International Workshop on Connections in Steel Structures: 2008
Chicago, Illinois, USA
June 22-25 2008

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PGECIV Post Graduate Program in Civil Engineering

STRUCTURAL RESPONSE OF K AND T TUBULAR JOINTS UNDER STATIC LOADING

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Summary

- Introduction
  - ✓ Why study structural tubular joints in Brazil?
- Eurocode 3 Provisions
- Numerical Model
- Results Analysis and Discussion
- Parametrical Analysis
- Final Remarks

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Introduction

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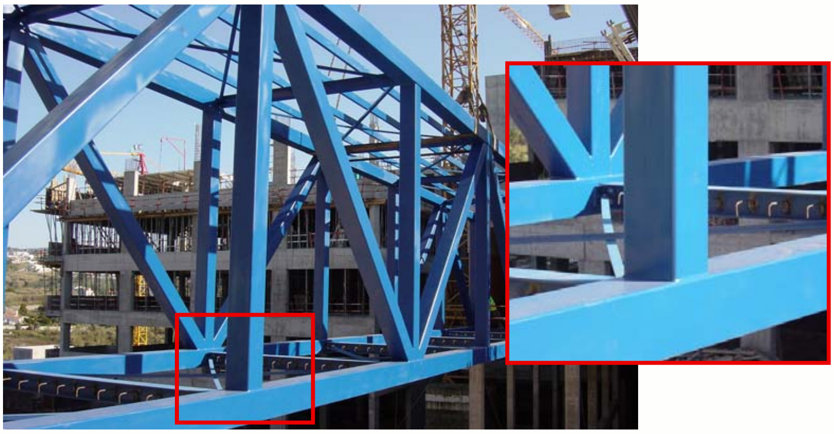
- The intensive worldwide use tubular structural elements



Footbridge – Pediatric Hospital – Coimbra - Portugal

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Introduction

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- The intensive worldwide use tubular structural elements

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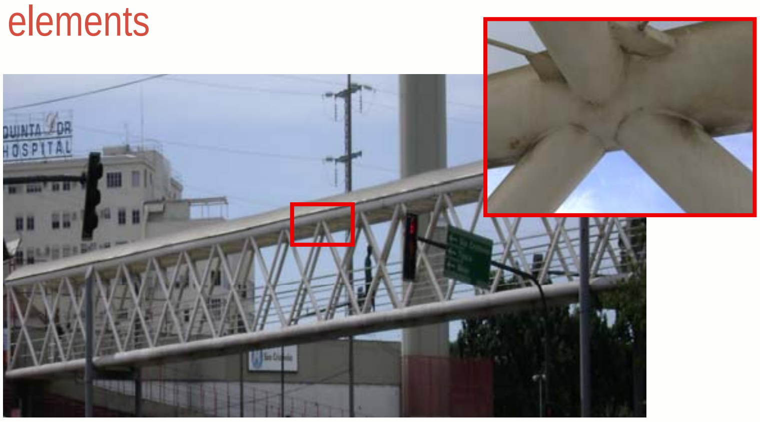
- The intensive worldwide use tubular structural elements



Footbridge – Rio de Janeiro - Brazil

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- Aesthetical and structural advantages → led designers to be focused on the technologic and design issues related to these structures
- Design methods accuracy is a fundamental aspect under the economical and safety points of view
- In Brazil → initially, tubular space trusses
- After 2000 → V&M → other structural types
- Design codes are required → EC3

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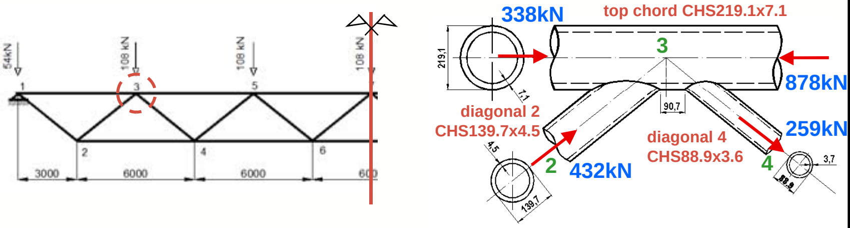
- Connection design → performed since their behaviour frequently governs the overall structural response
- Wardenier *et al.* (1991)



Joint design: 382.5kN → NO OK!

