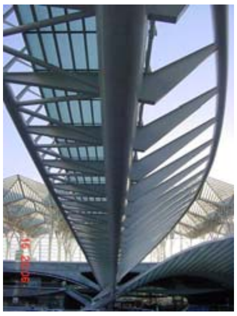
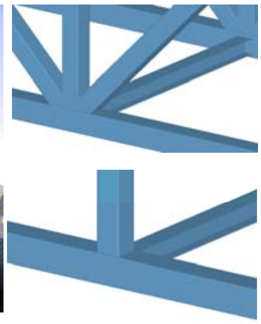
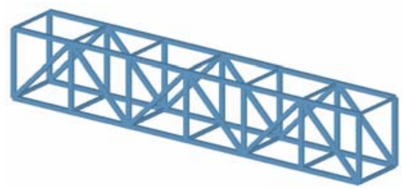




Ligações Tubulares – EC3

Programa de Pós-Graduação em Engenharia Civil

PGECIV - Mestrado Acadêmico

Faculdade de Engenharia – FEN/UERJ

Disciplina: Tópicos Especiais em Estruturas (Chapa Dobrada)

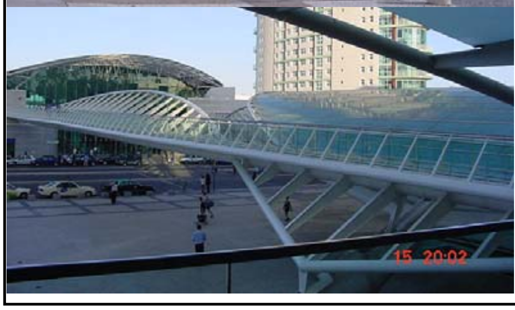
Professor: Luciano Rodrigues Ornelas de Lima

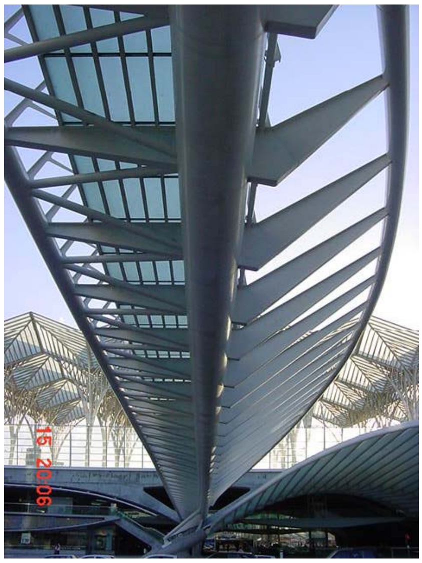
PGECIV FEN

1. Generalities

- Perfis tubulares são largamente utilizados na Europa, Sudeste Asiático, EUA e na Austrália
- Países como Canadá, Inglaterra, Alemanha e Holanda fazem uso intensivo de estruturas tubulares e contam com uma produção corrente, industrializada e contínua com alto grau de desenvolvimento tecnológico
- A situação do mercado brasileiro, no entanto, começa a se alterar em razão da oferta de perfis tubulares estruturais (Vallourec & Mannesmann)
- Frente a esta nova tecnologia, impõe-se a necessidade de divulgação e implementação do uso desse tipo de perfil em projetos de arquitetura e engenharia, e incrementar o número de trabalhos de pesquisa nesta área

1. Generalities

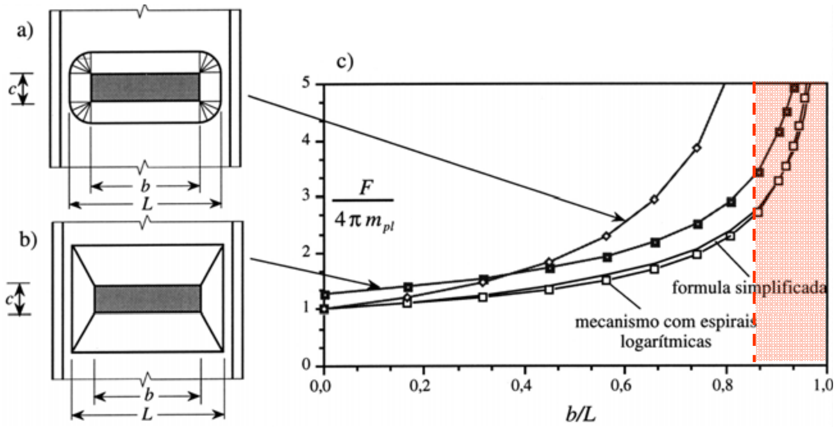




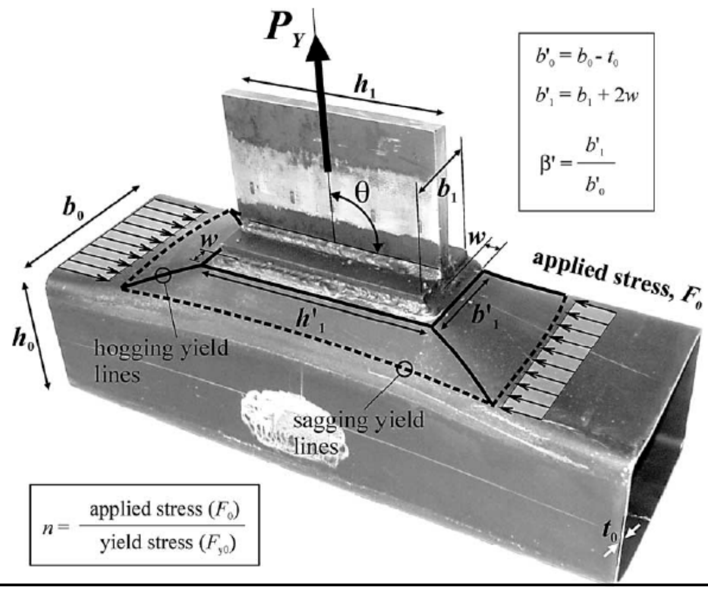
1. Generalities

- Ligação soldada de perfis tubulares → carga de ruína da face do perfil → flexão, cisalhamento, punção e efeito de membrana
- As normas de projeto de ligações de perfis tubulares em aço são normalmente baseadas em:
  - ✓ análise plástica (formação de linhas de ruptura – charneiras plásticas) → b elevado (P → irreal)
  - ✓ critérios de deformações limites → (1,2*t) ou 0,3*b_0 → acréscimo de resistência → efeito de membrana
- Melhores resultados → métodos analíticos → análise plástica + punção + fenômenos de instabilidade

1. Generalities



1. Generalities



1. Generalities

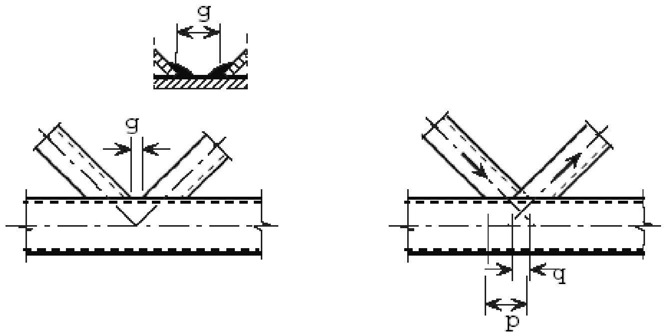
(2) The following standard abbreviations are used in section 7:

CHS for "circular hollow section";

RHS for "rectangular hollow section", which in this context includes square hollow sections.

gap g

overlap $\lambda_{ov} = (q/p) \times 100\ \%$



(a) Definition of gap

(b) Definition of overlap

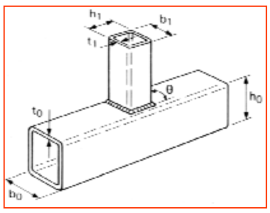
1. Generalities

(6) The geometric ratios used in section 7 are defined as follows:

β is the ratio of the mean diameter or width of the brace members, to that of the chord:

- for T, Y and X joints:

$$\frac{d_1}{d_0}\ ;\ \frac{d_1}{b_0}\ \text{or}\ \frac{b_1}{b_0}$$



- for K and N joints:

$$\frac{d_1 + d_2}{2\ d_0}\ ;\ \frac{d_1 + d_2}{2\ b_0}\ \text{or}\ \frac{b_1 + b_2 + h_1 + h_2}{4\ b_0}$$

- for KT joints:

$$\frac{d_1 + d_2 + d_3}{3\ d_0}\ ;\ \frac{d_1 + d_2 + d_3}{3\ b_0}\ \text{or}\ \frac{b_1 + b_2 + b_3 + h_1 + h_2 + h_3}{6\ b_0}$$

1. Generalities

β_p is the ratio b_i/b_p;

γ is the ratio of the chord width or diameter to twice its wall thickness:

$$\frac{d_0}{2\,t_0}\ ;\ \frac{b_0}{2\,t_0}\ \text{or}\ \frac{b_0}{2\,t_f}$$

η is the ratio of the brace member depth to the chord diameter or width:

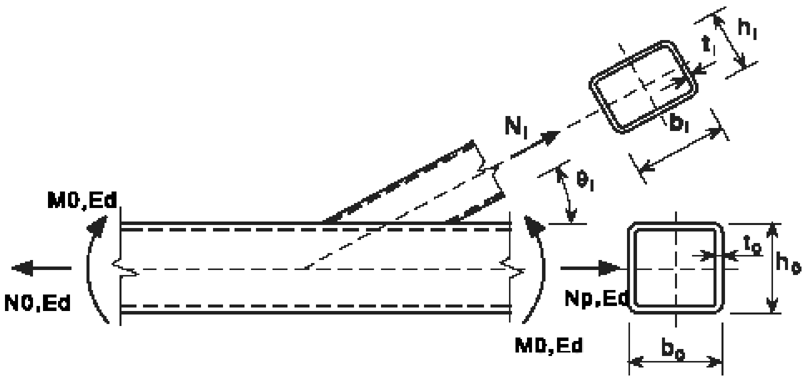
$$\frac{h_i}{d_0}\ \text{or}\ \frac{h_i}{b_0}$$

η_p is the ratio h_i/b_p;

λ_{ov} is the overlap ratio, expressed as a percentage (λ_{ov} = (q/p) x 100%) as shown in figure 1.3(b).

