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Influence of shear lag coefficienton circular hollow sections with bolted sleeve connections

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Abstract

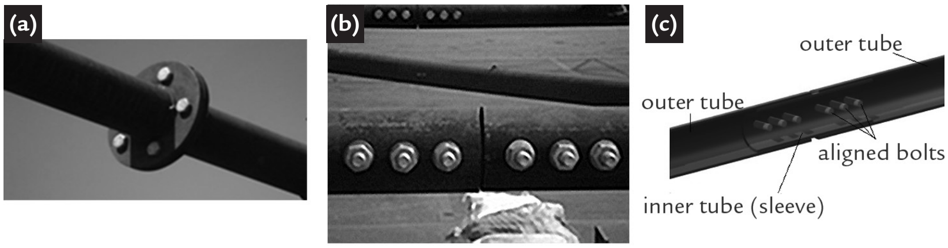
The circular hollow sections (CHS) are being widely employed in steel structures around the world, increasing the development of new researches. This article proposes an innovative connection model for circular hollow sections that facilitates and reduces the assembly cost of hollow section structures. The proposed connection is a tube sleeve, used to splice two tubes, composed of an inner tube with a diameter smaller than the connecting tubes, which is connected to the outer tubes by bolts passing through both tubes. This connection can be a cheaper and easier alternative to flange connections, which are widely used in large span tubular trusses. The connection was tested in laboratory under tension loading. The tests made it possible to identify the influence of stress distribution on tubes and the need for the use of a shear lag coefficient. The results of the ultimate load capacity demonstrated the viability of the tube sleeve connection use.

Keywords: steel structures, circular hollow sections, connections and bolt connection.

1. Introduction

Steel tubular structural sections allow a higher load capacity for axial force, and torsion as well as for combined effects. Recommendations for the use of circular hollow sections are generally based on CIDECT (2008). Many researches have been performed in order to develop new techniques and propose solutions for the proper use of these sections as seen in works done by Munse and Chesson (1963), Beke and Kvocak (2008), Martinez-Saucedo and Packer (2009), Freitas and Requena (2009), and others.

Square hollow sections (SHS), rectangular hollow sections (RHS), and circular hollow sections (CHS) are the tubular sections found in the market. This article deals with steel CHS submitted to tensile force with bolted connections. The connection is studied for use in a truss system. Differently from the tubular sections with flange studied by McGuire (1968), shown in Figure 1(a), the continuity of the profile is by a sleeve connection, which presents a much more elegant appearance and allows the use of standardized elements, as shown in Figure 1 (b). This new type of connection has been studied by Vieira *et al.* (2011), Silva (2012) and Amparo (2014), Amparo *et al.* (2014).



Flange connection (Vieira, 2011); Sleeve connection (Vieira, 2011); Sleeve connection scheme.

Figure 1
Tubular connections.

The sleeve connection is constituted by two tubes of the same diameter (outer tubes) connected by another tube with smaller diameter and bolts (inner tube), Figure 1 (c). This type of connections transfers the loading from the tube by its contact with the bolt. This characteristic shows the presence of the shear lag coefficient indicated by the high stress concentration on the region of the cross-section area with holes. This work shows one study about the influence of the shear lag coefficient in CHS with sleeve connection.

2. Materials and methods

To represent the connection, the prototypes are formed by an outer tube and an inner tube (sleeve) with aligned and crossed bolts. The prototypes were tested under tension in a controlled servo-hydraulic press with 200kN of capacity. An LVDT (Linear Variational Displacement Transducer) and strain gauges were used for the test instrumentation. Figure 2 shows the general scheme of the experiment.The displacement rate used was set to 0.4 mm/min.