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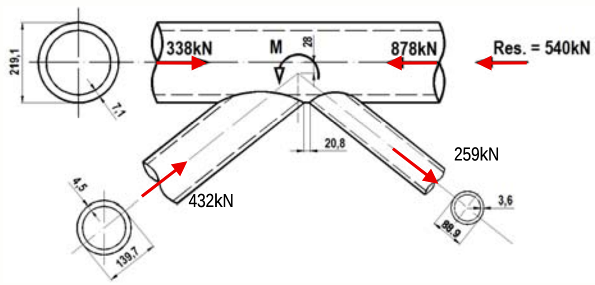
Introduction

- Solve the problem → two possibilities
  - ✓ change the top chord thickness;
  - ✓ use eccentricity in the joint → introduction of bending in the joint → but, more economical



Joint design: 657.6kN → OK!

Introduction

- Design rules HSS joints → plastic analysis or on deformation limit criteria
- Plastic analysis → joint ultimate limit state → plastic mechanism corresponding to the assumed yield line pattern
- Each plastic mechanism is associated to an unique ultimate load → suitable for this particular failure mechanism

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Introduction

- Deformation limits criteria → ultimate limit state of the chord face to a maximum out of plane deformation of this component
- Justification for a deformation versus plastic criterion → slender chord faces → the joint stiffness is not exhausted after complete onset of yielding, and can assume quite large values due to membrane effects

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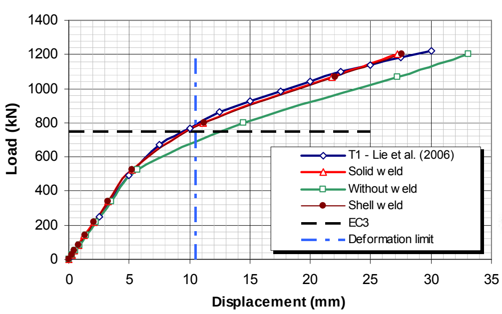
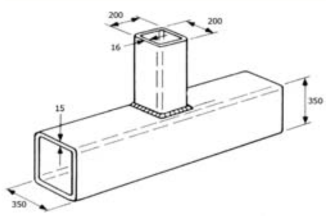
Introduction

- Deformation limit proposed by Lu et al. [7] → "T" Joints
  - ✓ Ultimate strength (N_u) → $\Delta_u = 0.03b_0$





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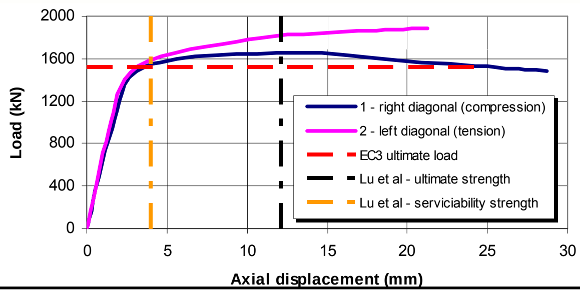
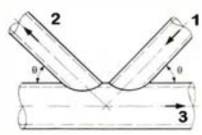
Introduction

- Deformation limit proposed by Lu et al. [7] and reported by Choo *et al.* [8] → "K" Joints
  - ✓ Ultimate strength (N_u) → $\Delta_u = 0.03d_0$
  - ✓ Serviceability strength (N_s) → $\Delta_s = 0.01d_0$
  - ✓ Se N_u/N_s>1.5 → Δ_u and N_u/N_s>1.5 → Δ_s





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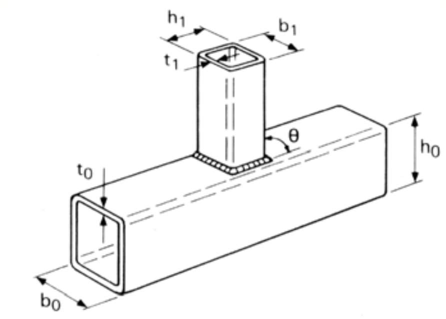
- Geometrical properties → "T" Joints



