\,kN \times 3{,}333\,cm \times \left(\frac{420{,}9}{420{,}9 - 182}\right) = 1068{,}8\,kN.cm$

$\sigma_{Msd_{y\,FINAL}} = 1068{,}8\,kN.cm / 648\,cm^3 = 1{,}649\,kN/cm^2$

- EQ. DE INTERAÇÃO:

$\frac{0{,}8426}{1{,}714} + \frac{1{,}649}{1{,}714} = 1{,}454 > 0$ FALHA!

F.S. ESTAB. $1/1{,}454 = 0{,}6878$ (Q02)

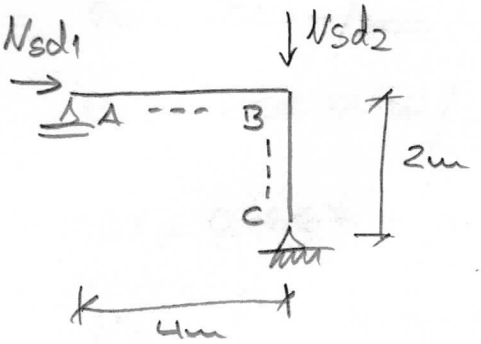
BLAM16BMA

→ VERIFICAÇÃO DA COLUNA BC;

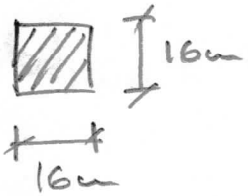
- MADEIRA DICOTILEDÔNEA CGO;
- AMBIENTE CLASSE 1 DE UMIDADE;
- PEÇAS DE 1ª CATEGORIA;
- CARGAS PERMANENTES E JÁ EM VALOR DE CÁLCULO;

$N_{sd1} = 4kN$

$N_{sd2} = 70kN$



SEÇÃO TRANSV.



(Q01) F.S. RESIST.

(Q02) F.S. ESTAB.

① PROP. MAD.: $k_{mod} = 0,6 \times 1,0 \times 1,0 = 0,6$

$f_{cod} = 0,6 \times 6\,kN/cm^2 / 1,4 = 2,571\,kN/cm^2$

$E_{cod} = 0,6 \times 2450\,kN/cm^2 = 1470\,kN/cm^2$

② SOLICITAÇÕES: $N_{sd} = 70kN$

$M_{sd} = 4kN \times 200cm = 800\,kN.cm$

③ PROP. GEOM.: $A = 16^2 = 256\,cm^2$

$I = 16^4/12 = 5461,3\,cm^4$

$W = 16^3/6 = 682,67\,cm^3$

④ VERIF. DE RESIST:

$\sigma_{Nsd} = 70kN / 256cm^2 = 0,2734\,kN/cm^2$

$\sigma_{Msd} = 800\,kN.cm / 682,67\,cm^3 = 1,172\,kN/cm^2$

(Q01)

$\left(\frac{0,2734}{2,571}\right)^2 + \frac{1,172}{2,571} = 0,4672 < 1$ ok!

$F.S. = \frac{1}{0,4672} = 2,140$

5 VERIF. DE ESTABILIDADE:

$e_a = 200\,cm/300 = 0{,}6667\,cm$

$e_i = 800\,kN\,cm/70\,kN = 11{,}43\,cm$

$\left\{ h/30 = 16/30 = 0{,}5333\,cm \right.$

$e_1 = 0{,}6667 + 11{,}43 = 12{,}10\,cm$

$$N_E = \frac{\pi^2 \times 1470\,kN/cm^2 \times 5461{,}3\,cm^4}{(200\,cm)^2} = 1981\,kN$$

$$Msd_{FINAL} = 70\,kN \times 12{,}1\,cm \times \left(\frac{1981}{1981-70}\right) = 878{,}0\,kN\,cm$$

$$\sigma_{Msd} = 878\,kN\,cm/682{,}67 = 1{,}286\,kN/cm^2$$

$$\frac{0{,}2734}{2{,}571} + \frac{1{,}286}{2{,}571} = 0{,}6065 < 1$$

ok.

