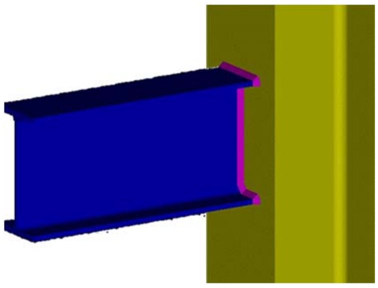
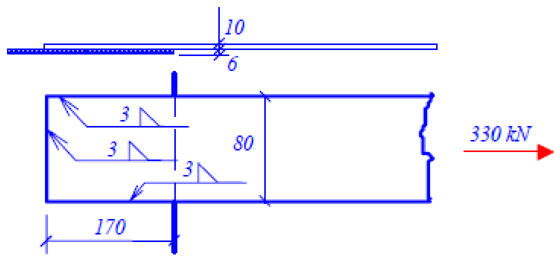


Ligações Soldadas – Parte III

Programa de Pós-Graduação em Engenharia Civil
PGECIV - Mestrado Acadêmico
Faculdade de Engenharia – FEN/UERJ
Disciplina: Ligações em Estruturas de Aço e Mistas
Professor: Luciano Rodrigues Ornelas de Lima

14. Exemplo 1

Check the resistance of the connection of the flat section, shown in Fig. 1WE3-1, loaded in tension by the factored force $F_{Sd} = 330\ kN$. The steel is Grade S460N. The material partial safety factors are $\gamma_{M0} = 1{,}0$ and $\gamma_{Mw} = 1{,}25$.



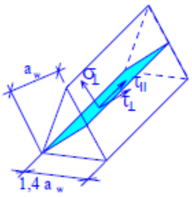
The structural welds should be (i) longer than $40\ mm$, and (ii) longer than $6\ a_w = 6 * 3 = 18\ mm$. Both of these are satisfied. The full length of the weld can be taken into account in the strength calculation, because $150\ a_w = 50 * 3 = 450\ mm > 170\ mm$.

14. Exemplo 1

Longitudinal welds

In the longitudinal welds is $\sigma_\perp = \tau_\perp = 0$. Based on the fillet welds resistance

$$\sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_{//}^2)} \le \frac{f_u}{\beta_w \gamma_{Mw}} \quad \text{and} \quad \sigma_\perp \le \frac{f_u}{\gamma_{Mw}}$$

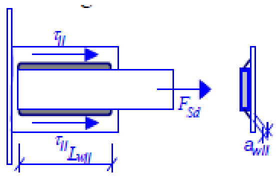


is the shear strain

$$\tau_{II.Rd} = \frac{f_u}{\sqrt{3}\,\beta_w \gamma_{Mw}} .$$

The design resistance is

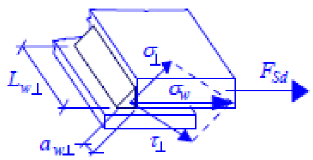
$$F_{II.w.Rd} = \tau_{II.Rd}\ a_{wII}\ 2\ L_{wII} = \frac{550}{\sqrt{3} * 1{,}0 * 1{,}25} * 3 * 2 * 170 = 259{,}1 * 10^3\,N$$



14. Exemplo 1

Front weld

The equation for the resistance may be at the front weld ($\tau_{II.Rd} = 0$ and $\sigma_\perp = \tau_\perp = \frac{\sigma_w}{\sqrt{2}}$) rewritten:



$$\sqrt{\left(\frac{\sigma_w}{\sqrt{2}}\right)^2 + 3\left(\frac{\sigma_w}{\sqrt{2}}\right)^2} \le \frac{f_u}{\beta_w\ \gamma_{Mw}} .$$

The front weld design strain is

$$\sigma_{w.Rd} = \frac{f_u}{\beta_w\ \gamma_{Mw}\ \sqrt{2}} .$$

The design resistance of the front weld is

$$F_{\perp w.Rd} = \sigma_{w.Rd}\ a_{w\perp}\ L_{w\perp} = \frac{550}{1{,}0 * 1{,}25 * \sqrt{2}} * 3 * 80 = 74{,}7 * 10^3\,N$$

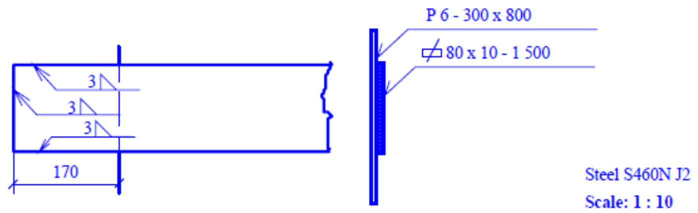
14. Exemplo 1

Connection resistance

The connection resistance is

$$F_{w.Rd} = F_{II.w.Rd} + F_{\perp w.Rd} = 259{,}1 + 74{,}7 = 333{,}8\ kN > F_{Sd} = 330\ kN\ .$$

The connection resistance is satisfactory.



