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NUMERICAL ANALYSIS OF CHS BOLTED SLEEVE CONNECTIONS

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INTRODUCTION

Steel tubular sections, with high strength-to-weight ratio, provide versatile, economical solutions along with a modern aesthetic appearance. The tubular geometry allows a higher load capacity for axial and transverse forces, as well as for torsion and combined effects. These components can cover larger spans, reducing the number of pillars needed. They also allow high precision planning, reducing construction time, maintenance and management costs. As a result of all this advantages, the use of steel tubular sections has increased greatly.

The tubular structural sections commonly found in the market include square hollow sections (SHS), rectangular hollow sections (RHS), and circular hollow sections (CHS), all constituted of high strength steel with Young's moduli near 350 MPa. Structures with great visual impact often rely on these components, some notable examples include airport terminals, shopping centers, bank branches, convention centers, parks, gyms and others. The ability to create large projects where visible tubular structural sections add to the aesthetic appeal greatly add to the creative possibilities available to architects.

The design of connections between tubular sections, a major factor in the cost of works, is of fundamental importance, and, as such, deserves special attention. Commercial software programs are sometimes suitable for these calculations, but tube dimensions may vary based on the rules and/or recommendations North American or European, which are presented in Eurocode 3 [1] Packer and Henderson (1997) [2], CIDECT (1992) [3] and [4] or Rautaruukki (1998) [5] . Tubular sections with flanges, while widely studied by McGuire (1968) [6], Cao & Packer (1997) [7] Packer & Henderson (1997) [1], Santos (2003) [8] and others, shown in *Fig. 1*, can present an undesirable visual effect by breaking the continuity of the profile. A better solution utilizes a sleeve connection shown in *Fig. 2*, which preserves a much more elegant appearance. The slack in these connections serves to facilitate the assembly of parts, because they present longer lengths with several holes that can fit perfectly to allow for the placement of the bolts.

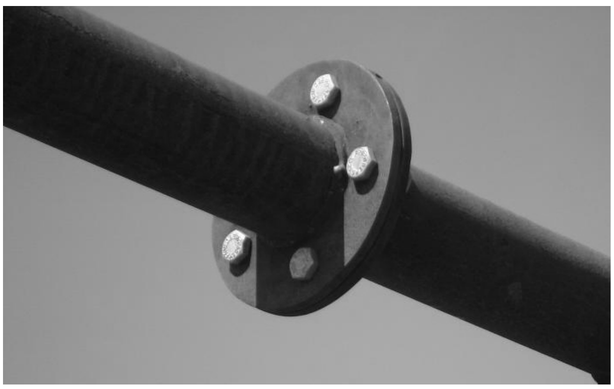

Fig. 1. Flange connection

Fig.2. Tube sleeve connection

The connection between tubular sections using circular inner sleeves with slack for aligned bolts has not yet received the scientific study required for safe design. This work attempts to fill this gap in the literature with a finite-element analysis of this connection. Included is a determination of the shear lag coefficient, which, due to stress concentration, indicates how the cross-sectional area, minus the holes, participates in the transmission of axial traction. Thus, studying sleeve connections between tubular sections can help replace flange connections, leading to lower-cost tubular structures with uninterrupted esthetic profiles. The slack between the tubular sections and the inner sleeve allows for a better fit between the parts to be connected.

1 NUMERICAL ANALYSES

Sleeve connection numerical analyses were performed using the Ansys v10.0 (2005) [9] finite element software. Two numerical models were defined, one with a total of six bolts and other with eight. Due to symmetry considerations, only the inner tube and one outer tube needed to be modeled, with half the number of bolts.

1.1 Finite elements

Solid finite elements were employed to model the tubes and bolts, and contact elements were used to simulate the interfaces between them. SOLID186, a 3-D solid element defined by 20 nodes with translational degrees of freedom in the X, Y and Z directions for each node, was chosen for this purpose, as illustrated in *Fig. 3*. To simulate the contacts between tubes and bolts, 3-D elements TARGE170 and CONTA174 were used in concert, according to *Fig. 4* and *Fig. 5*. These elements had eight nodes, also with three degrees of freedom per node.

