A NUMERICAL EVALUATION OF CHS T JOINTS UNDER AXIAL LOADS

Raphael S. da Silva[a], Luciano R. O. de Lima[b], Pedro C. G. da S. Vellasco[b],
José G. S. da Silva[b] and Luis F. da C. Neves[c]

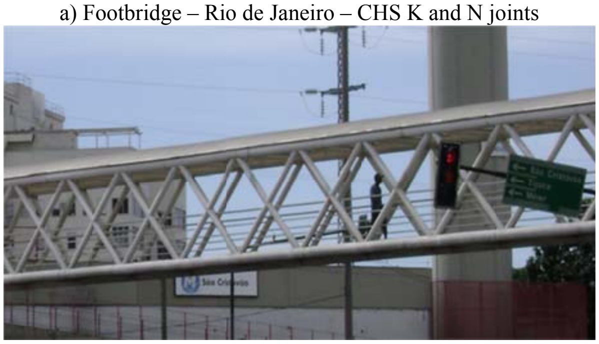
[a] PGECIV, Civil Engineering Post-Graduate Program, UERJ – State University of Rio de Janeiro, Brazil
[b] Structural Engineering Department, UERJ – State University of Rio de Janeiro, Brazil.
[c] Civil Engineering Department, ISISE - FCTUC –University of Coimbra, Portugal.

INTRODUCTION

The intensive worldwide use of tubular structural elements, such as the examples depicted in Figure 1, mainly due to its associated aesthetical and structural advantages, led designers to be focused on their technologic and design issues. Nowadays in Brazil, there is still a lack of code that deals specific with tubular joint design. This fact induces designers to use other international tubular joint design codes. Consequently, their design methods accuracy plays a fundamental role when economical and safety points of view are considered. Additionally, recent tubular joint studies indicate that further research is needed, especially for some particular geometries. This is even more significant for some failure modes where the collapse load predictions lead to unsafe or uneconomical solutions.

a) Footbridge – Rio de Janeiro – CHS K and N joints

b) V&M Office Building – Belo Horizonte – RHS/CHS joints



c) Footbridge – Rio de Janeiro – CHS K joints

d) Maria Lenk Aquatic Center – Rio de Janeiro – CHS T joints

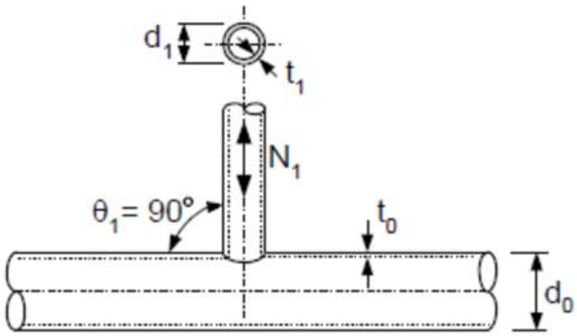
Fig. 1. Examples of structures using hollow sections in Brazil.

The first comprehensive investigation published in this area was made by Korol and Mirza [1] concerning a numerical model with shell elements and indicated a simultaneous increase of the joint resistance with the variable β and/or with the decrease of the variable γ. The authors also referred to the need for creating a deformation limit criteria for those connections.
Recently Lu et al. (cited in Kosteski et al. [2]), with results also validated and accepted by Zhao [3], established an approximate 3%d_0 deformation limit. This 3%d_0 limit is nowadays widely accepted and is also the value adopted by the International Institute of Welding (IIW) for the maximum acceptable displacement associate to the ultimate limit state while a 1%d_0 limit is adopted for the

service limit states. If the ratio of N_u/N_s is greater than 1.5, the joint strength should be based on the ultimate limit state, and if $N_u/N_s < 1.5$, the serviceability limit state controls the design. In the case of CHS joints, $N_u/N_s > 1.5$ and the appropriate deformation limit to be used to determine the ultimate joint strength should be equal to $0.03d_0$.
In this paper a numerical (i.e. non-linear FEM simulations) based on a parametric study is presented, for the analysis of T tubular joints where both chords and braces use circular hollow sections. The proposed model was validated by comparison to analytical results suggested by the Eurocode 3 [4], by the new CIDECT [5] and to literature classic deformation limits. The main variables of the present study were the brace diameter to chord diameter ratio and the thickness to chord face diameter ratio. These parameters were chosen based on recent studies results that indicated some Eurocode 3 rules discrepancies.