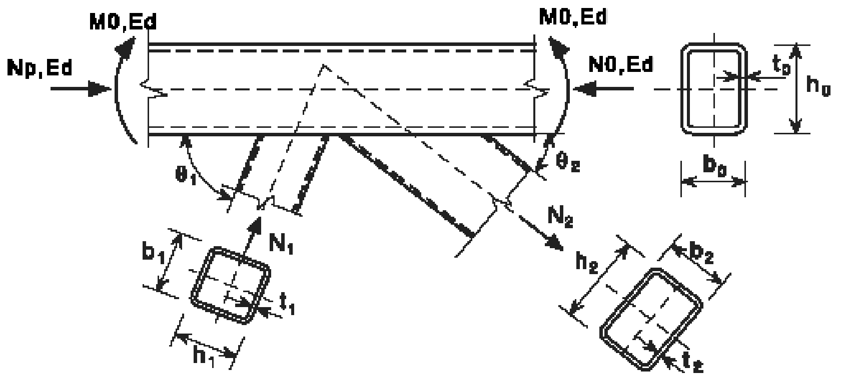
NOTE: Numerical values for γ_M may be defined in the National Annex. Recommended values are as follows: $\gamma_{M2} = 1{,}25$; $\gamma_{M3} = 1{,}25$ for hybrid connections or connections under fatigue loading and $\gamma_{M3} = 1{,}1$ for other design situations; $\gamma_{M4} = 1{,}0$; $\gamma_{M5} = 1{,}0$; $\gamma_{M6,ser} = 1{,}0$; $\gamma_{M7} = 1{,}1$.

1. Generalities



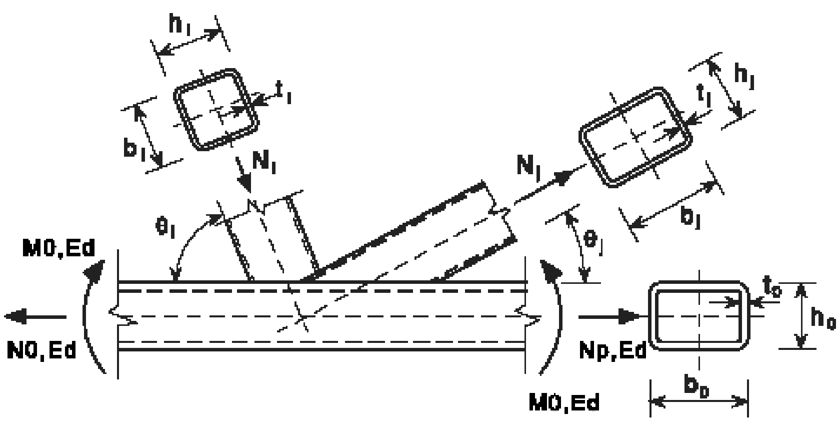
a) Joint with single brace member

1. Generalities



b) Gap joint with two brace members

1. Generalities



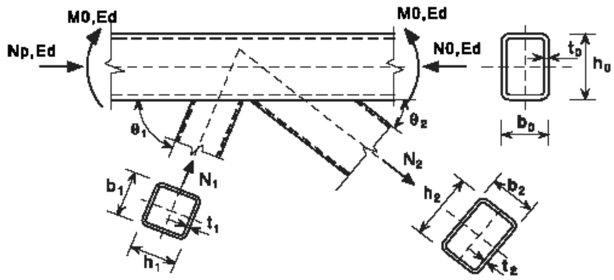
c) Overlap joint with two brace members

2. Design According to EC3

- For hot finished hollow sections and cold formed hollow sections:
  - ✓ the nominal yield strength < 460 N/mm^2
  - ✓ the nominal yield strength > 355 N/mm^2 → design resistances → reduced by a factor 0,9
  - ✓ The nominal wall thickness ≥ 2,5 mm
  - ✓ The nominal wall thickness < 25 mm
- Campo de Aplicação:
  - ✓ The compression elements of the members should satisfy the requirements for Class 1 or Class 2
  - ✓ The angles θ_i between the chords and the brace members ≥ 30º

2. Design According to EC3

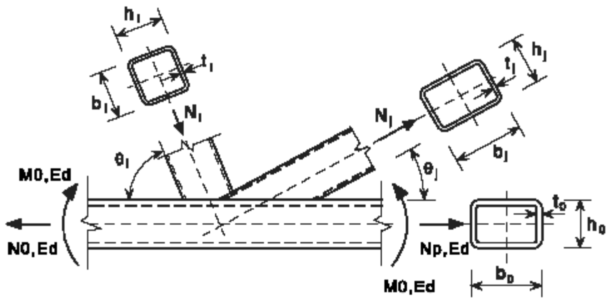
- Campo de Aplicação:
  - ✓ In gap type joints, in order to ensure that the clearance is adequate for forming satisfactory welds, the gap between the brace members should not be less than (t_1 + t_2)



b) Gap joint with two brace members

2. Design According to EC3

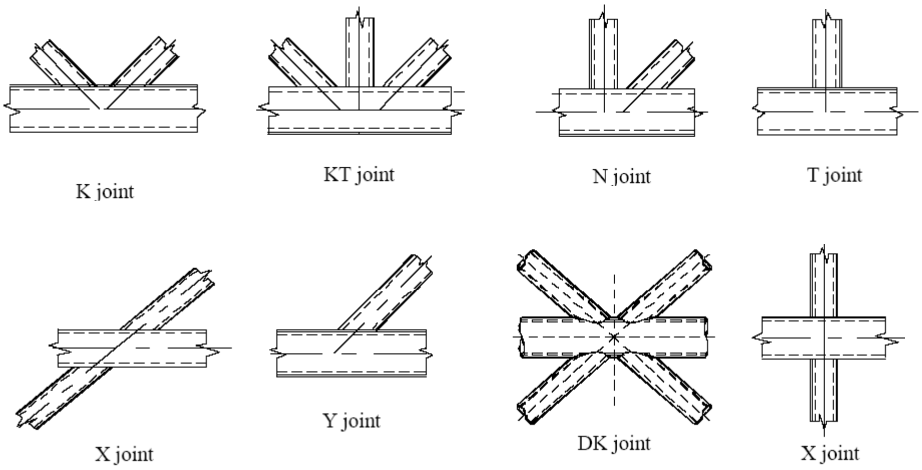
- Campo de Aplicação:
  - ✓ In overlap type joints, the overlap should be large enough to ensure that the interconnection of the brace members is sufficient for adequate shear transfer from one brace to the other. In any case the overlap should be at least 25%.



c) Overlap joint with two brace members

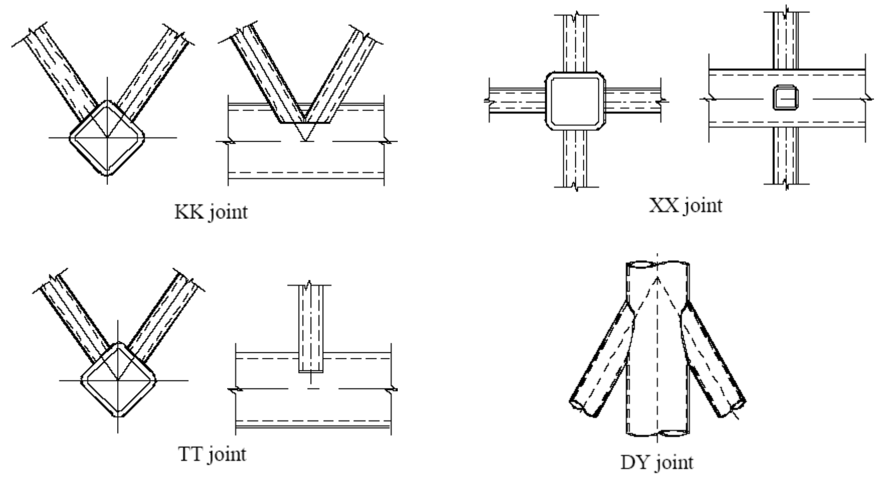
2. Design According to EC3

- Exemplos de Ligações Tubulares



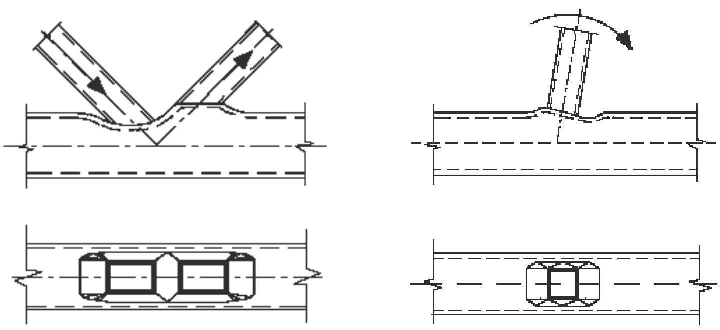
2. Design According to EC3

- Exemplos de Ligações Tubulares



2. Design According to EC3

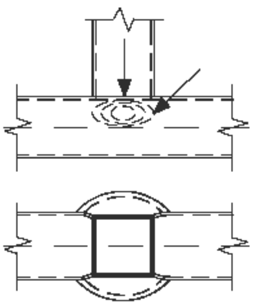
- Modos de Ruína
  - ✓ **Chord face failure** (plastic failure of the chord face) or chord plastification (plastic failure of the chord cross-section);