$0.25 \le \beta = \frac{b_1}{b_0} \le 0.85$ | $\gamma = \frac{b_0}{2t_0}$ | $10 \le \frac{b_0}{t_0} \le 35$ | $10 \le \frac{b_1}{t_1} \le 35$

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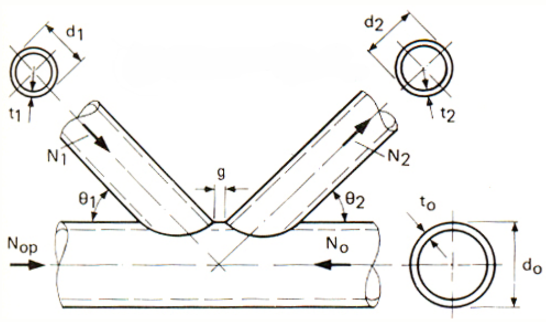
- Geometrical properties→ "K" Joints



$\beta = \frac{d_1 + d_2}{2d_0}$ | $\gamma = \frac{d_0}{2t_0} \le 25$ | $0.2 \le \frac{d_i}{d_0} \le 1.0$ | $10 \le \frac{d_0}{t_0} \le 50$ | $10 \le \frac{d_i}{t_i} \le 50$

Eurocode 3 Provisions

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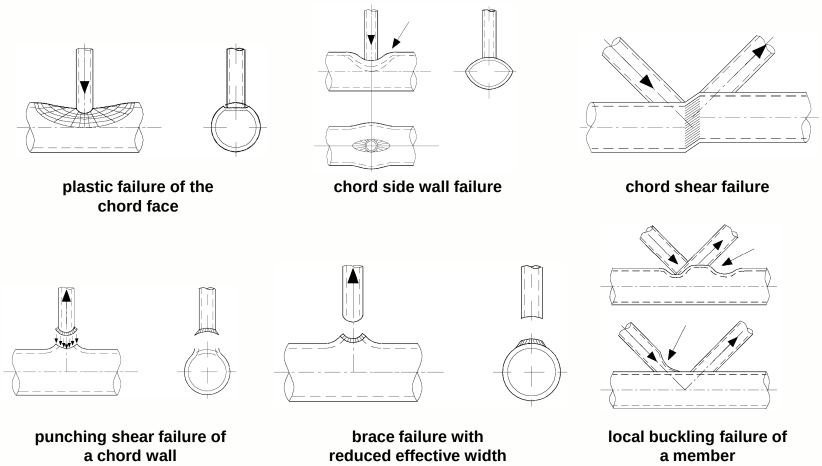
- Failure modes



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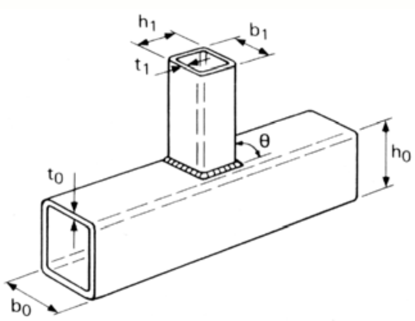
- Chord face plastic load → investigated "T" joint

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



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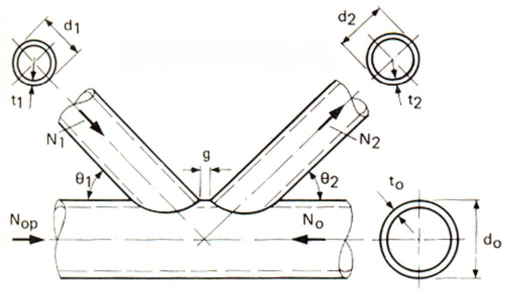
- Chord face plastic load → investigated "K" joint

$$N_{1,Rd} = \frac{k_g k_p f_{y0} t_0^2}{sen\theta_1}\left(1.8 + 10.2\frac{d_1}{d_0}\right)/\gamma_{M5} \quad \text{with} \quad N_{2,Rd} = \frac{\sin\theta_1}{\sin\theta_2} N_{1,Rd}$$