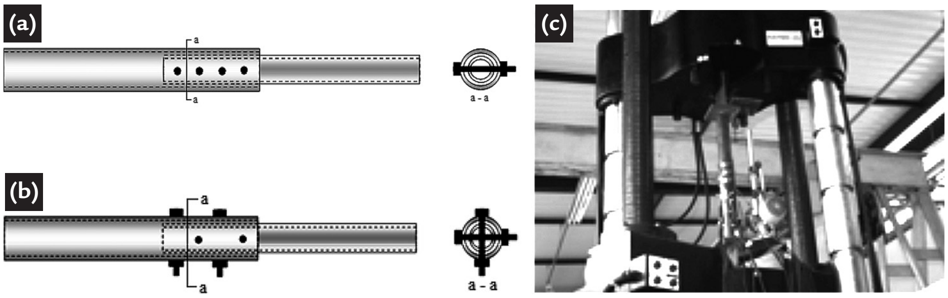


Figure 2
Scheme of the prototypes and the experiment: (a) aligned bolts; (b) crossed bolts; (c) prototype in the servo-hydraulic press.

The prototypes have geometric property variations: thickness and diameter. Therefore they were separated into 3 groups, as shown in Table 1. Each group had a variation in the number of bolts. Group A has prototypes with staggered bolts and groups B and C are prototypes with crossed bolts. X and Y is the steel resistance of outer and inner tube, respectively.

Group	Prototypes identification	Prototypes Numbers	Bolts Numbers	Outer tube				Inner tube			
				Diameter (mm)	Thickness (mm)	Steel Resistance		Diameter (mm)	Thickness (mm)	Steel Resistance	
						yielding	ultimate			yielding	ultimate
						f_y (MPa)	f_u (MPa)			f_y (MPa)	f_u (MPa)
A	LA-3-X3Y2	1	3	73.0	5.5	399.5	539.5	60.3	5.5	381.0	479.0
A	LA-4-X3Y2	2	4	73.0	5.5	399.5	539.5	60.3	5.5	381.0	479.0
B	CB-3-X2Y3	4	3	76.1	3.6	386.0	545.0	60.3	3.6	424.0	535.0
B	CB-4-X2Y3	3	4	76.1	3.6	386.0	545.0	60.3	3.6	424.0	535.0
C	CC-5-X2Y3	2	5	88.9	5.5	375.0	474.0	73.0	5.5	399.5	539.5

Table 1
Identification of the groupof prototypes.

After experimental analysis, it was observed that in some prototypes, the bolts showed a flexural mode. In some cases the limit state of bolt bending is dominant, and not the yielding of the gross section nor the fracture through the effective net area, group A. More details are shown in Amparo *et al.* (2014) and Amparo (2014), including one expression for the bolt bending failure.

The gross area and net area were calculated considering the tubular section as a rectangular prismatic bar (rectangular plate). The net area is calculated according to the scheme shown in Figure 3 (a) and (b); the figure also shows the possible fracture lines for the two configurations of the connection. The cross-sections analyzed are identifiedas 1-1, 2-2 or 3-3. This adaptation can be found in Amparo (2014).

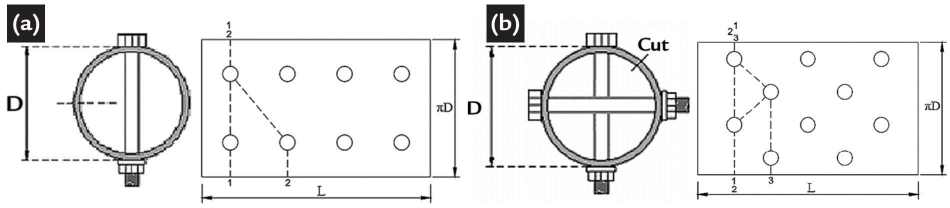


Figure 3
Configurations used to calculate the gross area and the net area, (a) aligned bolts and (b) crossed bolts.

The effective net area (A_e) is calculated according to Equation 1:

$$A_e = C_t A_n \quad (1)$$

The value considered for the shear lag coefficient (C_t) was equal to 1.0 for the calculation of theoretical values.