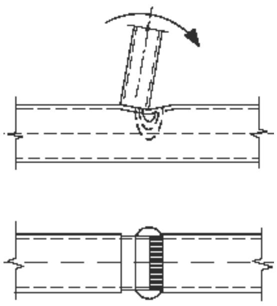
axial loading　　bending moment

2. Design According to EC3

- Modos de Ruína
  - ✓ **Chord side wall failure** (or **chord web failure**) by yielding, crushing or instability (crippling or buckling of the chord side wall or chord web) under the compression brace member;



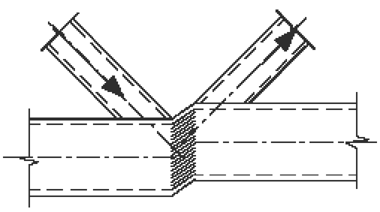
axial loading



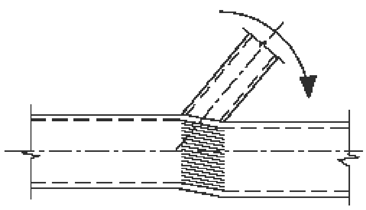
bending moment

2. Design According to EC3

- Modos de Ruína
  - ✓ Chord shear failure



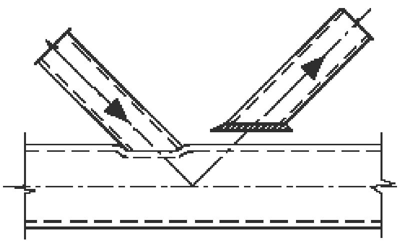
axial loading



bending moment

2. Design According to EC3

- Modos de Ruína
  - ✓ **Punching shear** failure of a hollow section chord wall (crack initiation leading to rupture of the brace members from the chord member);

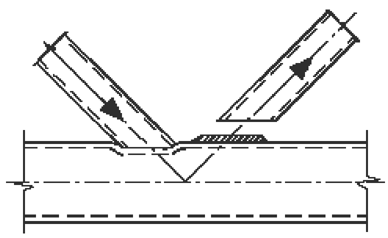


axial loading

bending moment

2. Design According to EC3

- Modos de Ruína
  - ✓ **Brace failure** with reduced effective width (cracking in the welds or in the brace members);

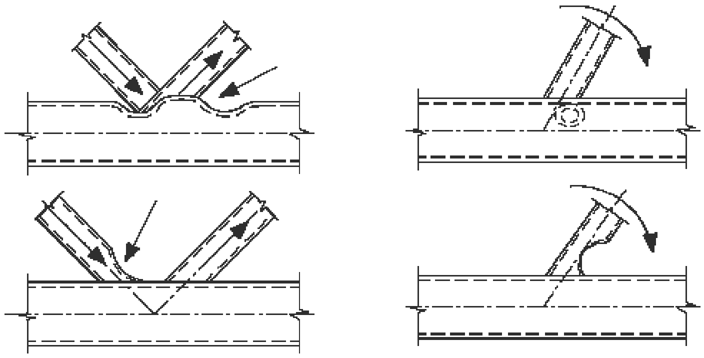


axial loading

bending moment

2. Design According to EC3

- Modos de Ruína
  - ✓ **Local buckling** failure of a brace member or of a hollow section chord member at the joint location.

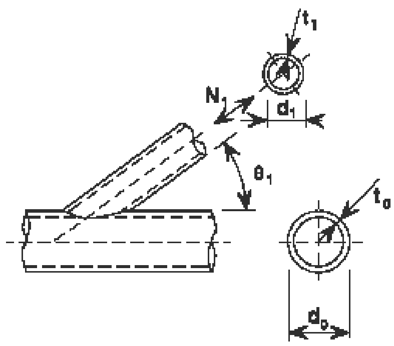


axial loading — bending moment

2. Design According to EC3

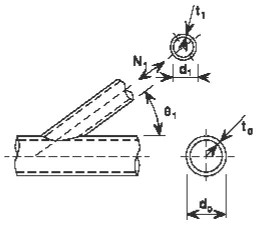
- Welded joints between CHS members

$0{,}2 \leq d_i/d_0 \leq 1{,}0$	
Class 2 and $10 \leq d_0/t_0 \leq 50$ generally but $10 \leq d_0/t_0 \leq 40$ for X joints	
Class 2 and $10 \leq d_i/t_i \leq 50$	
$\lambda_{ov} \geq 25\%$	
$g \geq t_1 + t_2$	



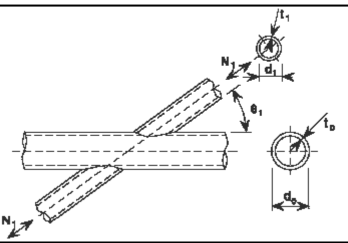
2. Design According to EC3

- Welded joints between CHS members – Axial Loading

Chord face failure - T and Y joints	
	$N_{1,\mathrm{Rd}} = \dfrac{\gamma^{0,2} k_p f_{y0} t_0^2}{\sin\theta_1}(2{,}8 + 14{,}2\beta^2) / \gamma_{M5}$

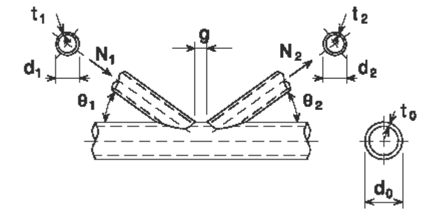
2. Design According to EC3

- Welded joints between CHS members – Axial Loading

Chord face failure - X joints	
	$N_{1,\mathrm{Rd}} = \dfrac{k_p f_{y0} t_0^2}{\sin\theta_1} \dfrac{5{,}2}{(1 - 0{,}81\beta)} / \gamma_{M5}$

2. Design According to EC3

- Welded joints between CHS members – Axial Loading

Chord face failure - K and N gap or overlap joints	
	$N_{1,Rd} = \frac{k_g k_p f_{y0} t_0^2}{\sin\theta_1}\left(1,8 + 10,2\frac{d_1}{d_0}\right)/\gamma_{M5}$ $N_{2,Rd} = \frac{\sin\theta_1}{\sin\theta_2} N_{1,Rd}$

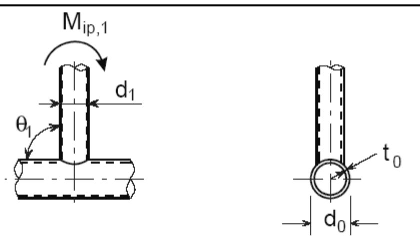
2. Design According to EC3

- Welded joints between CHS members – Axial Loading

Punching shear failure - K, N and KT gap joints and all T, Y and X joints	[i = 1, 2 or 3]
When $d_i \leq d_0 - 2t_0$: $N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_i \frac{1+\sin\theta_i}{2\sin^2\theta_i}/\gamma_{M5}$	
Factors k_g and k_p	
$k_g = \gamma^{0,2}\left(1 + \frac{0,024\gamma^{1,2}}{1+\exp(0,5g/t_0 - 1,33)}\right)$	(see Figure 7.6)
For $n_p > 0$ (compression): $k_p = 1 - 0,3\, n_p(1 + n_p)$ but $k_p \leq 1,0$ For $n_p \leq 0$ (tension): $k_p = 1,0$	

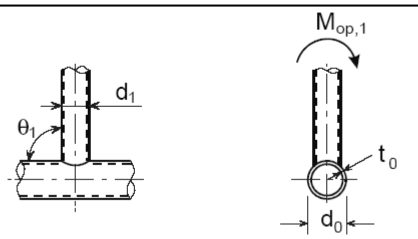
2. Design According to EC3

- Welded joints between CHS members – Bending Moment

Chord face failure - T, X, and Y joints	
	$M_{ip,1,Rd} = 4{,}85 \frac{f_{y0} t_0^2 d_1}{\sin\theta_1} \sqrt{\gamma}\beta k_p / \gamma_{M5}$