Numerical Model

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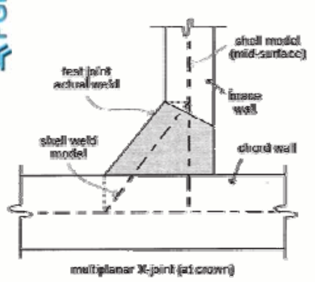
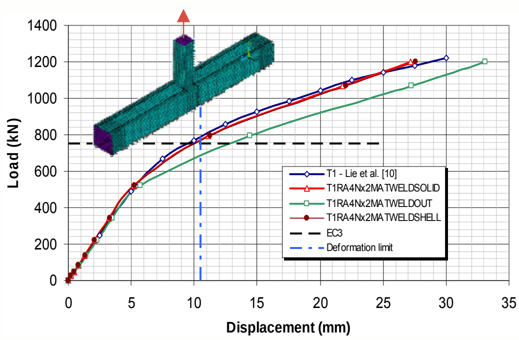
- Tubular joints → shell elements → mid-surfaces of the joint member walls
- Welds → three-dimensional solid or shell elements (Lee [11] and Van der Vegte [13])





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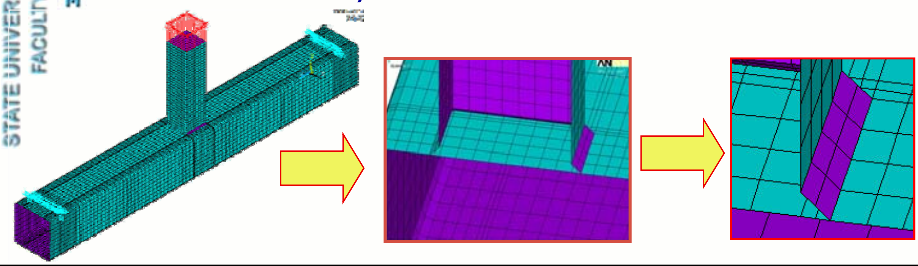
Numerical Model

- T joints → SHELL 181 → four-node thick shell elements → bending, shear and membrane deformations → Ansys 10.0
- Material (three-linear σ x ε relationship) and Geometrical Non-linearity (Updated Lagrangian Formulation)



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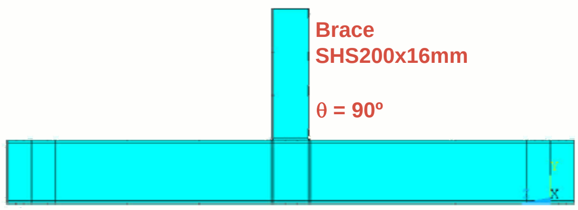
Numerical Model

- Considered T Joint → Lie *at al.* [12]



$$0.25 \le \beta = \frac{b_1}{b_0} = 0.57 \le 0.85 \qquad 10 \le b_1 / t_1 = 23.3 \le 35$$

$$\gamma = \frac{b_0}{2t_0} = 11.67 \qquad 10 \le b_0 / t_0 = 12.5 \le 35$$

Results Analysis and Discussion

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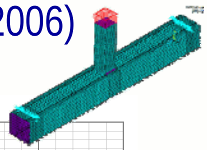
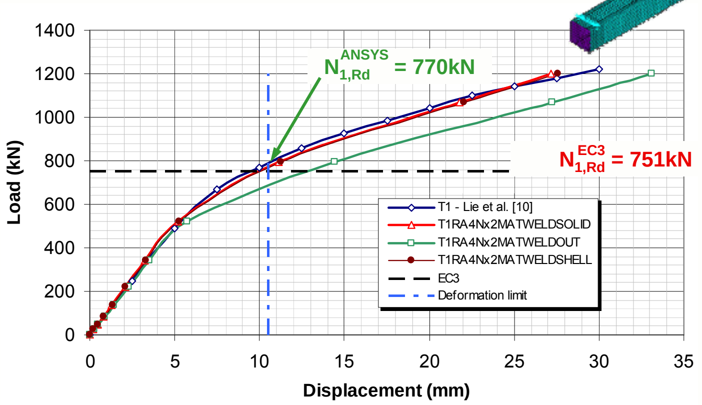
- T joints → Model Calibration → performed on SHS T-joints tested by Lie *et al.* (2006)