1 EUROCODE 3 AND CIDECT DESIGN CODES PROVISIONS

According to Eurocode 3 [4] and CIDECT [5], some geometrical limits need to be verified prior to the evaluation of the joint resistance. These limits are presented in Figure 2 where *d* and *t* represent, respectively, the tube diameter and thickness.



$$0.2 \le \beta = \frac{d_1}{d_0} \le 1.0 \tag{1}$$

$$2\gamma = \frac{d_{i,0}}{t_{i,0}} \le 50 \tag{2}$$

$$t_1 \le t_0 \tag{3}$$

Fig. 2. Geometrical properties of the CHS T joint in tension [2].

When CHS T joints are considered, some ultimate limit states should be verified. Despite this fact, the chord plastification controls the CHS T joint design in the majority of the cases. Eurocode 3 [4], expresses this ultimate limit state in eq. (4).

$$N_{1,Rd} = \frac{\gamma^{0.2} k_p f_{y0} t_0^2}{\sin\theta_1}\left(2.8 + 14.2\beta^2\right)/\gamma_{M5} \tag{4}$$

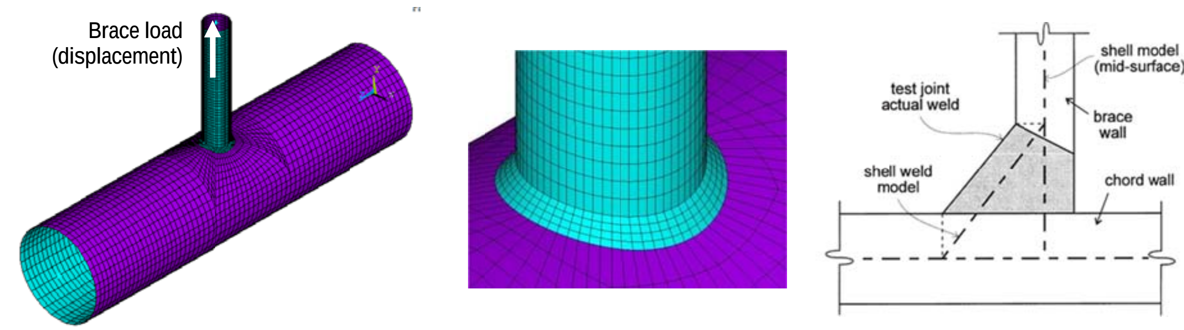
where $N_{1,Rd}$ is the chord face failure resistance,
γ is a geometrical parameter according to eq. (2),
k_p is taken equal to 1.0 for tension brace loads,
f_{y0} is the chord yield stress taken equal to 355MPa,
β is a geometrical parameter according to eq. (1),
γ_{M5} is the partial safety factor, in this case equal to 1.

The new joint strength equation (5) for chord plastification according to CIDECT [5] are expressed in terms of Q_u (influence of the parameters β and γ) and Q_f (influence of the parameter n). In these equations, the parameter C_1 is taken equal to 0.45-0.25β for chord compression stresses (n<0) and equal to 0.20 for chord tension stresses (n≥0). For the distinction with the formulae present in the previous edition, which are incorporated in various national and international codes, a slightly different presentation is used and presented below.

$$N_i^* = Q_u Q_f \frac{f_{y0} t_0^2}{\sin\theta_1} \quad \text{with} \quad Q_u = 2.6\left(1 + 6.8\beta^2\right)\gamma^{0.2} \quad , \quad Q_f = \left(1 - |n|\right)^{C_1} \quad \text{and} \quad n = \frac{N_0}{N_{pl,0}} + \frac{M_0}{M_{pl,0}} \tag{5}$$

2 NUMERICAL MODEL

The proposed numerical model adopted shell elements presented in the Ansys Element Library [6]. The model was developed using four-node thick shell elements (SHELL181), therefore considering bending, shear and membrane deformations. The finite element mesh was more refined near the weld, where the stress concentration is likely to happen, and the more regular as possible, with well-proportioned elements to avoid numerical problems. The welds were considered as shell elements according to Lee [11] – Figure 3(c). Figure 3(a) presents the general aspect of the developed finite element model. A full nonlinear analysis was performed considering material and geometrical nonlinearities. The adopted material presented a bilinear behaviour with no strain-hardening before failure with yield stresses of 355 MPa and 600 MPa for connected members and weld elements, respectively.



a) full model b) weld detail c) weld model after Lee [7]

Fig. 3. CHS T joint model.