2. Design According to EC3

- Welded joints between CHS members – Bending Moment

Chord face failure - K, N, T, X and Y joints	
	$M_{op,1,Rd} = \frac{f_{y0} t_0^2 d_1}{\sin\theta_1} \frac{2{,}7}{1-0{,}81\beta} k_p / \gamma_{M5}$

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2. Design According to EC3

- Welded joints between CHS members – Bending Moment

Punching shear failure - K and N gap joints and all T, X and Y joints
When $d_1 \le d_0 - 2t_0$: $$M_{ip,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{1 + 3\sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$ $$M_{op,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{3 + \sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$
Factor k_p
For $n_p > 0$ (compression): $k_p = 1 - 0{,}3\, n_p (1 + n_p)$ but $k_p \le 1{,}0$ For $n_p \le 0$ (tension): $k_p = 1{,}0$

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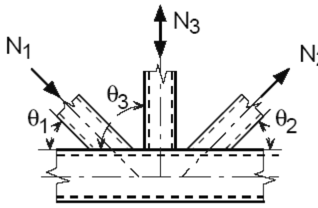
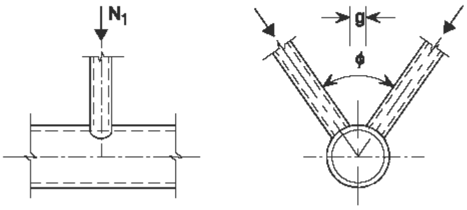
2. Design According to EC3

- Welded joints between CHS members – Special Types

Member 1 is always in compression and member 2 is always in tension. 	$N_{1,Ed}\sin\theta_1 + N_{3,Ed}\sin\theta_3 \le N_{1,Rd}\sin\theta_1$ $N_{2,Ed}\sin\theta_2 \le N_{1,Rd}\sin\theta_1$ where $N_{1,Rd}$ is the value of $N_{1,Rd}$ for a K joint from Table 7.2 but with $\frac{d_1}{d_0}$ replaced by: $\frac{d_1 + d_2 + d_3}{3d_0}$

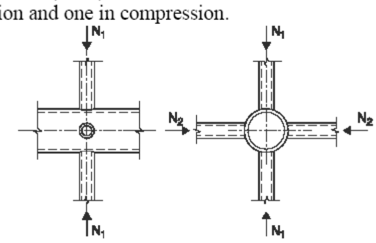
2. Design According to EC3

- Welded joints between CHS members – Reduction Factors

TT joint	$60° \le \varphi \le 90°$
Member 1 may be either tension or compression. 	$\mu = 1{,}0$

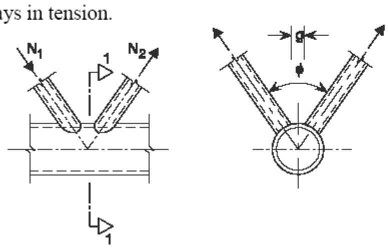
2. Design According to EC3

- Welded joints between CHS members – Reduction Factors

XX joint	
Members 1 and 2 can be either in compression or tension. $N_{2,Ed}/N_{1,Ed}$ is negative if one member is in tension and one in compression. 	$\mu = 1 + 0{,}33 N_{2,Ed} / N_{1,Ed}$ taking account of the sign of $N_{1,Ed}$ and $N_{2,Ed}$ where $\lvert N_{2,Ed} \rvert \le \lvert N_{1,Ed} \rvert$

2. Design According to EC3

- Welded joints between CHS members – Reduction Factors

KK joint	$60° \le \varphi \le 90°$
Member 1 is always in compression and member 2 is always in tension. 	$\mu = 0{,}9$ provided that, in a gap-type joint, at section 1-1 the chord satisfies: $\left[\frac{N_{0,Ed}}{N_{p\ell,0,Rd}}\right]^2 + \left[\frac{V_{0,Ed}}{V_{p\ell,0,Rd}}\right]^2 \le 1{,}0$

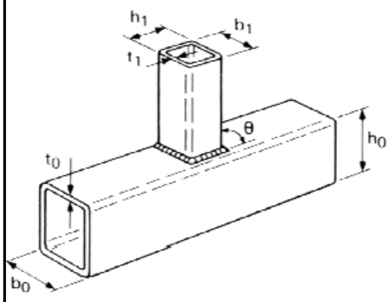
2. Design According to EC3

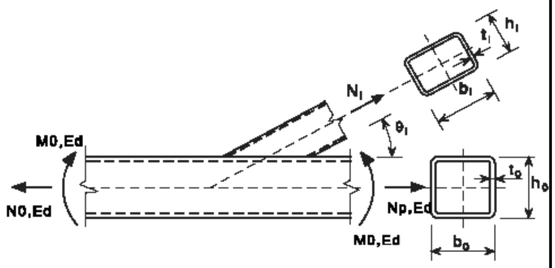
- Welded joints → CHS or RHS members and RHS chord members

Type of joint	Joint parameters [i = 1 or 2, j = overlapped brace]					
	b_i/b_0 or d_i/b_0	b_i/t_i and h_i/t_i or d_i/t_i — Compression	b_i/t_i and h_i/t_i or d_i/t_i — Tension	h_0/b_0 and h_i/b_i	b_0/t_0 and h_0/t_0	Gap or overlap b_i/b_j
T, Y or X	$b_i/b_0 \ge 0{,}25$	$b_i/t_i \le 35$ and $h_i/t_i \le 35$ and Class 2	$b_i/t_i \le 35$ and $h_i/t_i \le 35$	$\ge 0{,}5$ but $\le 2{,}0$	≤ 35 and Class 2	–
K gap N gap	$b_i/b_0 \ge 0{,}35$ and $\ge 0{,}1 + 0{,}01\, b_0/t_0$				≤ 35 and Class 2	$g/b_0 \ge 0{,}5(1-\beta)$ but $\le 1{,}5(1-\beta)$ [1] and as a minimum $g \ge t_1 + t_2$
K overlap N overlap	$b_i/b_0 \ge 0{,}25$	Class 1			Class 2	$\lambda_{ov} \ge 25\%$ but $\lambda_{ov} \le 100\%$ [2] and $b_i/b_j \ge 0{,}75$
Circular brace member	$d_i/b_0 \ge 0{,}4$ but $\le 0{,}8$	Class 1	$d_i/t_i \le 50$	As above but with d_i replacing b_i and d_j replacing b_j.		

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members





$\beta = \frac{b_1}{b_0}$ $\mu_1 = \frac{b_1}{t_1}$ $\mu_0 = \frac{b_0}{t_0}$ $\gamma = \frac{b_0}{2t_0}$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

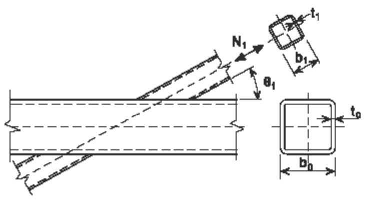
Additional conditions

Type of brace	Type of joint	Joint parameters	
Square hollow section	T, Y or X	$b_i/b_0 \leq 0{,}85$	$b_0/t_0 \geq 10$
	K gap or N gap	$0{,}6 \leq \frac{b_1 + b_2}{2b_1} \leq 1{,}3$	$b_0/t_0 \geq 15$
Circular hollow section	T, Y or X		$b_0/t_0 \geq 10$
	K gap or N gap	$0{,}6 \leq \frac{d_1 + d_2}{2d_1} \leq 1{,}3$	$b_0/t_0 \geq 15$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

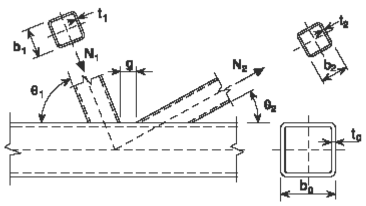
Axial loading

Type of joint	Design resistance [i = 1 or 2, j = overlapped brace]
T, Y and X joints	Chord face failure $\beta \leq 0,85$
	$N_{1,\mathrm{Rd}} = \frac{k_n f_{y0} t_0^{\,2}}{(1-\beta)\sin\theta_1}\left(\frac{2\beta}{\sin\theta_1} + 4\sqrt{1-\beta}\right) / \gamma_{M5}$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

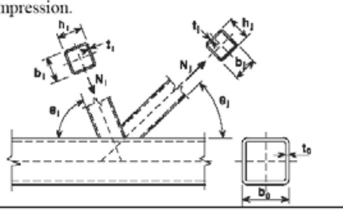
Axial loading

K and N gap joints	Chord face failure $\beta \leq 1,0$
	$N_{i,\mathrm{Rd}} = \frac{8,9\gamma^{0,5} k_n f_{y0} t_0^2}{\sin\theta_i}\left(\frac{b_1 + b_2}{2b_0}\right) / \gamma_{M5}$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

