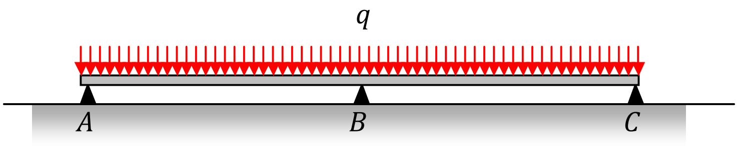
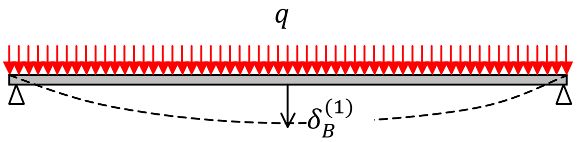
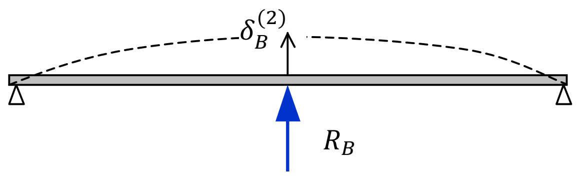
Problema 1.



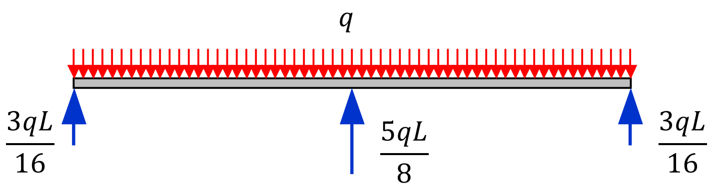


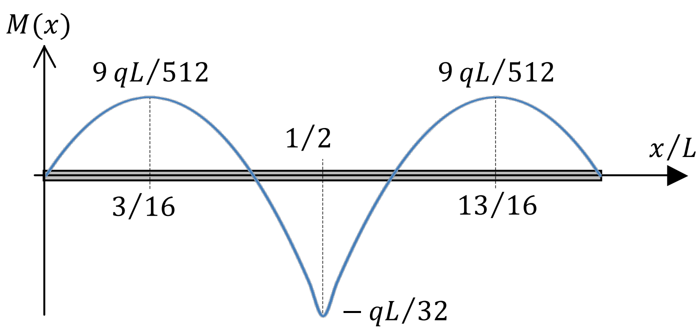
$$\delta_B^{(1)} = \frac{5qL^4}{384EI}$$



$$\delta_B^{(2)} = \frac{R_B L^4}{48EI}$$

$$\delta_B^{(1)} = \delta_B^{(2)} \implies \frac{R_B L^3}{48EI} = \frac{5qL^4}{384EI} \implies R_B = \frac{5qL}{8}$$

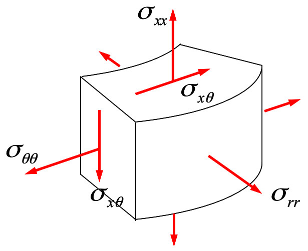




$$M(x) = \begin{cases} \dfrac{3qL}{16}\left[\left(\dfrac{x}{L}\right) - \dfrac{8}{3}\left(\dfrac{x}{L}\right)^2\right] & x \leq L/2 \\ \dfrac{3qL}{16}\left[\left(\dfrac{L-x}{L}\right) - \dfrac{8}{3}\left(\dfrac{L-x}{L}\right)^2\right] & x > L/2 \end{cases}$$

$$\max\{|\sigma_{xx}(x,y)|\} = \frac{h}{2}\frac{\max\{|M(x)|\}}{bh^3/12} = \frac{6}{bh^2}\frac{qL}{32} = \frac{3}{16}\frac{qL}{bh^2} < S_Y \implies q < \frac{16}{3}\left(\frac{S_Y bh^2}{L}\right)$$

Problema 2.