14. Exemplo 1

Note:

1) The weld resistance may conservatively be checked independent of the loading direction as follows:

$$F_{w.Rd} = \frac{f_u\ a_w\ L_w}{\beta_w\ \gamma_{Mw}\ \sqrt{3}} = \frac{550 * 3 * (2 * 170 + 80)}{1{,}0 * 1{,}25 * \sqrt{3}} = 320{,}0 * 10^3\ N < F_{Sd} = 330\ kN\ .$$

The welds are not satisfactory uder this model.

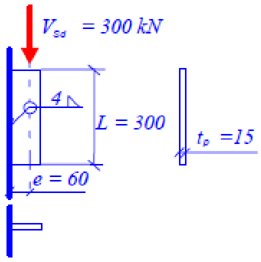
2) The tension resistance of a member is

$$N_{u.Rd} = \frac{A\ f_y}{\gamma_{M0}} = \frac{80 * 10 * 460}{1{,}0} = 368{,}0 * 10^3\ \ N > 330\ kN\ .$$

The tension resistance is satisfactory.

15. Exemplo 2

Check the resistance of the fillet-welded connection of the fin plate, shown in Figure 1WE3-2
The connection is subject to the vertical factored force $V_{Sd} = 300\ kN$, acting at an eccentricity $e = 60\ mm$.
The steel is Grade S235, and the material partial safety factors are $\gamma_{M0} = 1{,}0$ and $\gamma_{Mw} = 1{,}25$.



The structural welds should be (i) longer than $40\ mm$, and (ii) longer than $6\ a_u = 6 * 4 = 24\ mm$. Both of these are satisfied. The full length of the weld can be taken into account in the strength calculation, because $150 a_w = 50 * 4 = 600 mm > 300 mm$.
The shear stress perpendicular to the weld cross-section is

$$\tau_{II} = \frac{V_{Sd}}{a_w\ 2\ L} = \frac{300 * 10^3}{4 * 2 * 300} = 125{,}0\ MPa\,.$$

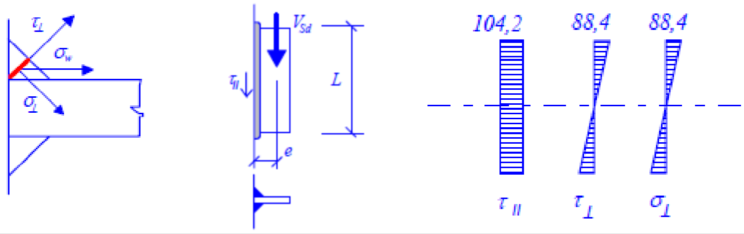
15. Exemplo 2

The maximum normal stress parallel to the weld cross-section, based on an elastic distribution of bending stresses is

$$\sigma_w = \frac{M}{W_{el.w}} = \frac{V_{Sd}\ e}{\frac{2\ a_w\ L^2}{6}} = \frac{300 * 10^3 * 60}{\frac{2 * 4 * 300^2}{6}} = 150{,}0\ MPa\,,$$

which may be decomposed (see Fig. 3WE22) into the shear across the critical plane (the weld throat) and the normal stress perpendicular to this plane:

$$\tau_\perp = \sigma_\perp = \frac{\sigma_w}{\sqrt{2}} = \frac{150}{\sqrt{2}} = 106{,}1\ MPa\,.$$



15. Exemplo 2

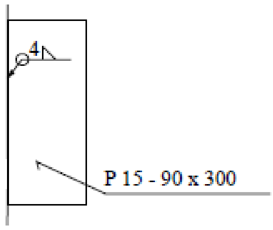
Check of the weld design resistance:

$$\sqrt{\sigma_\perp^2+3(\tau_\perp^2+\tau_{//}^2)} = \sqrt{106,1^2+3*(106,1^2+125,0^2)} = 303,2\ MPa < \frac{f_u}{\beta_w\ \gamma_{Mw}} = \frac{360}{0,8*1,25} = 360,0\ MPa$$

and

$$\sigma_\perp = 106,1\ MPa < \frac{f_u}{\gamma_{Mw}} = \frac{360}{1,25} = 288\ MPa\ .$$

The weld strength is satisfactory



Steel S235 J2

15. Exemplo 2

Note:

1) The weld resistance may conservatively be checked independent of the loading direction as follows:

$$\sqrt{\sigma_w^2+\tau_{II}^2} = \sqrt{150,0^2+125,0^2} = 195,3\ MPa < \frac{f_u}{\beta_w\gamma_{Mw}\sqrt{3}} = \frac{360}{0,8*1,25*\sqrt{3}} = 207,8\ MPa\ .$$

2) The plate's resistance in shear is

$$V_{pl.Rd} = \frac{A_v f_y}{\gamma_{M0}*\sqrt{3}} = \frac{15*300*235}{1,0*\sqrt{3}} = 610,5*10^3\ N > V_{Sd} = 300\ kN\ .$$

and in bending:

$$M_{c.Rd} = W_{el}\ f_y/\gamma_{M0} = \frac{15*300^2}{6}*235/1,0$$

$$= 52,9*10^6\ Nmm > M_{Sd} = 300*10^3*60 = 18*10^6\ Nmm\ .$$

The interaction of bending and shear need not be checked, because the shear resistance is more than double the shear force acting:

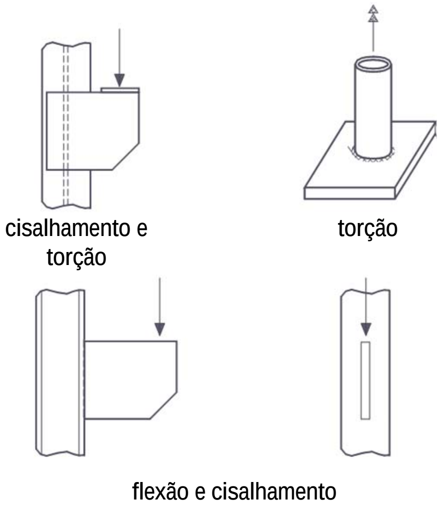
$$610,5*10^3/2 = 305,2*10^3 N > 300kN\ .$$

3) The elastic distribution of stresses in the welds is used because the above is an elastic check of the fin-plate connection. A plastic check of the welds may be performed, based on the expression

$$\sigma_w = \frac{M}{W_{pl.w}} = \frac{V_{Sd}\ e}{\frac{2\ a_w\ L^2}{4}}\ .$$

15. Carregamento Excêntrico

- Se a relação força por comprimento de solda *versus* deslocamento for admitida linear → princípio de superposição é válido e o cálculo das ligações sujeitas a cisalhamento, torção e flexão combinados, pode ser feito isoladamente



15. Carregamento Excêntrico

- Taxa de força devido ao cortante V

$$q_V = \frac{V}{L}$$

- Taxa de força devido ao momento fletor M

$$q_m = \frac{M \cdot c}{I}$$

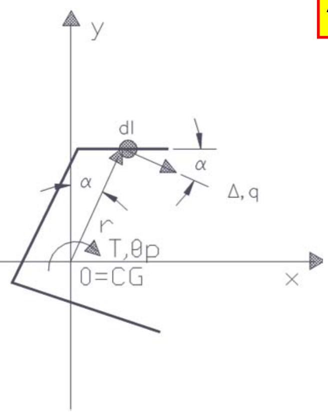
I é o momento de inércia do cordão de solda em relação ao eixo de flexão e c a distância deste eixo ao ponto da solda

- Taxa de força devido ao torsor T

$$q_t = \frac{T \cdot r}{I_p}$$

Ip é o momento polar de inércia da solda em relação ao seu centro geométrico, e r é a distância deste centro ao ponto da solda em consideração

15. Carregamento Excêntrico



$$\Delta = \theta_p \times r$$

$$q_t = k \times \Delta = k \times \theta_p \times r$$

fluxo / cordão de solda

$$T = \int_0^L q_t \cdot r \cdot dL = k \cdot \theta_p \int_0^L r^2 dL =$$

$$T = k \cdot \theta_p \cdot \bar{I}_p$$

15. Carregamento Excêntrico

$$q_t = \frac{T}{\bar{I}_p} r$$

$$q_{tx} = \frac{T}{I_p} r \cdot \cos\alpha = \frac{T}{I_p} y$$

$$q_{ty} = \frac{T}{I_p} r \cdot \mathrm{sen}\,\alpha = \frac{T}{I_p} x$$

Roteiro:

1. t_w → seção geométrica
2. sistema de coordenadas no CG da solda
3. cisalhamento, flexão e torção na solda
4. carga / comprimento de solda → resistências
5. combinação vetorial → resistência final da solda