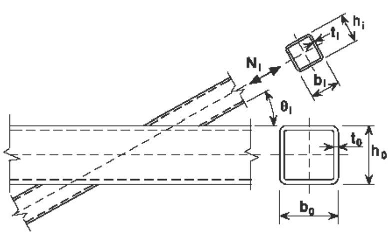
Axial loading

K and N overlap joints *)	Brace failure $25\% \le \lambda_{ov} < 50\%$
Member i or member j may be either tension or compression but one shall be tension and the other compression. 	$N_{i,Rd} = f_{yi} t_i \left(b_{eff} + b_{e,ov} + \frac{\lambda_{ov}}{50}(2h_i - 4t_i) \right) / \gamma_{M5}$
	Brace failure $50\% \le \lambda_{ov} < 80\%$
	$N_{i,Rd} = f_{yi} t_i \left[b_{eff} + b_{e,ov} + 2h_i - 4t_i \right] / \gamma_{M5}$
	Brace failure $\lambda_{ov} \ge 80\%$
	$N_{i,Rd} = f_{yi} t_i \left[b_i + b_{e,ov} + 2h_i - 4t_i \right] / \gamma_{M5}$
Parameters b_{eff}, $b_{e,ov}$ and k_n	
$b_{eff} = \frac{10}{b_0/t_0} \frac{f_{y0} t_0}{f_{yi} t_i} b_i$ but $b_{eff} \le b_i$	For $n > 0$ (compression): $k_n = 1{,}3 - \frac{0{,}4n}{\beta}$ but $k_n \le 1{,}0$
$b_{e,ov} = \frac{10}{b_j/t_j} \frac{f_{yj} t_j}{f_{yi} t_i} b_i$ but $b_{e,ov} \le b_i$	For $n \le 0$ (tension): $k_n = 1{,}0$
For circular braces, multiply the above resistances by $\pi/4$, replace b_1 and h_1 by d_1 and replace b_2 and h_2 by d_2.	

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

Axial loading → T, X and Y joints between RHS or CHS braces and RHS chords

Type of joint	Design resistance $[i = 1]$
	Chord face failure $\beta \le 0{,}85$
	$N_{1,Rd} = \frac{k_n f_{y0} t_0^2}{(1-\beta)\sin\theta_1} \left(\frac{2\eta}{\sin\theta_1} + 4\sqrt{1-\beta} \right) / \gamma_{M5}$
	Chord side wall buckling [1] $\beta = 1{,}0$ [2]
	$N_{1,Rd} = \frac{f_b t_0}{\sin\theta_i} \left(\frac{2h_i}{\sin\theta_1} + 10t_0 \right) / \gamma_{M5}$
	Brace failure $\beta \ge 0{,}85$
	$N_{1,Rd} = f_{yi} t_i (2h_i - 4t_i + 2b_{eff}) / \gamma_{M5}$
	Punching shear $0{,}85 \le \beta \le (1 - 1/\gamma)$
	$N_{1,Rd} = \frac{f_{y0} t_0}{\sqrt{3}\sin\theta_1} \left(\frac{2h_i}{\sin\theta_1} + 2b_{e,p} \right) / \gamma_{M5}$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

Axial loading → T, X and Y joints between RHS or CHS braces and RHS chords

[1] For X joints with $\theta < 90°$ use the smaller of this value and the design shear resistance of the chord side walls given for K and N gap joints in Table 7.12. [2] For $0,85 \leq \beta \leq 1,0$ use linear interpolation between the value for chord face failure at $\beta = 0,85$ and the governing value for chord side wall failure at $\beta = 1,0$ (side wall buckling or chord shear).
For circular braces, multiply the above resistances by $\pi/4$, replace b_1 and h_1 by d_1 and replace b_2 and h_2 by d_2.

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

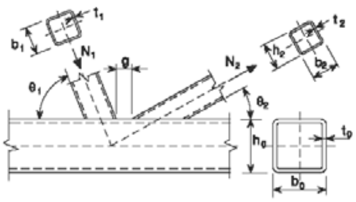
Axial loading → T, X and Y joints between RHS or CHS braces and RHS chords

For tension: $f_b = f_{y0}$ For compression: $f_b = \chi f_{y0}$ (T and Y joints) $f_b = 0,8\,\chi f_{y0} \sin\theta_i$ (X joints) where χ is the reduction factor for flexural buckling obtained from EN 1993-1-1 using the relevant buckling curve and a normalized slenderness $\bar{\lambda}$ determined from: $\bar{\lambda} = 3,46 \dfrac{\left(\dfrac{h_0}{t_0} - 2\right)\sqrt{\dfrac{1}{\sin\theta_i}}}{\pi\sqrt{\dfrac{E}{f_{y0}}}}$	$b_{eff} = \dfrac{10}{b_0/t_0}\dfrac{f_{y0}t_0}{f_{yi}t_i}b_i$ but $b_{eff} \leq b_i$ $b_{e,p} = \dfrac{10}{b_0 t_0} b_i$ but $b_{e,p} \leq b_i$ For $n > 0$ (compression): $k_n = 1,3 - \dfrac{0,4n}{\beta}$ but $k_n \leq 1,0$ For $n \leq 0$ (tension): $k_n = 1,0$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

Axial loading → welded K and N joints between RHS or CHS braces and RHS chords

Type of joint	Design resistance $[i = 1 \text{ or } 2]$
K and N gap joints	Chord face failure
	$N_{i,Rd} = \frac{8{,}9 k_n f_{y0} t_0^2 \sqrt{\gamma}}{\sin\theta_i} \left(\frac{b_1 + b_2 + h_1 + h_2}{4 b_0} \right) / \gamma_{M5}$
	Chord shear
	$N_{i,Rd} = \frac{f_{y0} A_v}{\sqrt{3} \sin\theta_i} / \gamma_{M5}$ $N_{0,Rd} = \left[(A_0 - A_v) f_{y0} + A_v f_{y0} \sqrt{1 - (V_{Sd} / V_{pl,Rd})^2} \right] / \gamma_{M5}$
	Brace failure
	$N_{i,Rd} = f_{yi} t_i (2h_i - 4t_i + b_i + b_{eff}) / \gamma_{M5}$
	Punching shear $\beta \leq (1 - 1/\gamma)$
	$N_{i,Rd} = \frac{f_{y0} t_0}{\sqrt{3} \sin\theta_i} \left(\frac{2h_i}{\sin\theta_i} + b_i + b_{e,p} \right) / \gamma_{M5}$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

Axial loading → T, X and Y joints between RHS or CHS braces and RHS chords

K and N overlap joints	As in Table 7.10.
For circular braces, multiply the above resistances by $\pi/4$, replace b_1 and h_1 by d_1 and replace b_2 and h_2 by d_2.	
$A_v = (2h_0 + \alpha b_0) t_0$ For a square or rectangular brace member: $\alpha = \sqrt{\frac{1}{1 + \frac{4g^2}{3t_0^2}}}$ where g is the gap, see Figure 1.3(a). For a circular brace member: $\alpha = 0$	$b_{eff} = \frac{10}{b_0 / t_0} \frac{f_{y0} t_0}{f_{yi} t_i} b_i$ but $b_{eff} \leq b_i$ $b_{e,p} = \frac{10}{b_0 t_0} b_i$ but $b_{e,p} \leq b_i$ For $n > 0$ (compression): $k_n = 1{,}3 - \frac{0{,}4 n}{\beta}$ but $k_n \leq 1{,}0$ For $n \leq 0$ (tension): $k_n = 1{,}0$

2. Design According to EC3

- Welded joints → CHS or RHS members and RHS chord members

Axial loading → T, X and Y joints between RHS or CHS braces and RHS chords

Brace member connections subjected to combined bending and axial force should satisfy the following requirement:

$$\frac{N_{i,Ed}}{N_{i,Rd}} + \frac{M_{ip,i,Ed}}{M_{ip,i,Rd}} + \frac{M_{op,i,Ed}}{M_{op,i,Rd}} \leq 1{,}0 \qquad \text{... (7.4)}$$

where:

$M_{ip,i,Rd}$ is the design in-plane moment resistance

$M_{ip,i,Ed}$ is the design in-plane internal moment

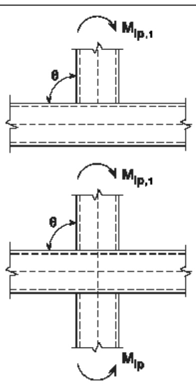
$M_{op,i,Rd}$ is the design out-of-plane moment resistance

$M_{op,i,Ed}$ is the design out-of-plane internal moment

2. Design According to EC3

- Welded joints → RHS members and RHS chord members

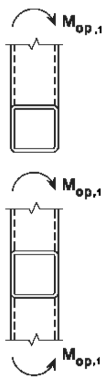
Bending moment

T and X joints	Design resistance
In-plane moments ($\theta = 90°$)	Chord face failure $\beta \leq 0{,}85$
	$M_{ip,1,Rd} = k_n f_{y0} t_0^2 h_1 \left(\frac{1}{2\eta} + \frac{2}{\sqrt{1-\beta}} + \frac{\eta}{1-\beta} \right) / \gamma_{M5}$
	Chord side wall crushing $0{,}85 \leq \beta \leq 1{,}0$
	$M_{ip,1,Rd} = 0{,}5 f_{yk} t_0 (h_1 + 5t_0)^2 / \gamma_{M5}$ $f_{yk} = f_{y0}$ for T joints $f_{yk} = 0{,}8 f_{y0}$ for X joints
	Brace failure $0{,}85 \leq \beta \leq 1{,}0$
	$M_{ip,1,Rd} = f_{y1} \left(W_{pl,1} - (1 - b_{eff}/b_1) b_1 h_1 t_1 \right) / \gamma_{M5}$

