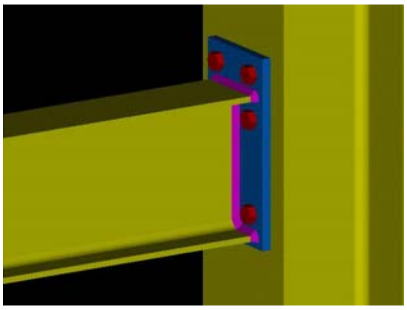




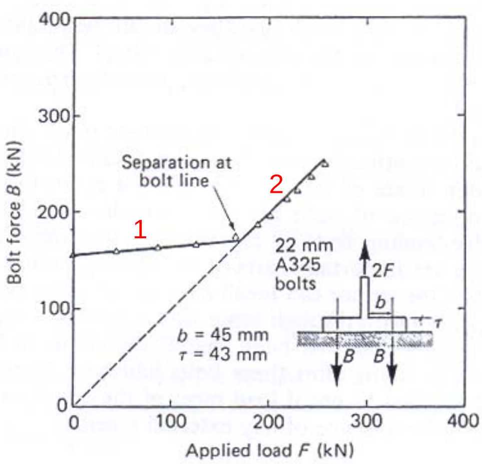
# Ligações Aparafusadas – Parte IV

**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**

---

# 15. Efeito de Alavanca

- **Efeito de Alavanca ("Prying Action")**

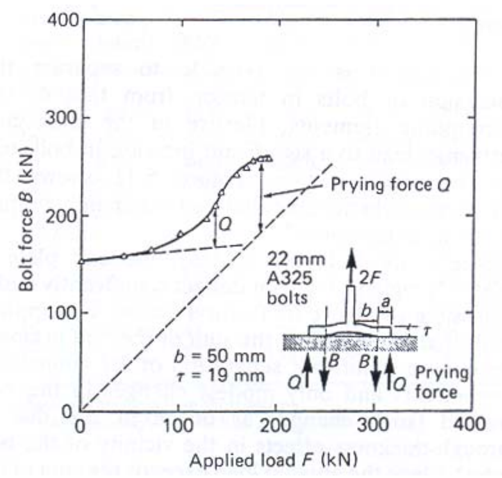



**Placas grossas**

1. **Carga menor do que o somatório das cargas de protensão mínimas aplicadas nos parafusos**
2. **Após este limite não ocorre mais deformação na placa devido sua rigidez elevada**

# 15. Efeito de Alavanca

- **Efeito de Alavanca ("Prying Action")**




**Placas finas (flexíveis)**

**2B = 2F + 2Q**

**Q ⟶ efeito de alavanca que amplifica a carga nos parafusos (B)**

**A separação das placas é antecipada**

**Redução na rigidez da ligação**

**Redução na capacidade última 260kN ⟶ 190kN**

# 15. Efeito de Alavanca

- **Efeito de alavanca – Eurocode 3 pt. 1.8**
  - Where fasteners are required to carry an applied tensile force, they should be designed to resist the additional force due to prying action
  - Rules given in 6.2.4 implicitly account for prying forces

# 15. Efeito de Alavanca

## Efeito de alavanca – Eurocode 3 pt. 1.8

**6.2.4 Equivalent T-stub in tension**

**6.2.4.1 General**

(1) In bolted connections an equivalent T-stub in tension may be used to model the design resistance of the following basic components:

- column flange in bending;
- end-plate in bending;
- flange cleat in bending;
- base plate in bending under tension.

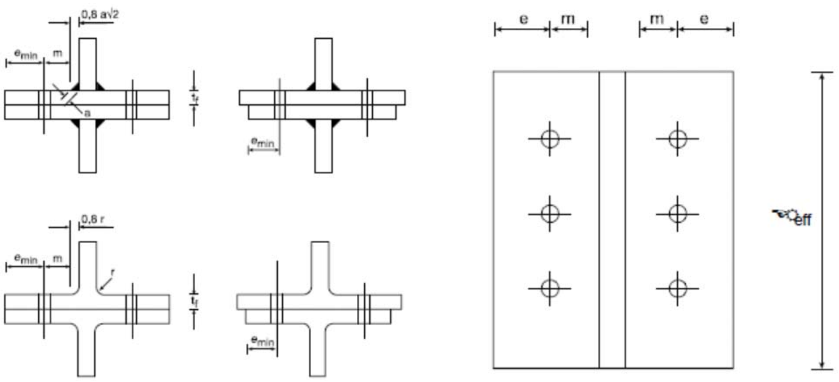
(2) Methods for modelling these basic components as equivalent T-stub flanges, including the values to be used for $e_{min}$, $\ell_{eff}$ and $m$, are given in 6.2.6.