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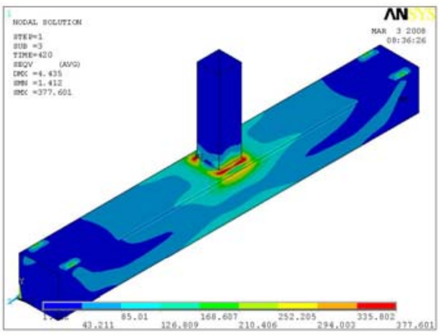
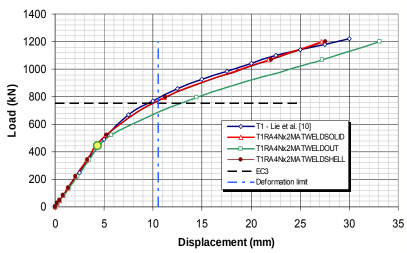
- Von Mises Stress (in MPa)





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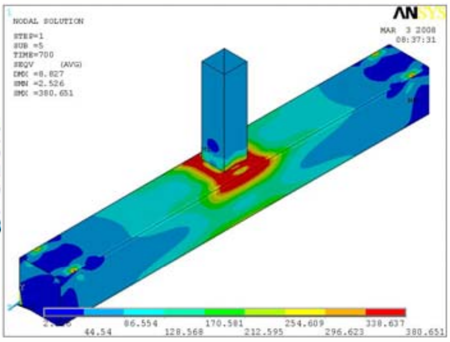
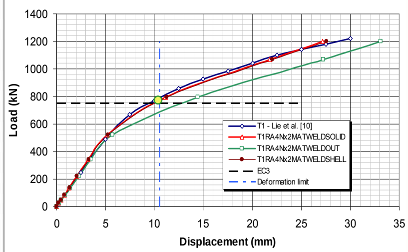
- Von Mises Stress (in MPa)





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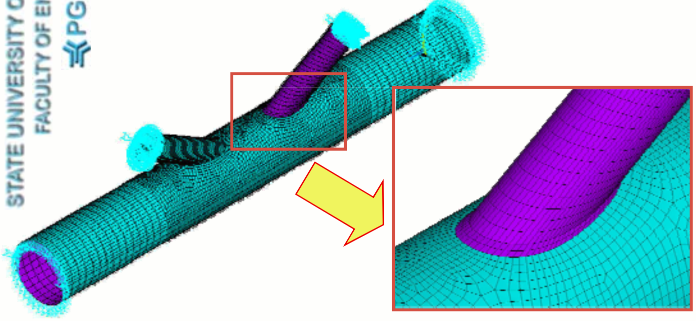
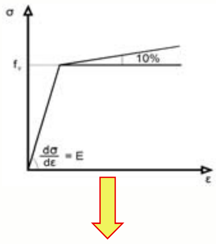
- K joints → also used SHELL181 (Ansys 10.0)
- Material (bi-linear σ x ε relationship – strain hardening) and Geometrical Non-linearity (Updated Lagrangean Formulation)





Best identification of yielded points in the joint

Numerical Model

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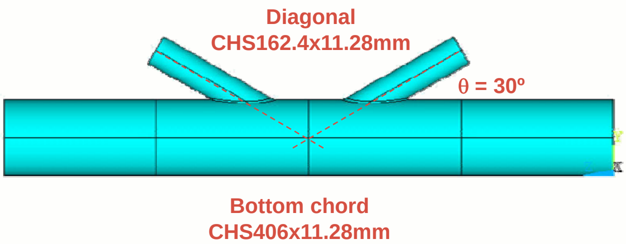
- Considered K Joint



$\beta = \frac{d_1}{d_0} = 0.40$	$10 < d_i / t_i = 14.4 < 50$
$\gamma = \frac{d_0}{2t_0} = 18 < 25$	$10 < d_0 / t_0 = 18 < 50$
	$0.2 < d_i / d_0 = 0.4 < 1.0$