Table 2 shows the expressions used to calculate the failure modes and the theoretical values adapted according to Brazilian code ABNT NBR:2008, using Ae as shown in Equation 1. The failure modes werethe yielding of the gross section (Y.G.S. - N_t), the fracture through the effective net area (F.N.A. - N_t), and the shear failure of bolt (S.B. - F_v).

Modes of failure	Equation
Y.G.S.	$N_t = A_g f_y$
F.N.A.	$N_t = A_e f_u$
S.B.	$F_v = 0{,}4\, A_b f_{ub}$

A_g is the gross area; f_y is the yielding resistance;

A_e is the effective net area;

A_n is the net area; f_u is the ultimate resistance;

A_b is the bolt gross area;

f_{ub} is the ultimate resistance of the bolt.

Prototype	Modes of failure		
	Y.G.S.	F.N.A.	S.B.
	N_t (kN)	N_t (kN)	F_s (kN)
LA-3-X3Y2	360.8	378.2	313.5
LA-4-X3Y2	360.8	378.2	418.0
CB-3-X2Y3	271.9	259.3	313.5
CB-4-X2Y3	271.9	259.3	418.0
CC-5-X2Y3	466.0	498.0	522.5

Table 2
Equations of modes of failure and theoretical values according to ABNT (2008).

3. Results and discussion

Table 3 shows the experimental maximum load capacity and the average load of the experimental maximum load capacity for all of the prototypes of each group.

Prototype	Experimental maximum load capacity (kN)				Average load (kN)
LA-3-X3Y2	425.7				440.4
LA-4-X3Y2	448.7		446.9		
CB-3-X2Y3	247.1	248.6	241.6	250.8	244.5
CB-4-X2Y3	244.2	232.8		246.4	
CC-5-X2Y3	400.7		425.3		413.0

Table 3
Experimental maximum load capacity.

The Figure 4 shows the curves of tension load (P) versus displacement for 3 prototypes of the group A. It was possible to observe that the load capacity of these prototypes was above the theoretical yielding gross section and the fracture through the effective net area (Table 2). The theoretical values of group A use the shear lag coefficient C_t equal 1.0.

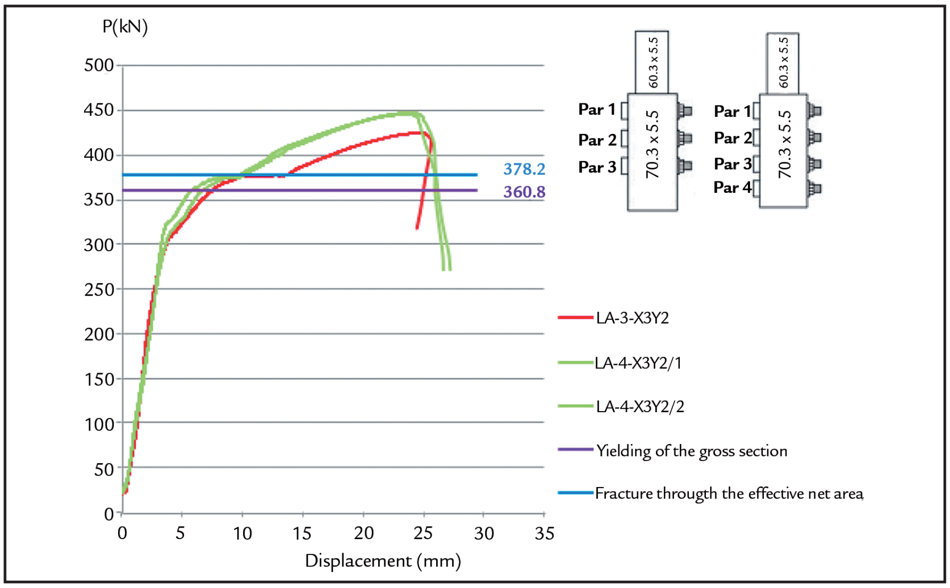


Figure 4
Curves of tension load (P) versus displacement, prototypes of group A.