(3) The possible modes of failure of the flange of an equivalent T-stub may be assumed to be similar to those expected to occur in the basic component that it represents.

(4) The total effective length $\sum \ell_{eff}$ of an equivalent T-stub, see Figure 6.2, should be such that the design resistance of its flange is equivalent to that of the basic joint component that it represents.

# 15. Efeito de Alavanca

## Efeito de alavanca – Eurocode 3 pt. 1.8



# 15. Efeito de Alavanca

- **Efeito de alavanca – Eurocode 3 pt. 1.8**

**Table 6.2: Design Resistance $F_{T,Rd}$ of a T-stub flange**

| | Prying forces may develop, i.e. $L_b \le L_b^*$ | | No prying forces |
|---|---|---|---|
| **Mode 1** | Method 1 | Method 2 (alternative method) | |
| without backing plates | $F_{T,1,Rd} = \frac{4M_{pl,1,Rd}}{m}$ | $F_{T,1,Rd} = \frac{(8n - 2e_w)M_{pl,1,Rd}}{2mn - e_w(m+n)}$ | $F_{T,1\text{-}2,Rd} = \frac{2M_{pl,1,Rd}}{m}$ |
| with backing plates | $F_{T,1,Rd} = \frac{4M_{pl,1,Rd} + 2M_{bp,Rd}}{m}$ | $F_{T,1,Rd} = \frac{(8n - 2e_w)M_{pl,1,Rd} + 4nM_{bp,Rd}}{2mn - e_w(m+n)}$ | |
| **Mode 2** | $F_{T,2,Rd} = \frac{2M_{pl,2,Rd} + n\Sigma F_{t,Rd}}{m+n}$ | | |
| **Mode 3** | $F_{T,3,Rd} = \Sigma F_{t,Rd}$ | | |

# 15. Efeito de Alavanca

Mode 1: Complete yielding of the flange
Mode 2: Bolt failure with yielding of the flange
Mode 3: Bolt failure

$L_b$ is - the bolt elongation length, taken equal to the grip length (total thickness of material and washers), plus half the sum of the height of the bolt head and the height of the nut or
- the anchor bolt elongation length, taken equal to the sum of 8 times the nominal bolt diameter, the grout layer, the plate thickness, the washer and half the height of the nut

$L_b^* = \frac{8{,}8m^3 A_s}{\Sigma \ell_{eff,1} t_f^3}$

$F_{T,Rd}$ is the design tension resistance of a T-stub flange
Q is the prying force

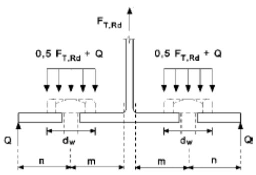
$M_{pl,1,Rd} = 0{,}25 \Sigma \ell_{eff,1} t_f^2 f_y / \gamma_{M0}$

$M_{pl,2,Rd} = 0{,}25 \Sigma \ell_{eff,2} t_f^2 f_y / \gamma_{M0}$

$M_{bp,Rd} = 0{,}25 \Sigma \ell_{eff,1} t_{bp}^2 f_{y,bp} / \gamma_{M0}$

$n = e_{min}$ but $n \le 1{,}25m$

$F_{t,Rd}$ is the design tension resistance of a bolt, see Table 3.4;
$\sum F_{t,Rd}$ is the total value of $F_{t,Rd}$ for all the bolts in the T-stub;
$\sum \ell_{eff,1}$ is the value of $\sum \ell_{eff}$ for mode 1;
$\sum \ell_{eff,2}$ is the value of $\sum \ell_{eff}$ for mode 2;
$e_{min}$, $m$ and $t_f$ are as indicated in Figure 6.2.
$f_{y,bp}$ is the yield strength of the backing plates;
$t_{bp}$ is the thickness of the backing plates;
$e_w = d_w / 4$;
$d_w$ is the diameter of the washer, or the width across points of the bolt head or nut, as relevant.