$\sigma_{\theta\theta}$ - Tensão circunferencial devido à pressão interna

σ_{rr} - Tensão radial devido à pressão interna

σ_{xx} - Tensão axial devido à pressão interna

$\sigma_{x\theta}$ - Tensão cisalhante devido à torção

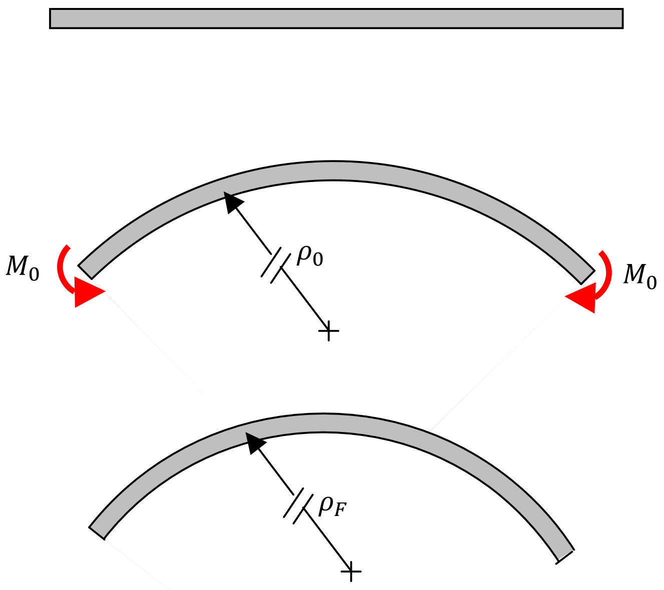
$$[\sigma] = \begin{bmatrix} \sigma_{xx} & \sigma_{x\theta} & 0 \\ \sigma_{x\theta} & \sigma_{\theta\theta} & 0 \\ 0 & 0 & \sigma_{rr} \end{bmatrix}$$

Tensão	***Parede Interna do Tubo***	***Parede Externa do Tubo***
$\sigma_{\theta\theta}$	$\sigma_{\theta\theta} = \frac{(b^2/a^2+1)}{(b^2/a^2-1)} P = 128\, MPa$	$\sigma_{\theta\theta} = \frac{2}{(b^2/a^2-1)} P = 101\, MPa$
σ_{rr}	$\sigma_{rr} = -P = -27.6\, MPa$	$\sigma_{rr} = 0$
σ_{xx}	$\sigma_{xx} = \frac{1}{(b^2/a^2-1)} P = 50.4\, MPa$	$\sigma_{xx} = \frac{1}{(b^2/a^2-1)} P = 50.4\, MPa$
$\sigma_{x\theta}$	$\sigma_{x\theta} = a\frac{T}{\pi(b^4-a^4)/2} = 22.8\, MPa$	$\sigma_{x\theta} = b\frac{T}{\pi(b^4-a^4)/2} = 28.4\, MPa$
σ_M	$\sigma_M = \frac{\sigma_{\theta\theta}+\sigma_{xx}}{2} = 89.4\, MPa$	$\sigma_M = \frac{\sigma_{\theta\theta}+\sigma_{xx}}{2} = 75.6\, MPa$
R	$R = \sqrt{(\frac{\sigma_{\theta\theta}-\sigma_{xx}}{2})^2 + \sigma_{x\theta}{}^2} = 45.2\, MPa$	$R = \sqrt{(\frac{\sigma_{\theta\theta}-\sigma_{xx}}{2})^2 + \sigma_{x\theta}{}^2} = 38.0\, MPa$
σ_1	$\sigma_1 = \sigma_M + R = 135\, MPa$	$\sigma_1 = \sigma_M + R = 114\, MPa$
σ_2	$\sigma_2 = \sigma_M - R = 44.2\, MPa$	$\sigma_2 = \sigma_m - R = 37.7\, MPa$
σ_3	$\sigma_3 = \sigma_{rr} = -27.6\, MPa$	$\sigma_3 = \sigma_{rr} = 0.0$
σ_{VM}	$\sigma_{VM} = 141\, MPa$	$\sigma_{VM} = 100\, MPa$
$\tau_{\max}$	$\tau_{\max} = 81.1\, MPa$	$\tau_{\max} = 56.8\, MPa$

A parede interna é a mais carregada. Portanto, os fatores de segurança são:

$$FS_{VM} = \frac{S_Y}{\sigma_{VM}} = 2.06 \qquad FS_{Tresca} = \frac{S_Y/2}{\tau_{\max}} = 1.79$$

Problema 3.



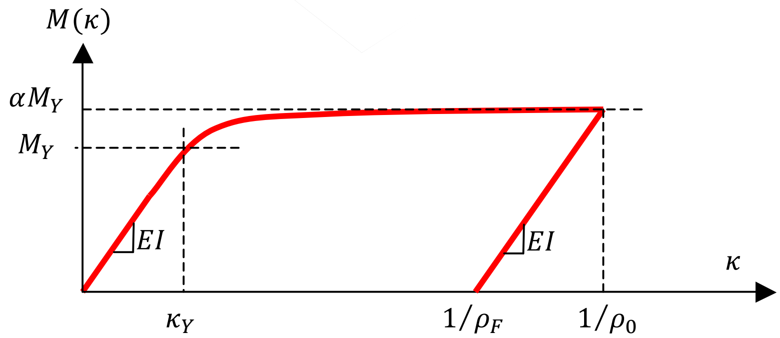
$$M(\kappa) = \begin{cases} \kappa EI, & \kappa \le \kappa_Y \\ \alpha M_Y \left[1 - \left(\frac{\alpha-1}{\alpha}\right)\left(\frac{\kappa_Y}{\kappa}\right)^2\right], & \kappa > \kappa_Y \end{cases}$$