A parametric study varying some geometrical parameters was performed to evaluate their influence in the connection resistance. Table 1 presents the variables used in the parametric study that totalized 15 simulations. It is important to emphasise that these combinations were chosen considering the limits imposed by the chord bending moment and brace normal plastic resistances. Three different profiles for the chord were used, 88.9x8, 298.5x25 and 660.0x60. For each chord, five braces were also chosen. The weld thickness was adopted as the minimum thickness of the plates to be connected. In this table are also presented the joints resistance considering the chord plastification failure according to Eurocode 3 [4] and CIDECT [5]. It is important to mention that, for all studied cases, the CIDECT resistance values were greater than the Eurocode 3 provisions.

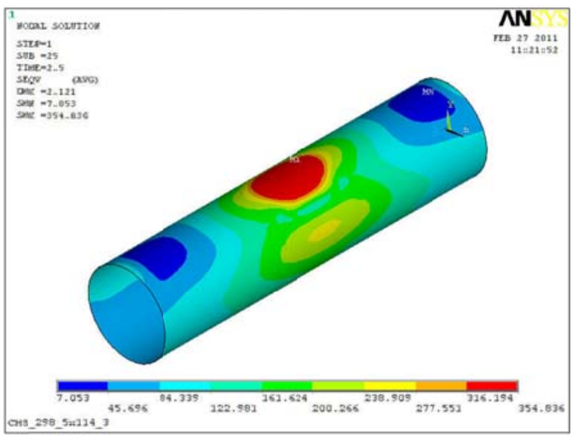
3 NUMERICAL RESULTS

As previously explained for this joint type, the ultimate limit state that governs the joint design is the chord plastification resistance. According to the deformation limit criteria of 3%d_0 [2], [3], for the studied joints, the chord out of plane displacement limits are equal to 2.7, 8.9 and 19.8 mm, respectively. In order to identify and confirm the initial assumptions regarding the ultimate limit state for CHS tubular joints, the joint between a 298.5x25 chord and a 114.3x16 brace was analyzed in terms of *Von Mises* stress distribution with its corresponding results presented in Figure 4. In this figure, it can be observed that the joint failure is controlled by the chord plastification and the Eurocode 3 and CIDECT resistances are less than the joint ultimate load. If the partial coefficient factor γ_{M5} was used, the joint design will lead to even more conservative limits. Figure 5 to 7 present the load *versus* displacement curves for all the investigated numerical models where the deformation limit criteria is marked in dashed lines. The application of this criteria (N_u and N_s) is summarized in Table 1. The conclusions will be presented in the next section of this paper.

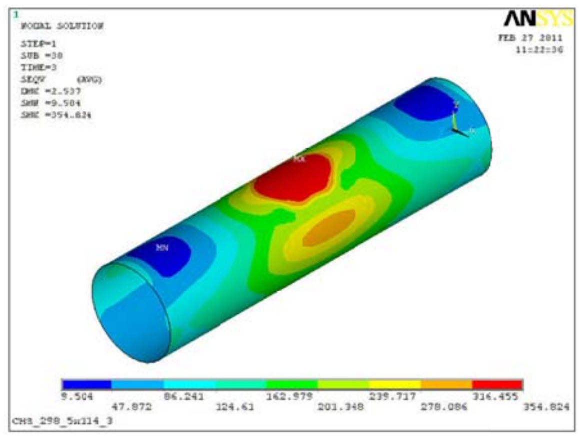
Table 1. Summary of the numerical models

Chord			Brace			$\beta = \frac{d_1}{d_0}$	$N_{1,Rd}$ (EC3)	N_i^* (CIDECT)	N_u (ANSYS)	N_s (ANSYS)	$\frac{N_{1,Rd}}{N^{[1]}}$	$\frac{N_i^*}{N}$
d_0	t_0	$\gamma=2d_0/t_0$	d_1	t_1	$\gamma=2d_1/t_1$							
88.9	8.0	5.56	33.7	6.3	2.67	0.38	154.9	164.5	185.8	187.7	0.86	0.94
			42.4	6.3	3.37	0.48	193.0	212.0	249.4	225.0	0.90	1.00
			48.3	6.3	3.83	0.54	223.8	250.3	293.0	249.8	0.91	1.03
			51.0	6.3	4.05	0.57	239.2	269.5	308.9	261.5	0.99	1.14
			60.3	6.3	4.79	0.68	298.8	343.6	344.6	300.8	0.95	1.02
298.5	25.0	5.97	114.3	16.0	3.57	0.38	1548.4	1646.8	1697.5	1622.2	1.00	1.10
			139.7	16.0	4.37	0.47	1874.6	2052.9	2163.0	1870.2	1.05	1.17
			159.0	16.0	4.97	0.53	2166.0	2415.7	2521.4	2056.9	1.08	1.21
			168.3	16.0	5.26	0.56	2319.8	2607.3	2695.9	2147.7	1.16	1.33
			193.7	16.0	6.05	0.65	2784.6	3185.9	3024.0	2397.5	0.86	0.94
660.0	60.0	5.50	244.5	40.0	3.06	0.37	8534.6	9033.4	9027.4	8762.3	0.97	1.03
			323.9	40.0	4.05	0.49	11178.7	12325.5	12314.6	12315.8	0.91	1.00
			355.6	40.0	4.45	0.54	12440.6	13896.8	13492.0	13739.6	0.91	1.01
			368.0	40.0	4.60	0.56	12966.3	14551.3	13937.2	14297.8	0.91	1.02
			457.0	40.0	5.71	0.69	17268.1	19907.3	16962.8	18325.0	0.94	1.09