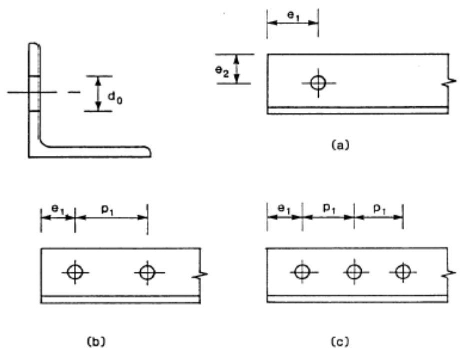
# 15. Efeito de Alavanca

**NOTE 1:** In bolted beam-to-column joints or beam splices it may be assumed that prying forces will develop.
**NOTE 2:** In method 2, the force applied to the T-stub flange by a bolt is assumed to be uniformly distributed under the washer, the bolt head or the nut, as appropriate, see figure, instead of concentrated at the centre-line of the bolt. This assumption leads to a higher value for mode 1, but leaves the values for $F_{T,1-2,Rd}$ and modes 2 and 3 unchanged.

# 17. Recomendações Eurocode 3

- Cantoneiras ligadas por uma aba – EC3 - 1.8
- The eccentricity in joints and the effects of the spacing and edge distances of the bolts, shall be taken into account in:
  - ✓ unsymmetrical members;
  - ✓ symmetrical members, connected unsymmetrically, (angles connected by one leg)

A – 1 bolt
B – 2 bolts
C – 3 bolts



# 17. Recomendações Eurocode 3

- where:
  - $\beta_2$ and $\beta_3$ are reduction factors dependent on the pitch $p_1$ as in Table 3.8. For intermediate values use linear interpolation;
  - $A_{net}$ is the net area of the angle;
  - For an unequal-leg angle connected by its smaller leg:
  - $A_{net}$ should be taken as equal to the net section area of an equivalent equal-leg angle of leg size equal to that of the smaller leg

| Pitch | $p_1$ | $\leq 2{,}5\ d_o$ | $\geq 5{,}0\ d_o$ |
|---|---|---|---|
| 2 bolts | $\beta_2$ | 0,4 | 0,7 |
| 3 bolts or more | $\beta_3$ | 0,5 | 0,7 |

# 17. Recomendações Eurocode 3

- A single angle in tension connected by a single row of bolts in one leg may be treated as concentrically loaded over an effective net section for which the ultimate resistance is:

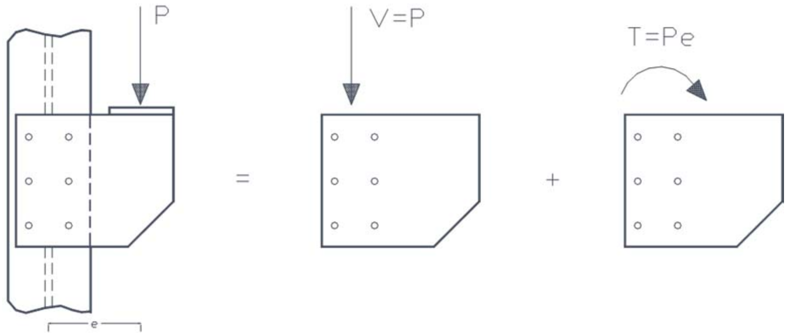
with 1 bolt $$N_{u,Rd} = \frac{2{,}0(e_2 - 0{,}5d_0)t\ f_u}{\gamma_{M2}}$$

with 2 bolts $$N_{u,Rd} = \frac{\beta_2\ A_{net}\ f_u}{\gamma_{M2}}$$

with 3 bolts $$N_{u,Rd} = \frac{\beta_3\ A_{net}\ f_u}{\gamma_{M2}}$$

# 19. Ligações Excêntricas no Plano

- **Decomposição ⟶ força centrada + momento torsor**
  - ✓ **conhecimento do comportamento da relação força versus deslocamento dos parafusos ao corte**