$$\sigma_{xx}(y) = \begin{cases} -S_Y, & -c \le y < -r_Y \\ yS_Y/r_Y, & -r_Y \le y < r_Y \\ S_Y, & r_Y \le y < c \end{cases}$$

$$M_Y = S_Y I/c$$

$$\kappa_Y = M_Y/EI = S_Y/Ec$$

$$r_Y = c(\kappa_Y/\kappa)$$



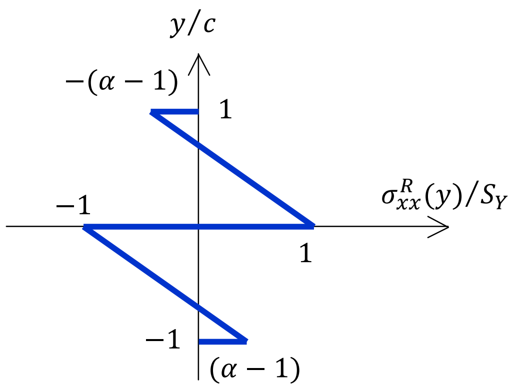
$$\kappa = 1/\rho$$

$$\frac{1}{\rho_0} - \frac{1}{\rho_F} \cong \frac{\alpha M_Y}{EI} \qquad (1/\rho_F \gg \kappa_Y)$$

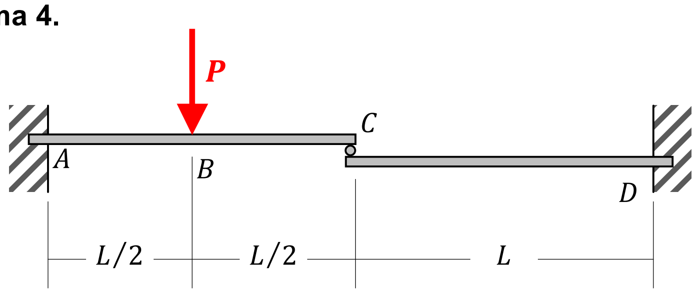
$$\rho_0 = \left(\frac{1}{\rho_F} + \frac{\alpha M_Y}{EI}\right)^{-1} = 76.4 \text{ mm}$$

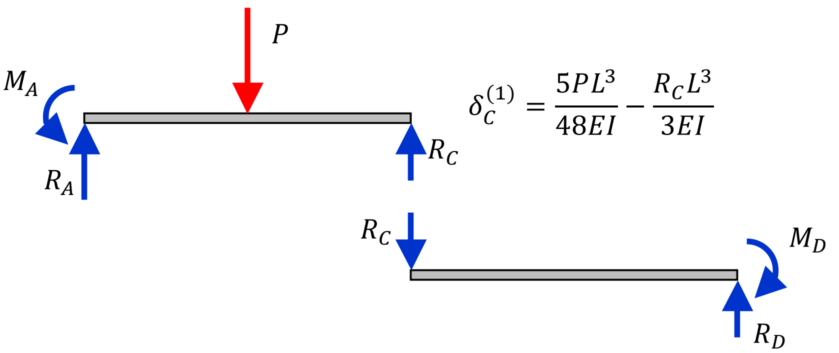
Distribuição da tensão residual:

$$\sigma_{xx}^R(y) = \begin{cases} -S_Y - y\alpha M_y/I, & -c \le y < 0 \\ S_Y - y\alpha M_y/I, & 0 \le y < c \end{cases}$$



Problema 4.