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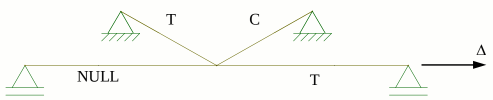
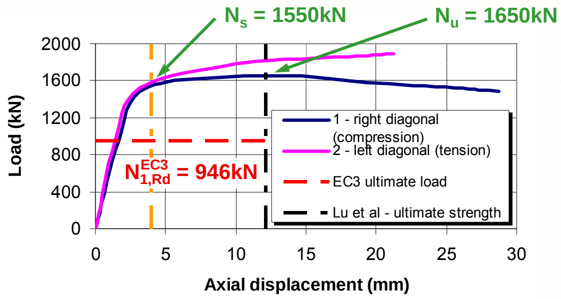
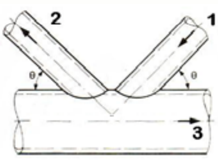
- Boundary conditions → according to Lee (1999)



- Model Calibration → performed comparing with EC3 formulation





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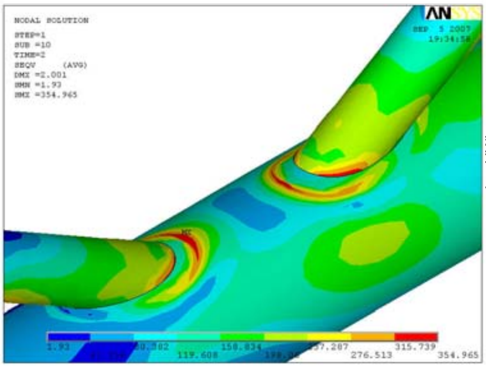
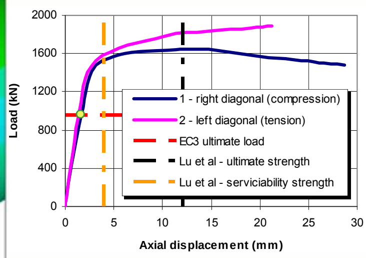
- Von Mises Stress (in MPa)





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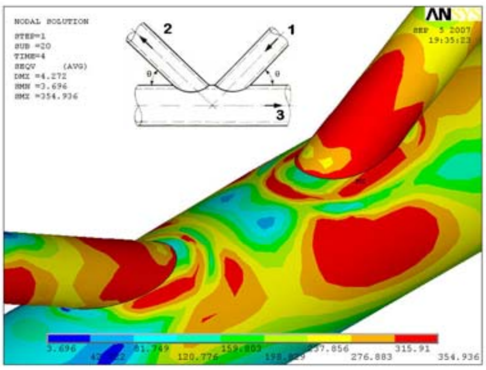
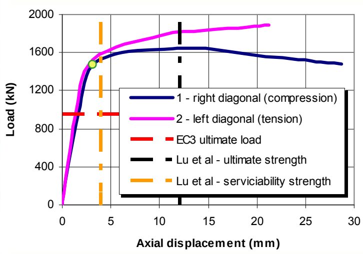
- Von Mises Stress (in MPa)





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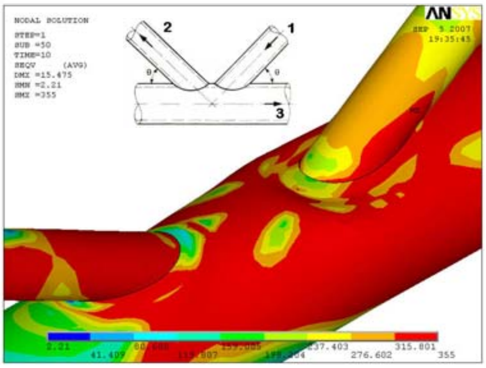
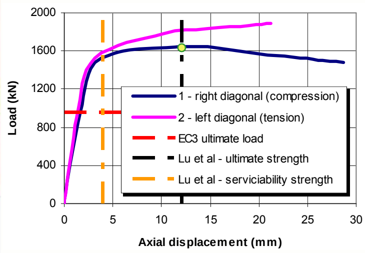
- Von Mises Stress (in MPa)





Scale factor = 2

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Parametrical Analysis

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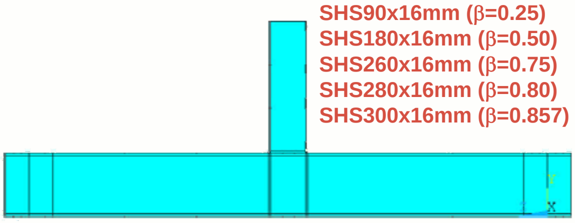
- T Joint