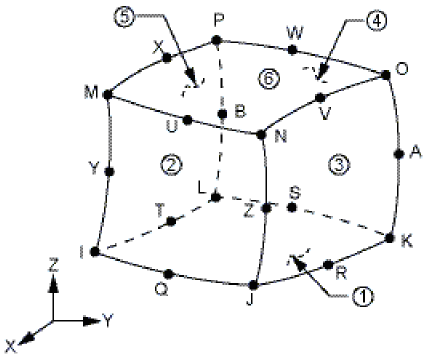

Fig. 3. SOLID186 element

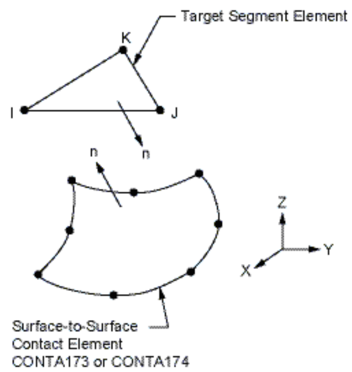

Fig. 4. TARGE170 element

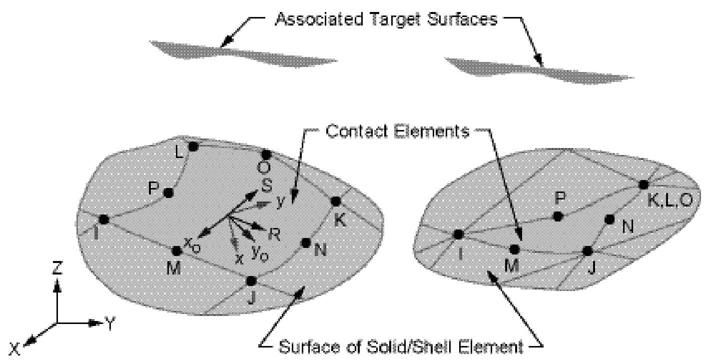

Fig. 5. CONTA174 element

1.2 Materials

Two types of steel were considered, one for the tubes and another for the bolts. Since the strain responses of the materials were taken to be nonlinear, bilinear stress-strain curves were used, with an assumed Young's modulus of 200000 MPa. The stress and strain values utilized are presented in *Table 1*.

Table 1. Materials

	Yielding		Ultimate	
Material	Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
Tubes	300	0.1500	415	11.0000
Bolts	635	0.3175	825	11.0000

At this point, only the numerical analyses of the connection were done, and tension tests for the proposed materials were not preformed. Instead, nominal tension values were adopted. Similarly, the ultimate strain value of 11% was used, since, following Yu (1924) [10], this deformation varies from 10 to 30%.

1.3 Numerical models

The tube and bolt dimensions used in both models can be found in *Table 2*. Since the two models differed in the number of bolts, the lengths were adjusted accordingly to allow for equal spacing between holes. For the model with three bolts (that is, six, using symmetry), the length of the inner and outer tubes was 285 mm, while for the model with four bolts, the tube length was 342 mm.

Table 2. Tube and bolt dimensions

Outer tube	Inner tube	Bolt diameter	Hole diameter	Distance between holes and between a hole and edge
60.3 x 3.6 mm	51 x 4.75 mm	19 mm	20.5 mm	57 mm

The bolts were modeled with two heads, one at each end, simulating the presence of a nut. As the hole diameter was larger than the bolt diameter, the gap allows the inner tube and bolts to shift until all parts are in contact. To simplify the model, the inner tube and the bolts were previously moved, eliminating the gap. *Fig. 6-8* show all sleeve connection components.

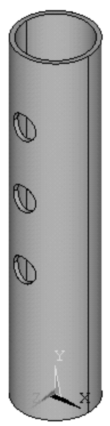

Fig. 6. Outer tube

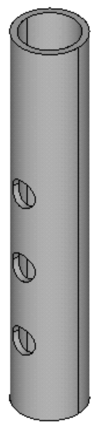

Fig. 7. Inner tube

Contact elements were placed between each bolt body and inner and outer tubes, as well as between the walls of the outer tube and bolt head, as shown in *Fig. 9*.