The average load corresponding to the fracture of the prototypes of the group A was 440.4kN (Table 3), 16.45% higher than the expected theoretical value (Table 2). Changes in the experimental curve slopes characterize the different failure modes. In this group, the bending in bolts was the first failure mode of the connection, observed experimentally.

In the prototypes of the groups B and C, which have a sleeve connection with crossed bolts, the experimental load failure mode in the net area had a lower value than the theoretical load, as shown in Figure 5(a) and (b). Figure 5 shows the curves of tension load (P) versus displacement for the prototypes of groups B and C, respectively.

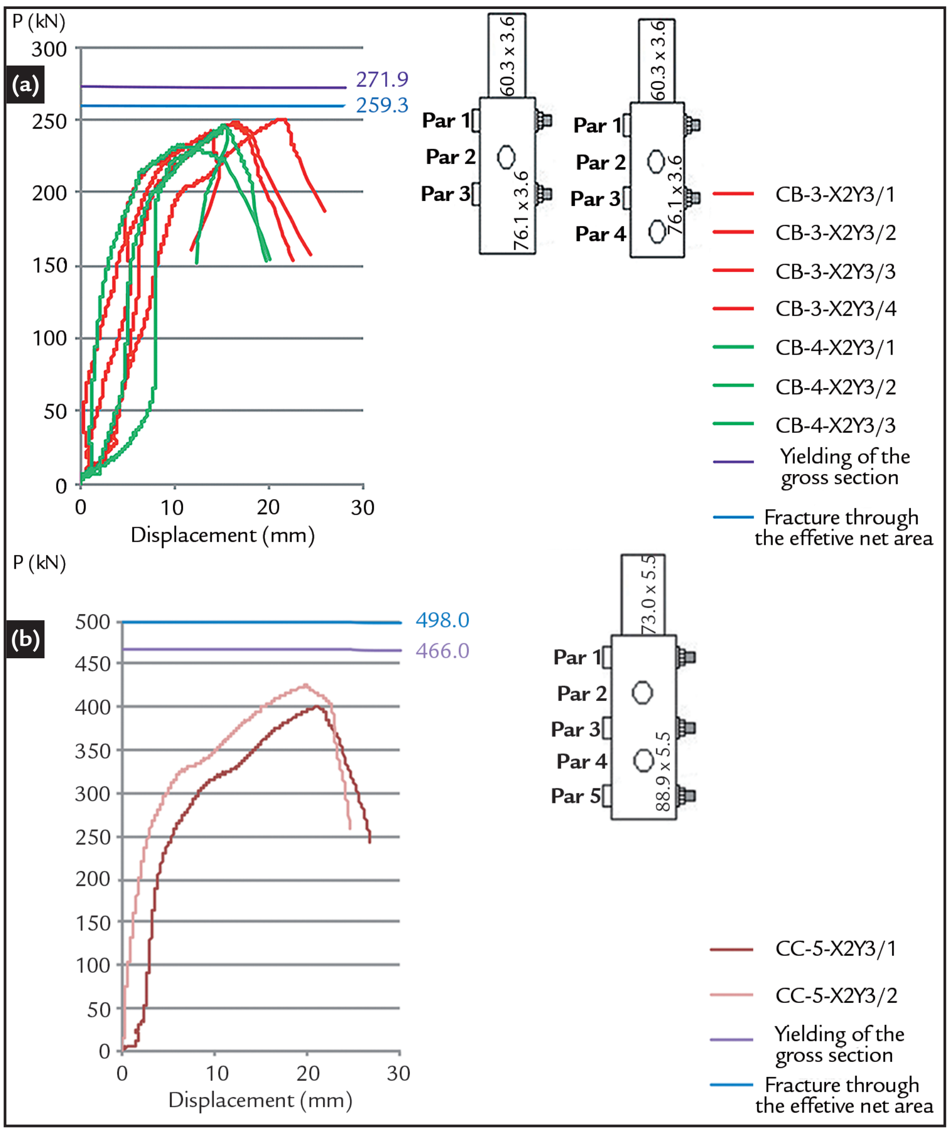


Figure 5
Curves of tension load (P) versus displacement: (a) prototypes of group B;(b)prototypes of group C.