- **força centrada ⟶ P / nº de parafusos**

# 19. Ligações Excêntricas no Plano

- **momento torsor $T_d$ ⟶ P . e**

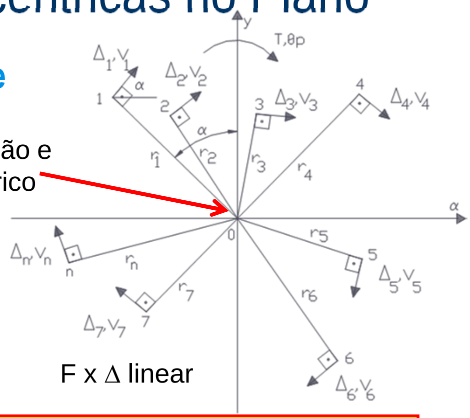
$$T_d = \sum_{i=1}^{n} V_i \times r_i$$

centro de rotação e centro geométrico

$$\Delta_i = \theta_p \times r_i$$

Placa rígida

$$V_i = k \times \Delta_i = k \times \theta_p \times r_i$$




$$T_d = \sum_{i=1}^{n} k \times \theta_p \times r_i^2 = k \times \theta_p \sum_{i=1}^{n} r_i^2 \Rightarrow k \times \theta_p = \frac{T_d}{\sum_{i=1}^{n} r_i^2}$$

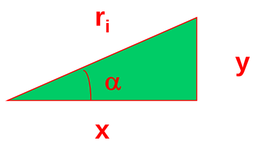
## 19. Ligações Excêntricas no Plano

- momento torsor $T_d \rightarrow P \, . \, e$

$$V_j = \frac{T_d}{\sum_{i=1}^{n} r_i^2} r_i$$

$$V_{jx} = V_j \; x \; \cos\left(\alpha_j \; x \; r_j\right)$$

$$V_{jy} = V_j \; x \; sen\left(\alpha_j \; x \; r_j\right)$$




$$V_{jx} = \frac{T}{\sum_{i=1}^{n} r_i^2} r_j \cos\alpha_j = \frac{T}{\sum_{i=1}^{n}\left(x_i^2 + y_i^2\right)} y_j$$

$$V_{jy} = \frac{T}{\sum_{i=1}^{n} r_i^2} r_j sen\,\alpha_j = \frac{T}{\sum_{i=1}^{n}\left(x_i^2 + y_i^2\right)} x_j$$

## 19. Ligações Excêntricas no Plano

- A posição do centro de rotação da placa é determinada pelas equações de equilíbrio das forças nas direções x e y

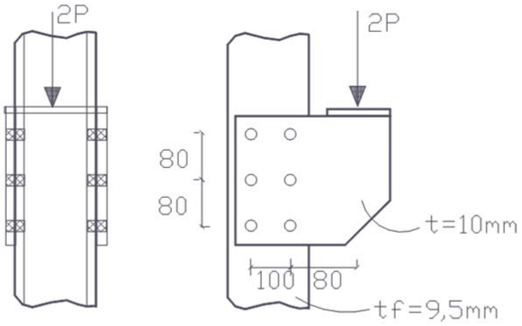
$$\sum_{j=1}^{n} V_{jx} = 0 \qquad \sum_{j=1}^{n} V_{jy} = 0$$

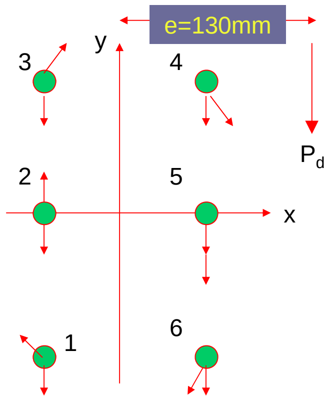
$$\sum_{j=1}^{n} y = 0 \qquad \sum_{j=1}^{n} x = 0$$

- Estas equações localizam o centro de rotação da placa no centro geométrico dos parafusos

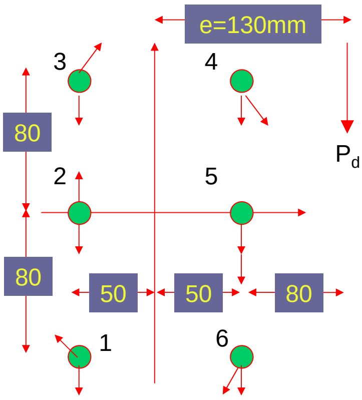
# 19. Ligações Excêntricas no Plano

- Verificar a ligação aparafusada abaixo considerando a resistência ao corte dos parafusos, as distâncias indicadas e a rosca excluída do plano de corte
  - ✓ Dados: Aço MR250, parafusos M16 A325 (Fu=825MPa) e $P_d$=120kN




# 19. Ligações Excêntricas no Plano




| Parafuso | x | y | $x^2$ | $y^2$ |
|---|---|---|---|---|
| 1 | -50 | -80 | 2500 | 6400 |
| 2 | -50 | 0 | 2500 | 0 |
| 3 | -50 | 80 | 2500 | 6400 |
| 4 | 50 | 80 | 2500 | 6400 |
| 5 | 50 | 0 | 2500 | 0 |
| 6 | 50 | -80 | 2500 | 6400 |
| | | Σ | 15000 | 25600 |