2. Design According to EC3

- Welded joints → RHS members and RHS chord members

Bending moment

Out-of-plane moments ($\theta = 90°$)	Chord face failure $\beta \leq 0,85$
	$M_{op,1,Rd} = k_n f_{y0} t_0^2 \left(\frac{h_1(1+\beta)}{2(1-\beta)} + \sqrt{\frac{2b_0 b_1(1+\beta)}{1-\beta}} \right) / \gamma_{M5}$
	Chord side wall crushing $0,85 \leq \beta \leq 1,0$
	$M_{op,1,Rd} = f_{yk} t_0 (b_0 - t_0)(h_1 + 5t_0) / \gamma_{M5}$ $f_{yk} = f_{y0}$ for T joints $f_{yk} = 0,8 f_{y0}$ for X joints
	Chord distortional failure (T joints only) *)
	$M_{op,1,Rd} = 2 f_{y0} t_0 \left(h_1 t_0 + \sqrt{b_0 h_0 t_0 (b_0 + h_0)} \right) / \gamma_{M5}$
	Brace failure $0,85 \leq \beta \leq 1,0$
	$M_{op,1,Rd} = f_{y1} \left(W_{pl,1} - 0,5 (1 - b_{eff}/b_1)^2 b_1^2 t_1 \right) / \gamma_{M5}$

2. Design According to EC3

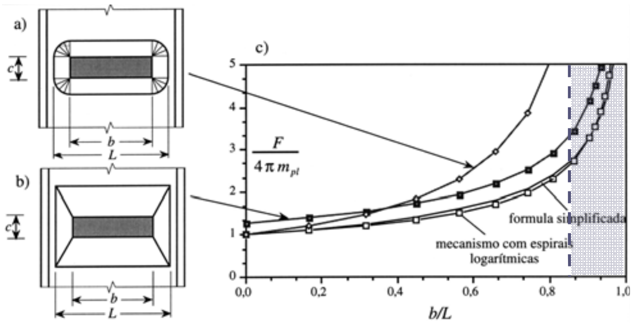
- Welded joints → RHS members and RHS chord members

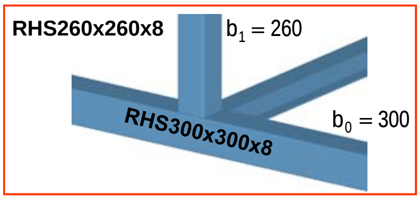
Bending moment

Parameters b_{eff} and k_n	
$b_{eff} = \frac{10}{b_0/t_0} \frac{f_{y0} t_0}{f_{y1} t_1} b_1$ but $b_{eff} \leq b_1$	For $n > 0$ (compression): $k_n = 1,3 - \frac{0,4n}{\beta}$ but $k_n \leq 1,0$ For $n \leq 0$ (tension): $k_n = 1,0$
*) This criterion does not apply where chord distortional failure is prevented by other means.	

3. Examples

- RHS members and RHS chord members





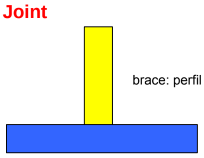
Joint parameters	
$b_1/b_0 \leq 0{,}85$	$b_0/t_0 \geq 10$

$\beta = \frac{b_1}{b_0} = 0{,}875 > 0{,}85$ (EC3)

3. Examples

- RHS members and RHS chord members

"T" Joint



b1	h1	t1	fy1
260	260	8	275

teta 1 = 90 °

b0	h0	t0	fy0
300	300	8	275

Verificações da Norma

beta = b1 / b0 =	260 / 300	=	0.867	>	0.85	não OK
b0 / t0 =	300 / 8	=	37.500	>	10	OK
b1 / t1 =	260 / 8	=	32.500	<	35	OK
h1 / t1 =	260 / 8	=	32.500	<	35	OK
h0 / b0 =	300 / 300	=	1.000	>	0.5	OK
h1 / b1 =	260 / 260	=	1.000	>	0.5	OK
c0 / t0 =	284 / 8	=	35.500	>	30,36	OK
c1 / t1 =	244 / 8	=	30.500	>	30,36	OK

3. Examples

- RHS members and RHS chord members

$$N_{1,Rd} = \frac{k_n f_{y0} t_0^2}{(1-\beta)\,\text{sen}\theta_1}\left(\frac{2\beta}{\text{sen}\theta_1} + 4\sqrt{1-\beta}\right)/\gamma_{M5}$$

For $n > 0$ (compression): $k_n = 1{,}3 - \frac{0{,}4n}{\beta}$ but $k_n \le 1{,}0$

For $n \le 0$ (tension): $k_n = 1{,}0$

$k_{n\,(tração)}$ = 1.00 ; n = 1.00 $k_{n\,(comp)}$ = 0.838

$N_{1,Rd\,(t)}$ = 1.00 * 275 * (8)^2 / (1 - 0.867) * sen 90 *

2 * 0.867 / sen 90 + 4 * RAIZ (1 - 0.867)

$N_{1,Rd\,(t)}$ = 421.60 kN

$N_{1,Rd\,(c)}$ = 0.84 * 275 * (8)^2 / (1 - 0.867) * sen 90 *

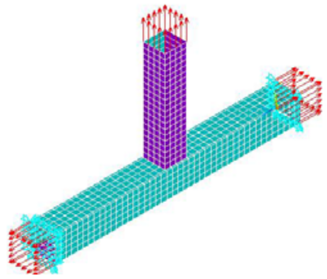
2 * 0.867 / sen 90 + 4 * RAIZ (1 - 0.867)

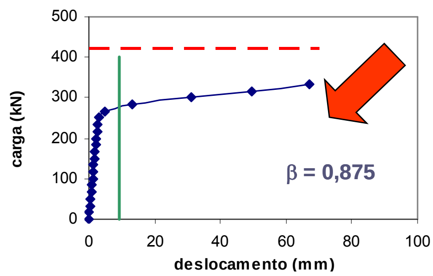
$N_{1,Rd\,(c)}$ = 353.49 kN

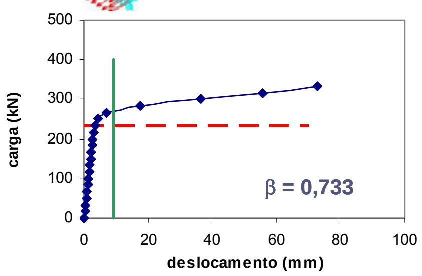
Vale ressaltar que $N_{1,Rd}$ representa a carga a ser aplicada no braço que provoca a plastificação da face da corda.