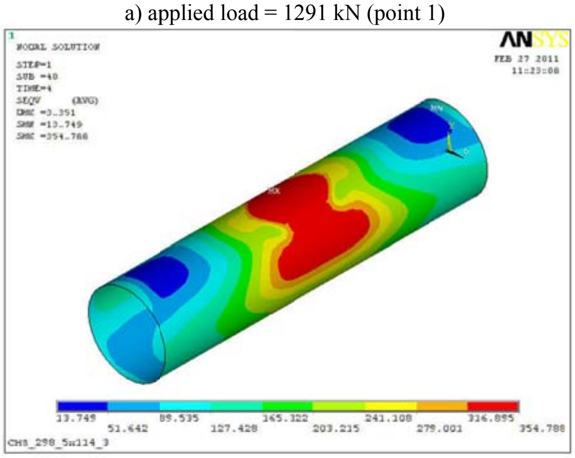
[1] If $N_u/N_s > 1.5$ then $N = N_u$ else $N = N_s$
dimensions [mm] and loads [kN]



a) applied load = 1291 kN (point 1)



b) applied load = 1475 kN (point 2)



c) applied load = 1697 kN (point 3)

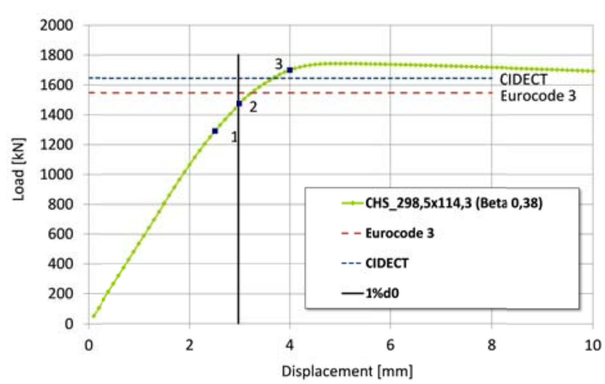


Fig. 4. CHS 298.5x25 with 114.3x16 – *Von Mises* stress distribution

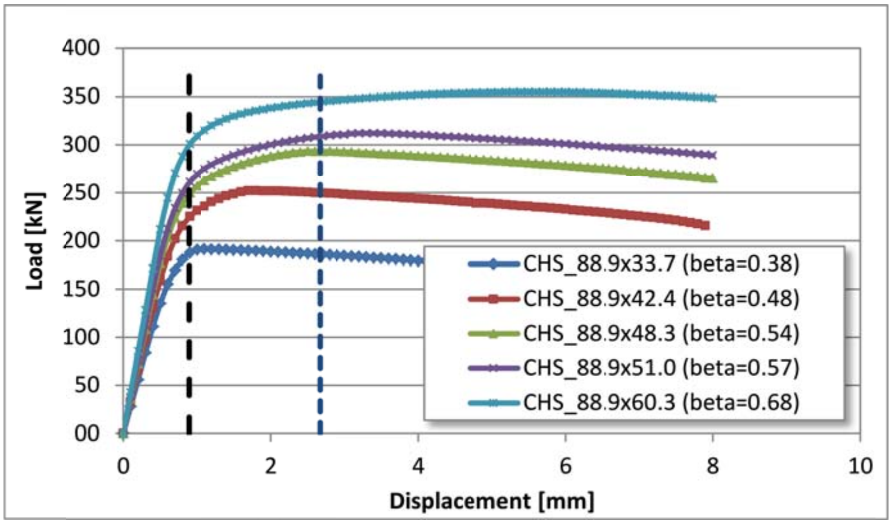


Fig. 5. CHS 88.9 chord – *loads* versus *displacement curves*

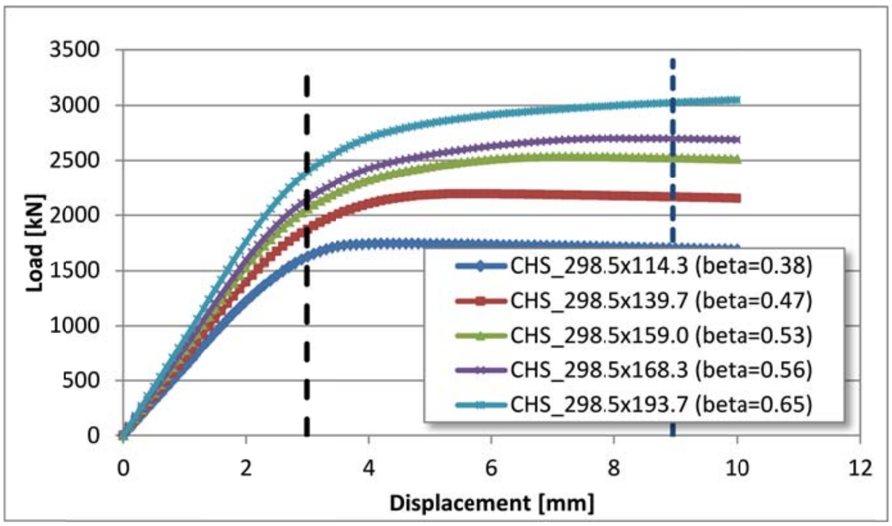


Fig. 6. CHS 298.5 chord – *loads* versus *displacement curves*

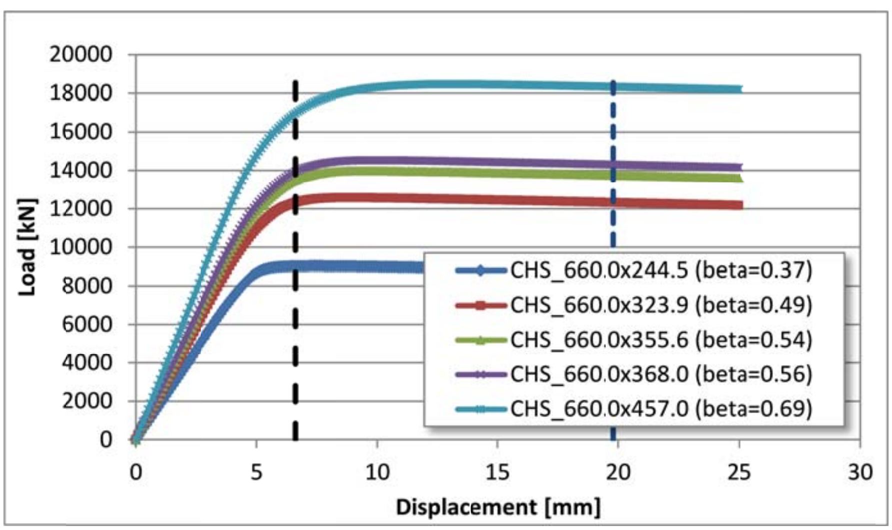


Fig. 7. CHS 660.0 chord – *loads* versus *displacement curves*

4 FINAL REMARKS

This paper presented an Ansys numerical study of CHS T tubular joints subjected to tensioned braces. Three data set were considered keeping the same variation for the β parameter. These sets considered chords with small, medium and large diameter according to V&M profile table[8]. The numerical results were compared to analytical results proposed by Eurocode 3 [4] and CIDECT [5] recommendations. It is important to emphasise that for this joint type, the Eurocode 3 results were more conservative when compared with the CIDECT results.

Figures 5 to 7 indicate that when the parameter β increase, the joints resistances also increase according to eq. (4) and (5). It could also be observed that the parameter γ also contributed to the joint resistance increase. The ultimate limit state for this joint type was the chord plastification according to the Eurocode 3 [4], CIDECT [5] and to the numerical results.

For the first and third set of joints, according to the observation of Table 1, the numerical resistances obtained from the deformation limit criteria were higher than the Eurocode 3 provisions evidencing the code safety. For these same set of joints, some cases presented a ratio higher than 1.00 when CIDECT recommendations were used. For the second set of joints, both Eurocode 3 and CIDECT recommendations provided higher resistances than the numerical analysis indicating an unsafe design.

5 ACKNOLEDGMENTS

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