The prototypes of the group B had the average load value corresponding to the fracture equal to 244.5kN (Table 3). This value is 10.08% lower than the expected theoretical value (Table 2). Meanwhile, for the prototypes of group C, the average load value corresponding to the fracture was equal to 413.0kN (Table 3), 17.07% lower than the expected theoretical value.

The prototypes of groups B and C had a different behaviour compared with the prototypes of group A; all experimental curves of tension load (P) versus displacement were below the theoretical values. In these prototypes, the value 1.0 was used as the shear lag coefficient. So, it is necessary to adopt a value that reduces the net area of the effective net area, improving the results.

The international standards do not provide a shear lag coefficient for this type of connection given by the eq. (2). This equation was proposed by AISC (2005) and ABNT NBR 8800:2008 for a slotted tube connected to a gusset plate, (Figure 6), adapted to sleeve connections. Table 4 shows the experimental shear lag coefficient determined by dividing the average value for the experimental load corresponding to the fracture by the net area and the ultimate stress of the inner tube (tube where the fracture occurred).

$$C_t = 1 - \frac{e_c}{l_c} \qquad (2)$$

where: C_t is the shear lag coefficient, e_c is the connection eccentricity, l_c is the length of connection.

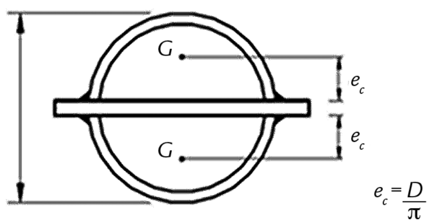


Figure 6
Representation of value e_c in tubular section.

Table 4
Shear lag coefficients (C_t).

Prototypes	Number of bolts	Experimental C_t	C_t by NBR
CB	3	0.909	0.760
	4	0.887	0.840
CC	5	0.829	0.855

The prototypes with crossed bolts do not have a geometric configuration equal to the model presented by ABNT NBR 8800:2008 (Figure 3 (b) and Figure 6). Consequently, the stress distribution is different in these prototypes. This fact could explain the differences shown in Table 4 between the experimental C_t and the C_t by NBR. However, the use of the equation proposed by AISC (2005) and ABNT NBR 8800 (2008) provides conservative results and therefore is reliable.

4. Conclusions

The goal of this work was perform theoretical and experimental evaluations of the influence of the shear lag coefficient on the new connection known as sleeve connection. This connection is constituted by steel hollow sections, and the prototypes were formed by two tubes, the outer tube and the inner tube, connected with aligned bolts or crossed bolts in 90º. The inner tube represented the sleeve.

The theoretical analysis of the modes of failure was based according to ABNT NBR 8800:2008, and the consideration of the shear lag coefficient (*Ct*) was based on the equation proposed by AISC (2005) and NBR.

The methodology used in the experiments was adequate to evaluate the new connection. For group A, the experimental results were good and showed high capacity load resistance, while the flexural failure mode was dominant, and the C_t=1.0. It was observed that the fracture through the net area, in the prototypes with crossed bolts, needs to consider a coefficient that reduces this net area to an effective net area, since the fractures occurred at levels below the load stipulated as standard.

The international and national standards do not yet include the sleeve connections. The results and the analyses proved the need and suitability of a formulation for the calculation of the shear lag coefficient for crossed bolts. Thus, an equation based in AISC/NBR to calculate the C_t, was proposed. The results showed good correlation with the experimental results.

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