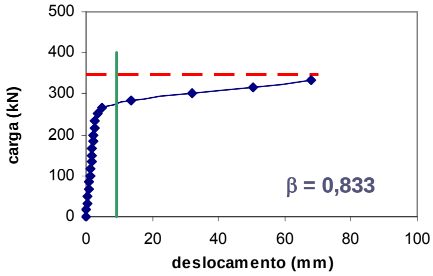
3. Examples

- RHS members and RHS chord members



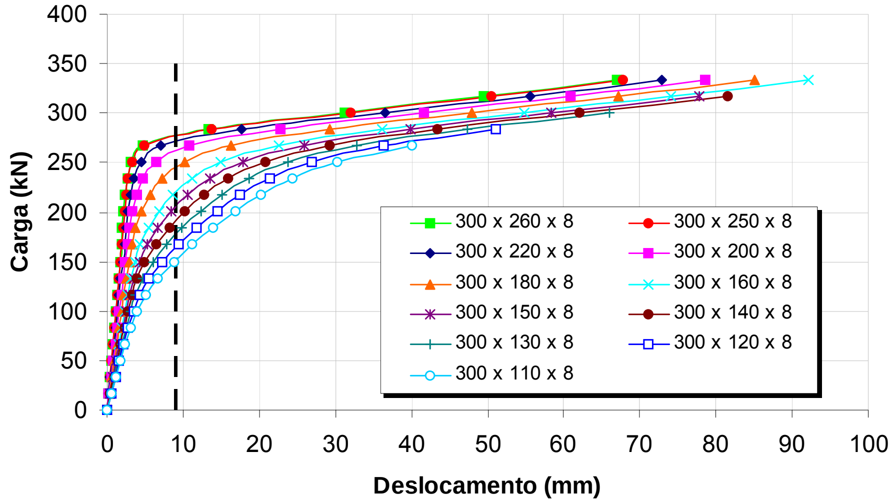






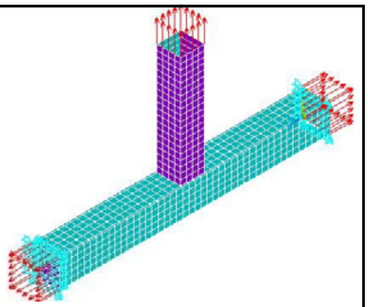
3. Examples

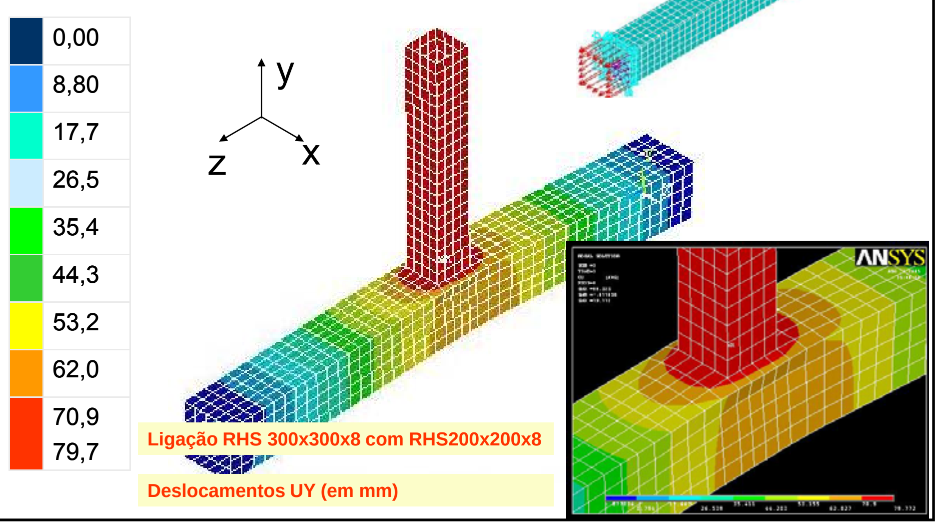
- RHS members and RHS chord members



3. Examples

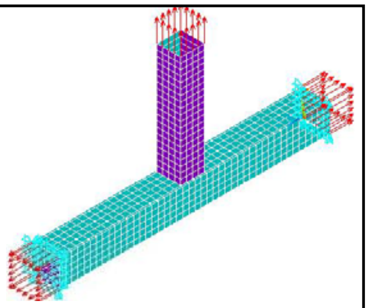
- RHS members and RHS chord members

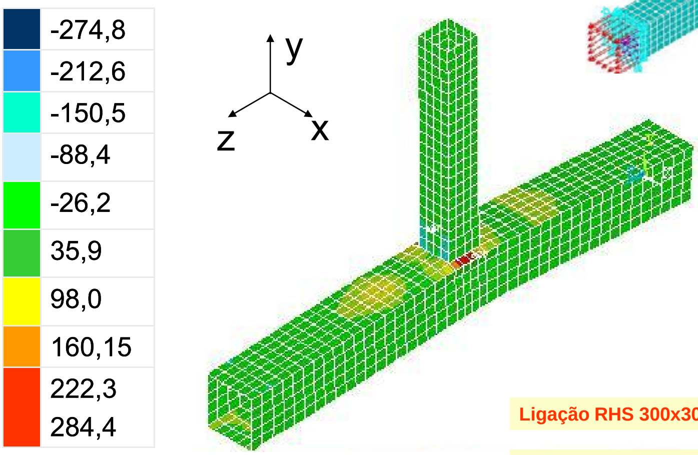




3. Examples

- RHS members and RHS chord members



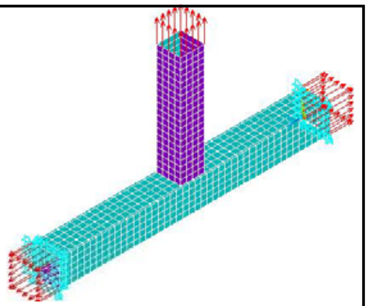


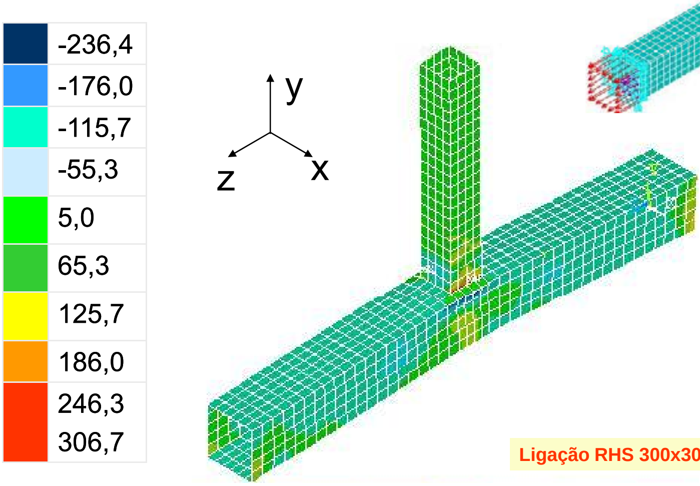
Ligação RHS 300x300x8 com RHS200x200x8

Tensões na direção X (em MPa)

3. Examples

- RHS members and RHS chord members



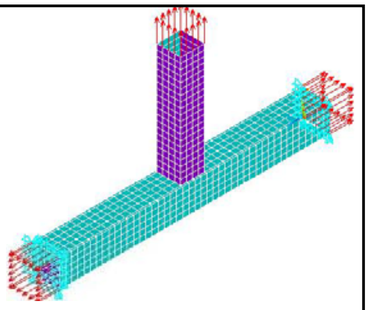


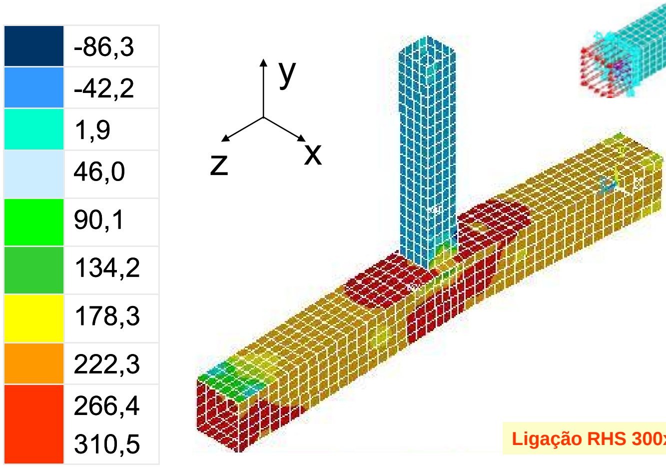
Ligação RHS 300x300x8 com RHS200x200x8

Tensões na direção Y (em MPa)

3. Examples

- RHS members and RHS chord members



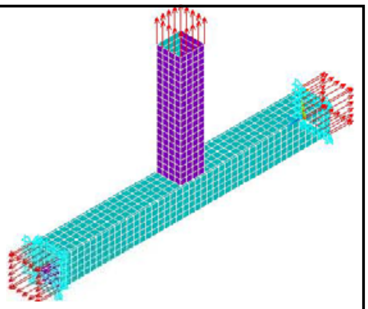


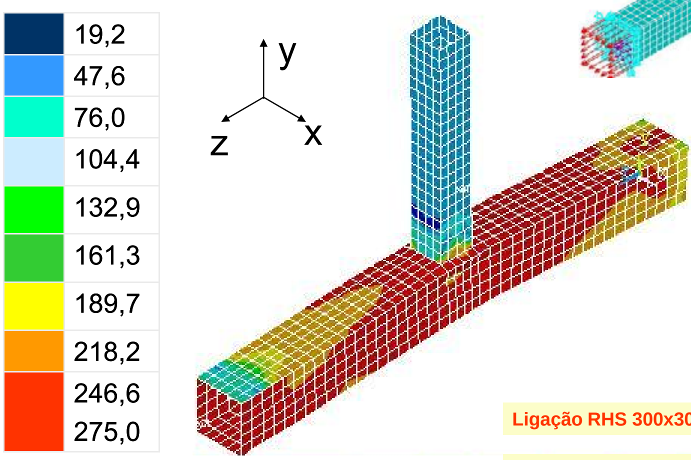
Ligação RHS 300x300x8 com RHS200x200x8

Tensões na direção Z (em MPa)

3. Examples

- RHS members and RHS chord members



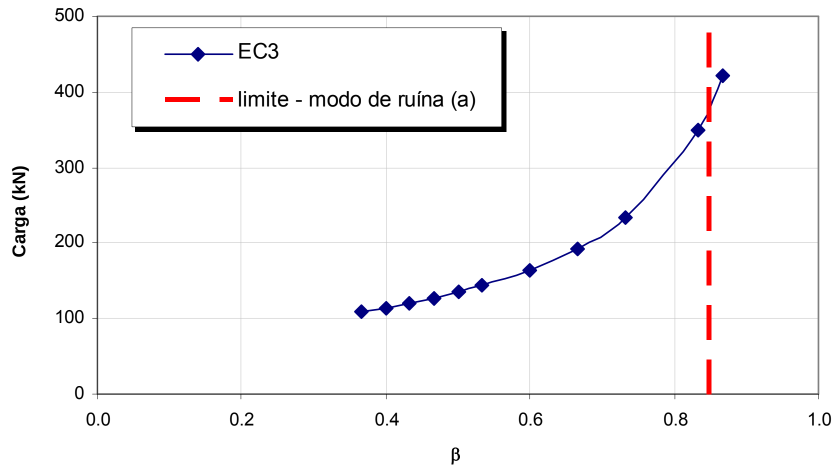


Ligação RHS 300x300x8 com RHS200x200x8

Tensões de *Von Mises* (em MPa)