Braces:

SHS90x16mm (β=0.25)
SHS180x16mm (β=0.50)
SHS260x16mm (β=0.75)
SHS280x16mm (β=0.80)
SHS300x16mm (β=0.857)



Same bottom chord
SHS350x15mm

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Parametrical Analysis

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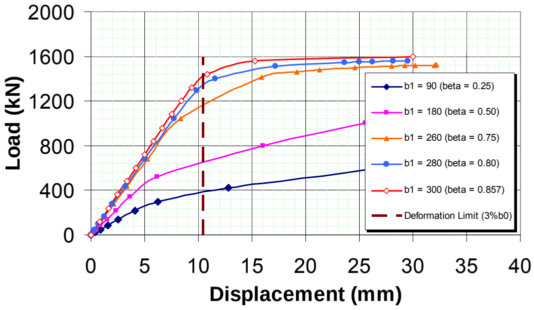
◆ T Joint



β	EC3 (kN)	Ansys (kN) – 3%b_0
0.25	456.8	400.0
0.50	672.3	668.0
0.57	751.0	770.0
0.75	1169.4	1168.0
0.80	1450.0	1302.0
0.86	1932.0	1440.0

As expected, increasing the value of β leads to a strong increase in the strength of the connection specially if β ≤ 0.75. However, if β ≥ 0.75, an increase of this parameter leads to an increase of strength with a magnitude much smaller than expected. This is due to the fact that for large values of β, the limit state related to bending does not control, while shear and punching shear begins to be the governing limit states.

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◆ K Joint

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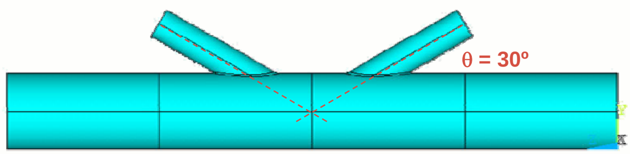
Diagonals:

CHS125x11.28mm (β=27)
CHS162x11.28mm (β=40)
CHS205x11.28mm (β=31.2)
CHS245x11.28mm (β=36)



Same bottom chord
CHS406x11.28mm

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Parametrical Analysis

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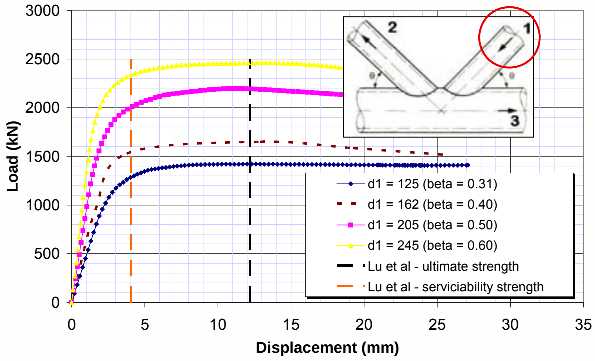
- K Joint



β	EC3 (kN)	Ansys (kN)	
		$1\%d_0$	$3\%d_0$
0.31	795	1316	1419
0.40	946	1600	1820
0.50	1118	2010	2306
0.60	1280	2341	2537

As expected, increasing the value of β leads to a substantial increase in the connection load carrying capacity. It may be observed that the joint resistance evaluated according to Eurocode 3 (2003) provisions represents a lower limit for the analysed joints.

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Final Remarks

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- FEM → T and K tubular joints → four-node thick shell elements → bending, shear and membrane deformations
- Deformation limits criteria were used to obtain the joint ultimate load
- The analysis results → assess the EN 1993-1-8 [4] performance
  - ✓ maximum load
  - ✓ global load versus displacement curves → fully joint structural response → stiffness and ductility capacity

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Final Remarks

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- Observing analytical curves → numerical results achieved a good agreement with the Eurocode 3 [4] previsions for the K joint resistance combined with a deformation limit criterion for the deformation of the joint chord face
- For T joints → with elevated β values → difference between numerical and EC3 results
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