$$F.S = 1/0{,}6065 = 1{,}649 \quad (Q02)$$

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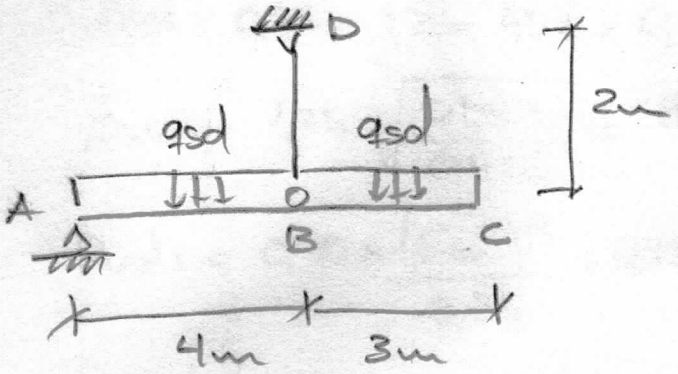
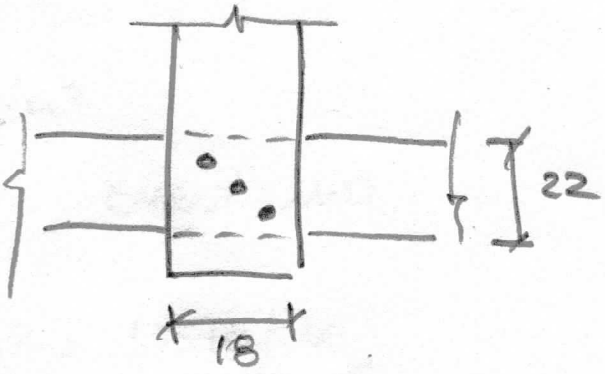
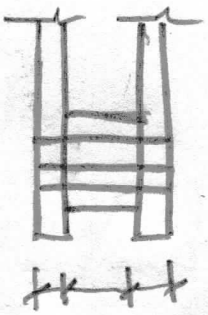


• DETALHES DA LIGAÇÃO EM B





$\phi = 5/8''$

- DICOTILEDÔNEA C30
- $K_{mod} = 0{,}56$

Q01) MÁXIMO qsd [tu/m] DE MODO QUE A LIGAÇÃO AINDA RESISTA?

$f_{cod} = 0{,}56 \times 3\ tu/cm^2 / 1{,}4 = 1{,}2\ tu/cm^2$

$\sum M_A = 0 \circlearrowleft \oplus \quad V_D \times 4 - q_{sd} \times 7 \times 7/2 = 0$

$V_D = 1/4 \times 49/2\ q_{sd} \qquad V_D = 49/8\ q_{sd}$

$q_{sd} = 8/49\ V_D$

PEÇAS LATERAIS: $\beta = t/d = 3cm/1{,}6cm = 1{,}875$

$f_{cd} = f_{cod} = 1{,}2\ tu/cm^2$

$\beta_{LIM} = 1{,}25\sqrt{\frac{21{,}82}{1{,}2}} = 5{,}33$ EMBUT. DA MADEIRA

$R_{vd1} = 0{,}40 \times \frac{(3cm)^2}{1{,}875} \times 1{,}2\ tu/cm^2 = 2{,}304\ tu$

PEÇA CENTRAL: $\beta = 6cm / 1,6cm = 3,75$

$f_{cd} = 0,25 \times 1,2 \times 1,52 = 0,456 kN/cm^2$

$\beta_{lim} = 1,25 \sqrt{\frac{21,83}{0,456}} = 8,646$ EMBUT. MAD.

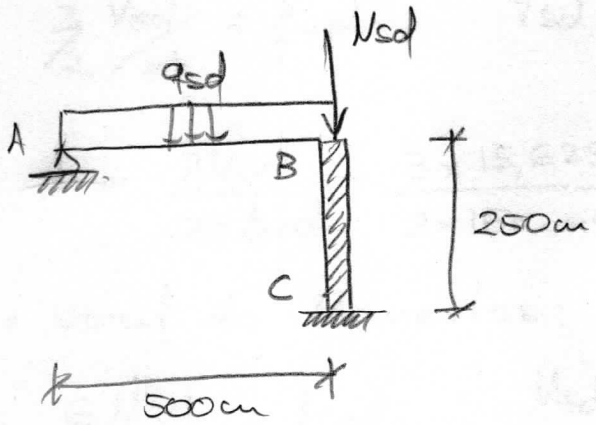
$R_{vd1} = 0,40 \times \frac{(6cm)^2}{3,75} \times 0,456 kN/cm^2 = 1,7510 kN$

$V_D = 3 \times 2 \times 1,7510 kN = 10,506 kN$

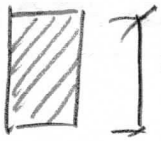
$q_{sd} = 8/49 \times 10,506 kN = \boxed{1,715 kN/m}$

Teoria das Estruturas

B4MM17CNB



VIGA AB  h=? CASSENTE AO PLANO ABC

PILAR BC  20cm (ASSENTE AO PLANO ABC)



CARGAS PERMANENTES JÁ EM VALOR DE CÁLCULO: $\begin{cases} N_{sd} = 45\,kN \\ q_{sd} = 5\,kN/m \end{cases}$

→ VIGA COM TRAVAMENTO LATERAL AO LONGO DE TODO COMP.;

→ MADEIRA DICOTILEDÔNEA C60, AMBIENTE CLASSE 1 DE UMIDADE E PEÇAS DE 1ª CATEGORIA;