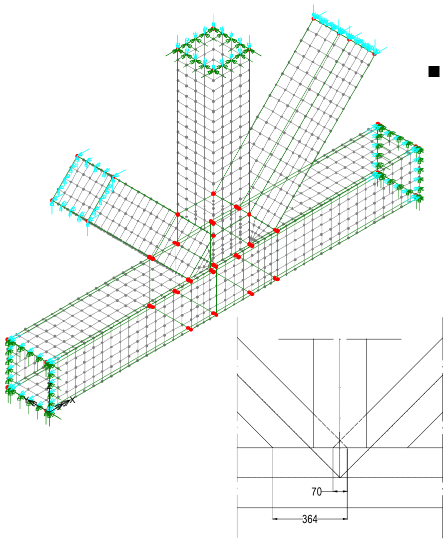
3. Examples

- RHS members and RHS chord members



3. Examples

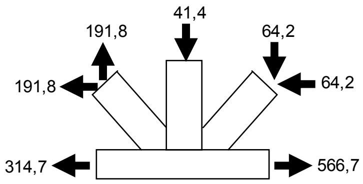
- “KT” Joint - RHS members and RHS chord members

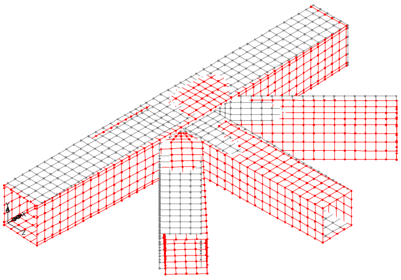


- For the “KT” joint, the Eurocode 3 provisions consider these types of joints as a “K” joint, of a gap or overlap type, depending on the joint geometry. Since $\mu_0 = 37{,}5$, and the overlap ratio, λ_{ov} is 19 %, the current joint is again slightly out of the Eurocode rules range of validity that assume $\mu_0 \leq 35$ and $\lambda_{ov} \geq 25\%$.

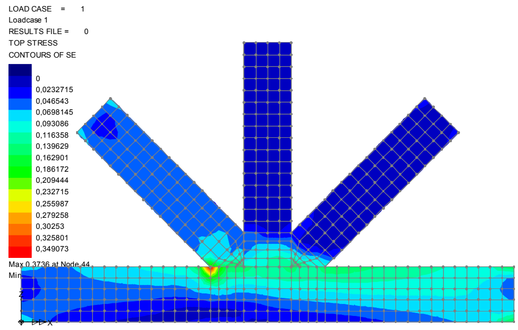
3. Examples

- "KT" Joint - RHS members and RHS chord members





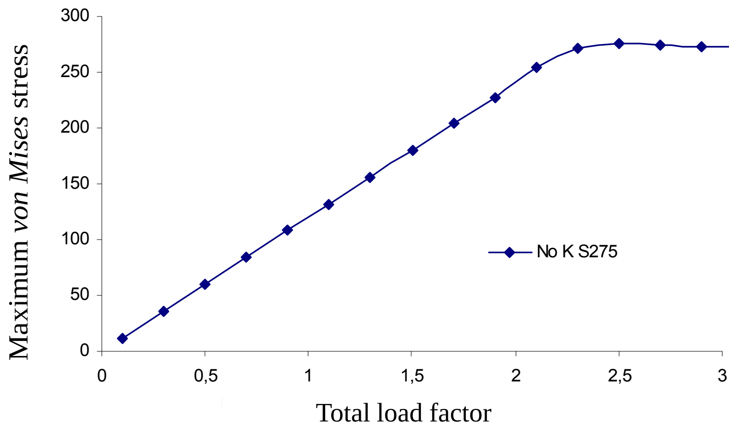
deformed mesh



Von Mises (in GPa)

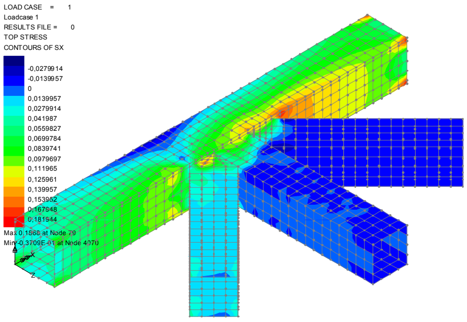
3. Examples

- "KT" Joint - RHS members and RHS chord members

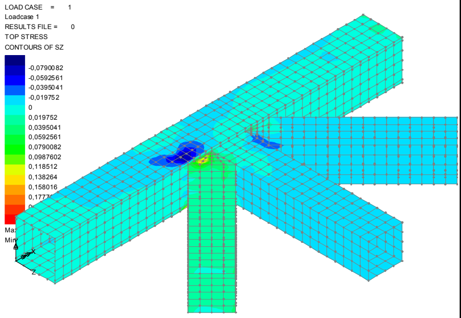


3. Examples

- "KT" Joint - RHS members and RHS chord members



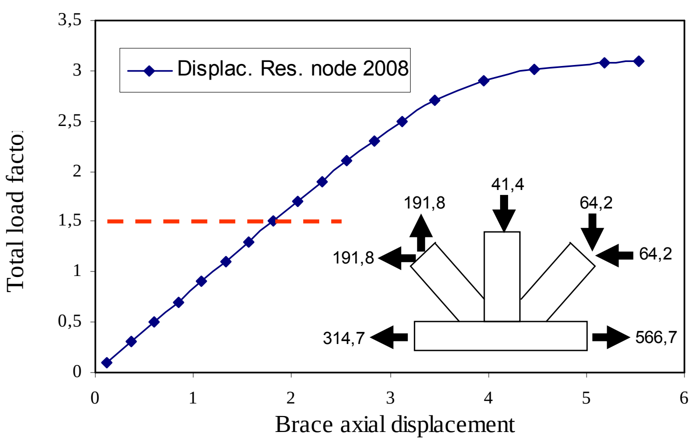
Stresses in direction X
(chord axis)



Stresses in direction Z
(middle brace axis)

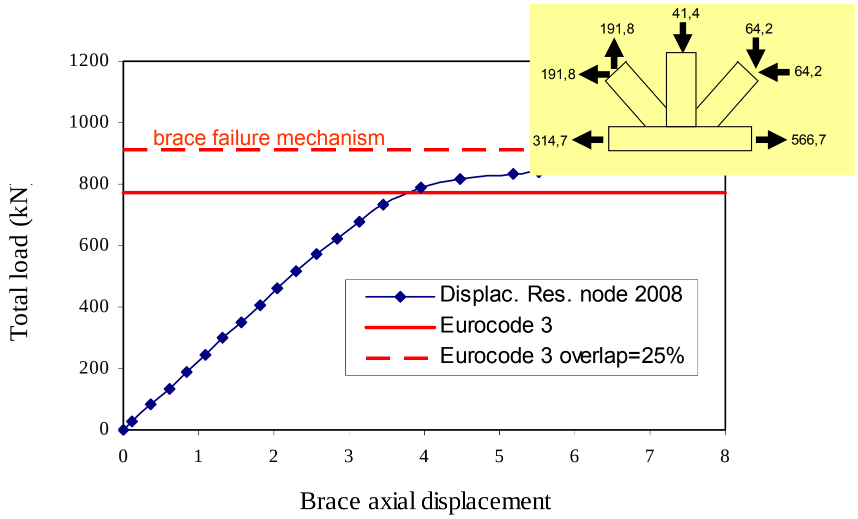
3. Examples

- "KT" Joint - RHS members and RHS chord members



3. Examples

- "KT" Joint - RHS members and RHS chord members



3. Examples

- "KT" Joint - RHS members and RHS chord members

- The EC 3 failure load → brace failure mechanism, represented by the full horizontal line
- This force is the resultant axial force in the most loaded brace member (770*kN*).
- The application of EC3 is out of its validity range
  - ✓the overlap ratio, λ_{ov} is 19% < the minimum of 25%
- The same exercise - minimum EC3 value of $\lambda_{ov} = 25\%$ → maximum load of 910*kN*, represented by the horizontal dotted line
- maximum load obtained is 841*kN*

4. Important References

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- Eurocode 3, prEN 1993-1.8, 2003. *Design of steel structures – Part 1.8: Design of joints* ("final draft"), CEN, European Committee for Standardisation, Brussels.

4. Important References

- Kosteski, N., Packer, J.A., Puthli, R.S., 2003. A finite element method based yield load determination procedure for hollow structural section connections, *J. Constructional Steel Research, vol. 59, nº 4*, pp. 427-559.
- Vallourec & Mannesmann do Brasil, 2004. Catálogo de Produtos: Tubos Estruturais de Seções Circulares, Quadradas e Retangulares, 8 pp.

4. Important References

- Neves, L.F. C., Lima, L. R. O. de, Jordão, S. and Silva, J. G. S. da, 2005. Structural Analysis of “T” and “KT” Joints of a Steel Truss Structure Using the Finite Element Method. *Proceedings of the Tenth International Conference on Civil, Structural and Environmental Engineering Computing,* Civil-Comp Press, Stirling, Scotland, pp. 1-15.