15. Carregamento Excêntrico

Seção b = largura e d = altura	$\bar{x}$ e $\bar{y}$	Módulo da seção $I_x / \bar{y}$	Momento Polar de Inércia em relação ao centro geométrico
1. d		$W = \frac{d^2}{6}$	$\bar{I}_p = \frac{d^3}{12}$
2. b d		$W = \frac{d^2}{3}$	$\bar{I}_p = \frac{d(3b^2 + d^2)}{6}$
3. b d		$W = b\,d$	$\bar{I}_p = \frac{b(3d^2 + b^2)}{6}$
4. b $\bar{y}$ d $\bar{x}$	$\bar{y} = \frac{d^2}{2(b+d)}$ $\bar{x} = \frac{b^2}{2(b+d)}$	$W = \frac{4bd + d^2}{6}$	$\bar{I}_p = \frac{(b+d)^4 - 6b^2d^2}{12(b+d)}$

15. Carregamento Excêntrico

5. b d x	$\bar{x} = \frac{b^2}{2b+d}$	$W = bd + \frac{d^2}{6}$	$\bar{I}_p = \frac{8b^3 + 6bd^2 + d^3}{12} - \frac{b^4}{2b+d}$
6. b $\bar{y}$ d	$\bar{y} = \frac{d^2}{b+2d}$	$W = \frac{2bd + d^2}{3}$	$\bar{I}_p = \frac{b^3 + 6b^2d + 8d^3}{12} - \frac{d^4}{2d+b}$
7. b		$W = bd + \frac{d^2}{3}$	$\bar{I}_p = \frac{(b+d)^3}{6}$
8. b $\bar{y}$ d	$\bar{y} = \frac{d^2}{b+2d}$	$W = \frac{2bd + d^2}{3}$	$\bar{I}_p = \frac{b^3 + 8d^3}{12} - \frac{d^4}{b+2d}$
9. b d		$W = bd + \frac{d^2}{3}$	$\bar{I}_p = \frac{b^3 + 3bd^2 + d^3}{6}$
10. x r x		$W = \pi r^2$	$\bar{I}_p = 2\pi r^3$

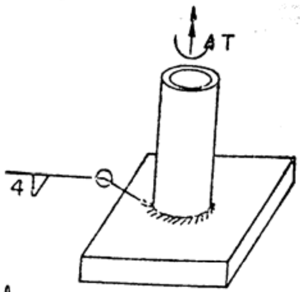
16. Exemplos com Cargas Excêntricas

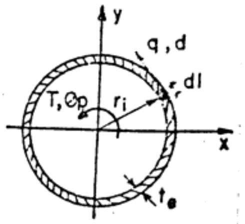
EXEMPLO 6

DETERMINE O TORSOR DE PROJETO MÁXIMO DA LIGAÇÃO ABAIXO

E60XX $X_u = 415$ MPa , $F_y = 250$ MPa , $F_u = 400$ MPa

RAIO = 240 mm





$t_w = 0{,}707\,D = 0{,}707 \times 4 = 2{,}83$ mm

– Esforços

$q_t = \dfrac{T r}{I_p}$ $I_p \cong 2\pi r^3$ (cordão de solda anular) $= 2 . \pi . 240^3 = 8{,}69 \times 10^7$ N mm^3

$q_t = \dfrac{T_d\, r}{I_p} = \dfrac{T_d . 240}{8{,}69 \times 10^7} = 2{,}76 \times 10^{-6}\, T_d$

16. Exemplos com Cargas Excêntricas

– Resistência

$A_w = t_w . \times 1$ mm $- 2{,}83$ mm^2; $A_m = 4 \times 1 = 4$ mm^2

~~$0{,}67\, \phi_w\, A_w\, X_u = 0{,}67 \times 0{,}67 \times 2{,}83 \times 415 = 527{,}21$ N/mm^2 → controla~~

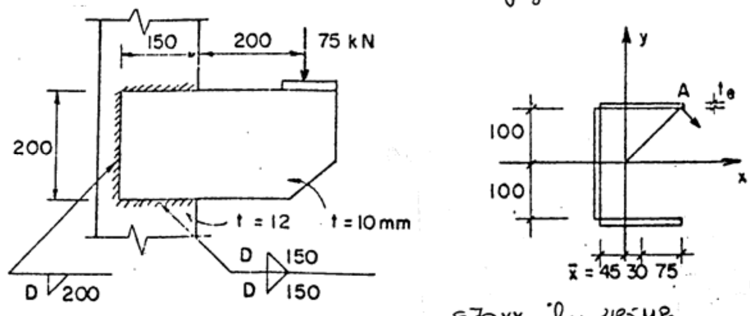
~~$0{,}67\, \phi\, A_m\, F_y = 0{,}67 \times 0{,}9 \times 4 \times 250 = 603{,}0$ N/mm^2~~