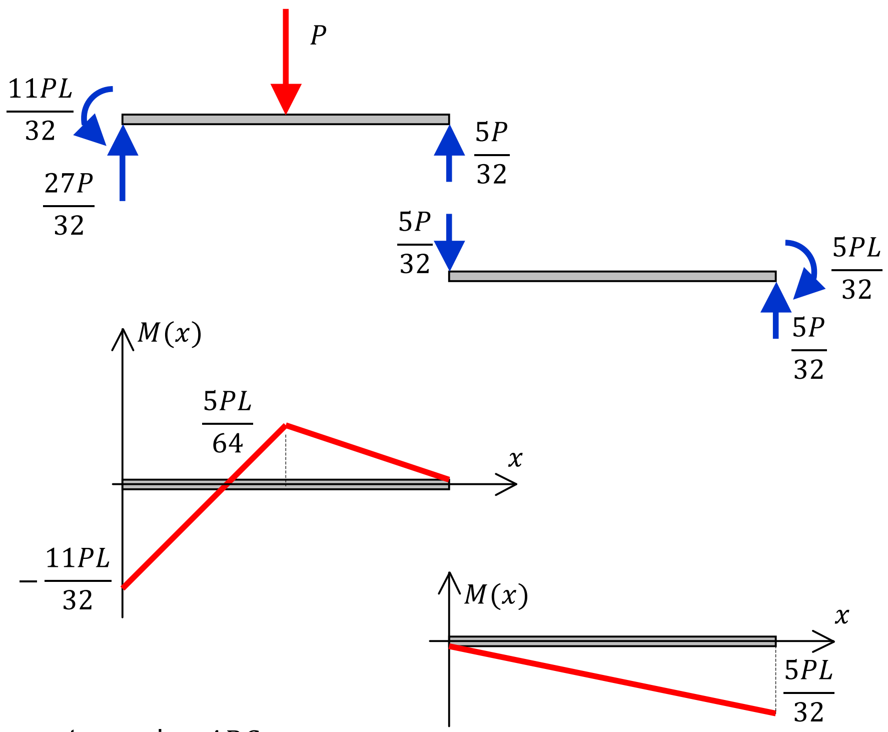




$$\delta_C^{(1)} = \frac{5PL^3}{48EI} - \frac{R_C L^3}{3EI}$$

$$\delta_C^{(2)} = \frac{R_C L^3}{3EI}$$

$$\delta_C^{(1)} = \delta_C^{(2)} \Longrightarrow \frac{5PL^3}{48EI} - \frac{R_C L^3}{3EI} = \frac{R_C L^3}{3EI} \Longrightarrow R_C = \frac{5P}{32}$$



Escoamento na viga ABC

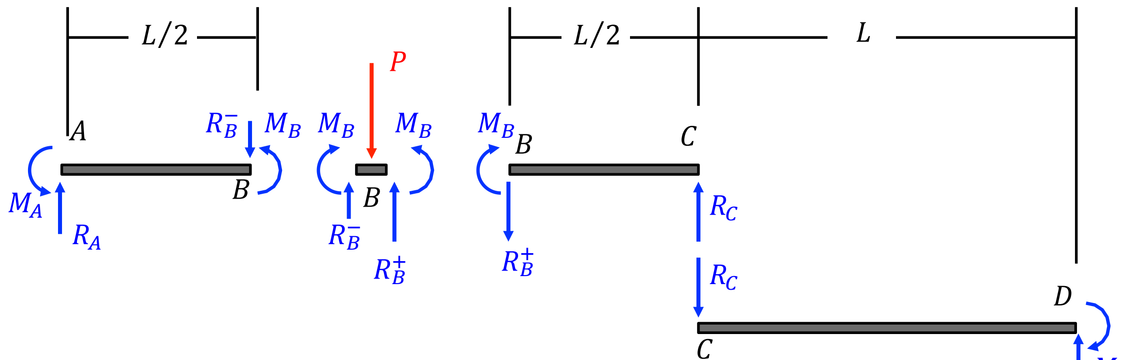
$$\max\{|\sigma_{xx}(x,y)|\} = \frac{h}{2}\frac{\max\{|M(x)|\}}{bh^3/12} = \frac{6}{bh^2}\frac{11PL}{32} = \frac{33PL}{16bh^2} < S_Y \Longrightarrow P_Y = \frac{16S_Y bh^2}{33L}$$

Há duas possibilidades de colapso plástico:

(a) Rótulas plásticas em A e B

(b) Rótulas plásticas em A e D

Equilíbrio:



$R_A = R_B^-$ $\quad$ $M_B + M_B = R_A L/2$

$P = R_B^+ + R_B^-$

$R_B^+ = R_C$ $\quad$ $M_B = R_C L/2$

$R_C = R_D$ $\quad$ $M_D = R_C L$

Hipótese (a), rótulas plásticas em A e B: $M_A = M_B = M_L$

$$R_C = 2M_B/L = 2M_L/L$$

$$R_A = P_L - R_C = P_L - 2M_B/L = P_L - 2M_L/L$$

$$M_A + M_B = 2M_L \Rightarrow 2M_L = (P_L - 2M_L/L)L/2 = P_L L/2 - M_L$$

logo $P_L = 6M_L/L$

Hipótese (b), rótulas plásticas em A e D: $M_A = M_D = M_L$

$$R_C = M_D/L = M_L/L$$

$$M_B = R_C L/2 = M_L/2$$

$$R_A = P_L - R_C = P_L - M_L/L$$

$$M_A + M_B = 3M_L/2 \Rightarrow 3M_L/2 = (P_L - M_L/L)L/2 = P_L L/2 - M_L/2$$

logo $P_L = 4M_L/L$

A carga de colapso plástico será a menor entre as calculadas para as hipóteses (a) e (b).

Portanto:

$$P_L = 4\frac{M_L}{L}$$