→ CONSIDERAR O PILAR BC INFINITAMENTE RÍGIDO P/ FINS DE CÁLCULO DE ESFORÇOS;

Qual a mínima altura h para que a viga AB atenda:

Q01) A verificação de cortantes [cm]

Q02) A verificação de momentos [cm]

Qual o fator de segurança do Pilar BC para:

Q03) A verificação de resistência;

Q04) A verificação de estabilidade;

- Prop. da Madeira: $k_{mod} = 0{,}6 \times 1{,}0 \times 1{,}0 = 0{,}60$

$f_{cod} = 0{,}60 \times 6\,kN/cm^2 / 1{,}4 = 2{,}571\,kN/cm^2$

$f_{vd} = 0{,}60 \times 0{,}8\,kN/cm^2 / 1{,}8 = 0{,}2667\,kN/cm^2$

$E_{cod} = 0{,}60 \times 2450\,kN/cm^2 = 1470\,kN/cm^2$

- Verif. de Cortantes:

$$\frac{3}{2}\frac{V_{sd}}{bh} = f_{vd} \qquad V_{sd} = \frac{5}{8} q_{sd} L = \frac{5}{8} \times 5\,kN/m \times 5m = 15{,}625\,kN$$

$$h = \frac{3V_{sd}}{2bf_{vd}} = \frac{3 \times 15{,}625\,kN}{2 \times 15cm \times 0{,}26667\,kN/cm^2} = 5{,}859\,cm \quad (Q01)$$

- Verif de Momentos:

$$\frac{6M_{sd}}{bh^2} = f_{cod} \qquad M_{sd} = q_{sd}\frac{L^2}{8} = \frac{5\,kN/m \times (5m)^2}{8} = 15{,}625\,kN\,m$$

$$M_{sd_B} = 1562{,}5\,kN\,cm$$

$$h = \sqrt{\frac{6M_{sd}}{bf_{cod}}} = \sqrt{\frac{6 \times 1562{,}5}{15 \times 2{,}571}} = 15{,}59\,cm \quad (Q02)$$

- Prop. Geométricas do Pilar:

$$A_g = 15 \times 20 = 300\,cm^2 \qquad W = 15 \times 20^2/6 = 1000\,cm^3$$

$$I = 15 \times 20^3/12 = 10000\,cm^4$$

$$r = \sqrt{\frac{10000}{300}} = 5{,}774\,cm$$

- Verificação de Resistência:

$$\left(\frac{\tau_{Nsd}}{f_{cod}}\right)^2 + \frac{\tau_{Msd}}{f_{cod}} \leq 1 \qquad N_{sd} = 45\,kN + 15{,}625\,kN = 60{,}625\,kN$$

$$\tau_{Nsd} = 60{,}625\,kN / 300cm^2 = 0{,}2021\,kN/cm^2$$

$$\tau_{Msd} = 1562{,}5\,kN\,cm / 1000\,cm^3 = 1{,}563\,kN/cm^2$$

$$\left(\frac{0{,}2021}{2{,}571}\right)^2 + \frac{1{,}563}{2{,}571} = 0{,}6141 < 1 \quad \text{ok!}$$

$$F.S = \frac{1}{0{,}6141} = 1{,}628 \quad (Q03)$$

- Verificação de Estabilidade:

$$e_a = L_0/300 = 250\,cm/300 = 0{,}8333\,cm$$

$$e_i = M_{sd}/N_{sd} = \frac{1562{,}5\,kN\cdot cm}{60{,}63\,kN} = 25{,}771\,cm$$

$$\left.\begin{array}{l} e_a = 0{,}8333\,cm \\ e_i = 25{,}771\,cm \end{array}\right\} > h/30 = 20/30 = 0{,}6667\,cm$$

$$e_t = 25{,}771 + 0{,}8333 = 26{,}60\,cm$$

$$F_E = \frac{\pi^2 \times 1470\,kN/cm^2 \times 10000\,cm^4}{(250\,cm)^2} = 2321\,kN$$

$$N_{sd\,FINAL} = 60{,}63\,kN \times 26{,}60\,cm \times \left(\frac{2321\,kN}{2321\,kN - 60{,}63\,kN}\right) = 1656\,kN/cm$$

$$\frac{\sigma_{usd}}{f_{cod}} + \frac{\sigma_{Msd\,FINAL}}{f_{cod}} \leq 1{,}0 \qquad \sigma_{Msd\,FINAL} = \frac{1656\,kN/cm}{1000\,cm} = 1{,}656\,kN/cm^2$$

$$\frac{0{,}2021}{2{,}571} + \frac{1{,}656}{2{,}571} = 0{,}7227 < 1 \quad ok$$

$$F.S. = \frac{1}{0{,}7227} = 1{,}383 \quad (Q04)$$