$R_d = 0{,}527$ kN/mm^2

$R_d \geq q_d$ $0{,}527 \geq T_d . 2{,}76 \times 10^{-6}$ ∴ $T_d \leq 1{,}91 \times 10^5$ kN mm

16. Exemplos com Cargas Excêntricas

EXEMPLO 7 Dimensione a solda da figura abaixo



$\ell = (2\times150 + 200) = 500mm$

$\bar{x} = \frac{2\times150\times75}{500}$

$\bar{x} = 45mm$

E70XX (MR-250) $f_w = 485\ MPa$

16. Exemplos com Cargas Excêntricas

$I_p = I_x + I_y$, $I_y = \frac{2\times150^3}{12} + 2\times150\times30^2 + 200\times45^2 + \left(\frac{200}{12}\right) = 1{,}24\times10^6$

$I_x = \frac{200^3}{12} + \left(2\times\frac{150}{12}\right) + 2\times150\times100^2 = 3{,}67\times10^6\ mm^4 \therefore\ I_p = 4{,}91\times10^6\ mm^4$

- Esforços

$q_{vy} = \frac{75}{500} = 0{,}15\ kN/mm\ (\downarrow)$, $T = 75(\overset{e}{200} + \overset{(L-\bar{x})}{105}) = 22{,}9\times10^3\ kN\,mm$

$q_{tx} = \frac{T\,y}{I_p} = \frac{22{,}9\times10^3\times100}{4{,}91\times10^6} = 0{,}466\ kN/mm\ (\rightarrow)$

$q_{ty} = \frac{T\,x}{I_p} = \frac{22{,}9\times10^3\times105}{4{,}91\times10^6} = 0{,}490\ kN/mm\ (\downarrow)$

$q_d = \sqrt{(0{,}466+0)^2 + (0{,}490+0{,}15)^2} = 0{,}791\ KN/mm$

16. Exemplos com Cargas Excêntricas

- Resistência

$A_w = 0{,}707\, D \cdot 1 = 0{,}707\, D$

$A_m = D \cdot 1 = D$

$0{,}67\, \phi_w\, A_w\, X_u = 0{,}67 \cdot 0{,}67 \cdot 0{,}707 D \cdot 0{,}485 = 0{,}154\, D$ kN/mm

$0{,}67\, \phi\, A_m\, F_y = 0{,}67 \cdot 0{,}9 \cdot D \cdot 0{,}25 = 0{,}151\, D$ kN/mm → controla

$q_r = 0{,}151\, D$ kN/mm

$q_r \geq q_d$

$0{,}151\, D \geq 0{,}791 \quad \therefore D \geq 5{,}25$ mm

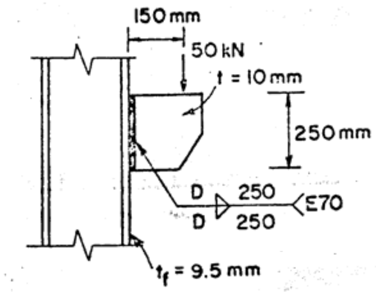
$t = 12$ mm $D_{mín} = 5$ mm

usa $D = 6$ mm

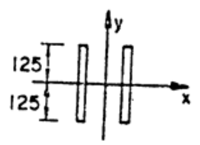
PGECIV

16. Exemplos com Cargas Excêntricas

EXEMPLO 8: Dimensione a ligação da figura abaixo



AÇO MR-250



$L = 2 \times 250 = 500$ mm

$$I_x = \frac{2 \times 250^3}{12} = 260 \times 10^4\ mm^4$$

16. Exemplos com Cargas Excêntricas

– Esforços

$$q_{vy} = \frac{P}{l} = \frac{50}{500} = 0{,}1 \ KN/mm$$

$$q_{mz} = \frac{Mc}{I_x} = \frac{(50 \times 150) \times 125}{260 \times 10^4} = 360 \ N/mm = 0{,}360 \ KN/mm$$

$$q_d = \sqrt{(0{,}1)^2 + (0{,}36)^2} = 0{,}374 \ KN/mm$$

Do exemplo 7 $\quad q_r = 0{,}151 D$

$$0{,}151 D \geq 0{,}374 \quad \therefore \quad D \geq 2{,}48 \ mm$$

$t = 10$ mm (Chapa + espessura) $\rightarrow D_{min} = 5$ mm

usar $D = 5$ mm