- Esforços na ligação
  - $V_d$ = 120kN
  - $M_d$ = 120 . 130 = 15600kN.mm

# 19. Ligações Excêntricas no Plano

- **Esforços máximos nos parafusos**
  - ✓ **devido ao cortante**

$$F_{xc} = \frac{V_{dx}}{n} = 0$$

  - ✓ **devido ao momento → os parafusos 1, 3, 4 e 6 são os mais solicitados (nos parafusos 4 e 6 esta solicitação se soma a do cortante)**

$$F_{xM4} = \frac{M_d}{\sum (x^2 + y^2)} y_4 = \frac{15600}{40600} x\ 80 = 30{,}7kN$$

$$F_{yM4} = \frac{M_d}{\sum (x^2 + y^2)} x_4 = \frac{15600}{40600} x\ 50 = 19{,}2kN$$

# 19. Ligações Excêntricas no Plano

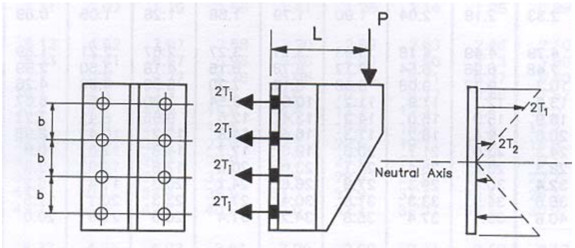
- **Resultante**

$$F_4 = \sqrt{(F_{xM4} + F_{xc})^2 + (F_{yM4} + F_{yc})^2}$$

$$F_4 = \sqrt{(30{,}7 + 0)^2 + (19{,}2 + 20)^2} = 49{,}8kN$$

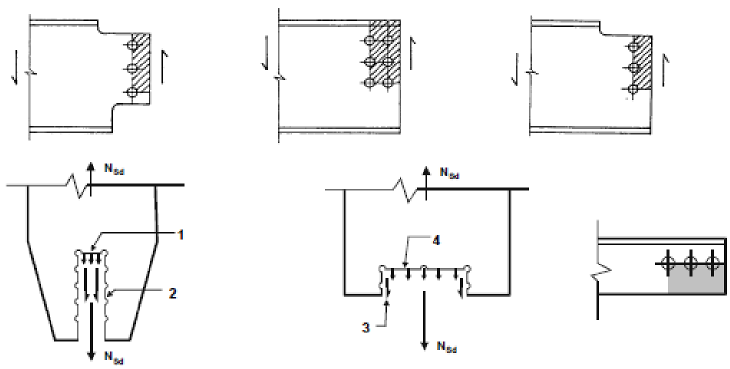
- **Resistência dos parafusos ao corte**
- **Resistência ao esmagamento**
- **...**

# 20. Lig. Excêntricas Fora do Plano

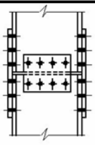



- Resistência dos parafusos a tração
- Resistência dos parafusos ao corte
- Resistência ao esmagamento
- Resistência dos parafusos a tração e ao corte combinados
- ...

# 21. Cisalhamento em Bloco




*1 small tension force*
*2 large shear force*
*3 small shear force*
*4 large tension force*



# 21. Cisalhamento em Bloco

Block tearing consists of failure in shear at the row of bolts along the shear face of the hole group accompanied by tensile rupture along the line of bolt holes on the tension face of the bolt group. Figure 3.8 shows block tearing.

For a symmetric bolt group subject to concentric loading the design block tearing resistance, $V_{eff,1,Rd}$ is given by:

$$V_{eff,1,Rd} = f_u A_{nt} / \gamma_{M2} + (1 / \sqrt{3}) f_y A_{nv} / \gamma_{M0} \qquad \text{... (3.9)}$$

where:

$A_{nt}$ is net area subjected to tension;

$A_{nv}$ is net area subjected to shear.

For a bolt group subject to eccentric loading the design block shear tearing resistance $V_{eff,2,Rd}$ is given by:

$$V_{eff,2,Rd} = 0{,}5\, f_u A_{nt} / \gamma_{M2} + (1 / \sqrt{3}) f_y A_{nv} / \gamma_{M0} \qquad \text{... (3.10)}$$