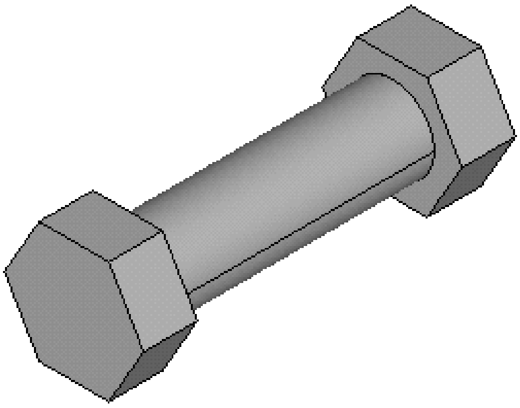

Fig. 8. Bolt

Fig. 9. Contact between bolts and tubes

The boundary conditions of both numerical models were the same. Node translations below the bottom of the outer tube were prevented, while at the top of the inner tube, translations in the X and Z directions were prevented, while allowing vertical displacement in Y direction. At the inner tube top surface, a tension pressure of 300 N/mm² was applied in the Y direction, and the nodes of this area were coupled. The analyses were performed for large displacements and the pressure was increased in steps of 5 N/mm².

2 RESULTS

The von Mises stresses obtained for the final converging load step for the models with three and four bolts can be seen in *Fig. 10* and *Fig. 11*, respectively. In both cases, collapse occurred in the outer tube due to the rupture of the net area around the bottom bolt.

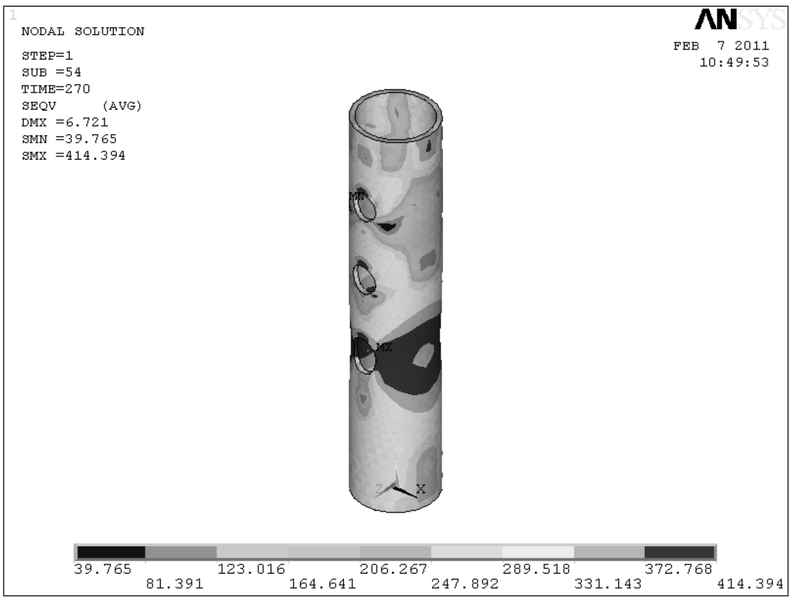

Fig. 10. Three-bolt model von Mises stresses

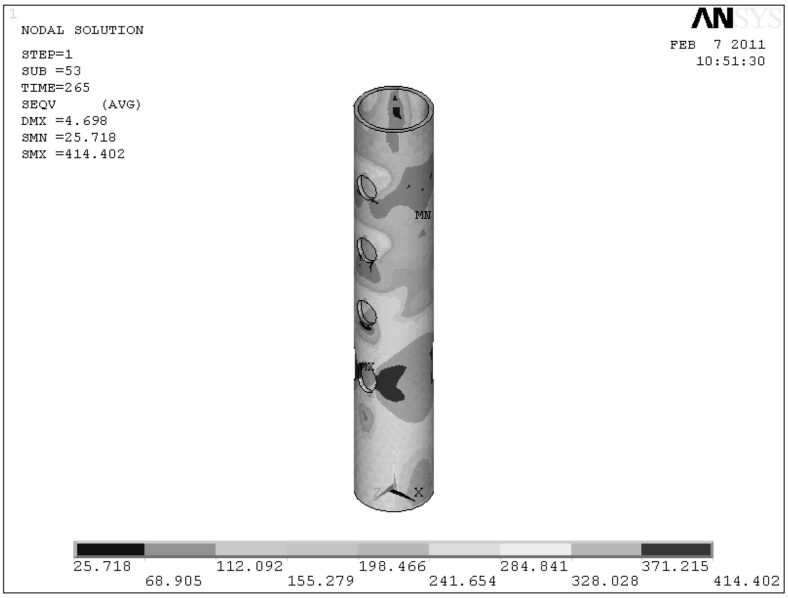

Fig. 11. Four-bolt model von Mises stresses

The tension pressure values for the final converging load step were, respectively, 270 N/mm² and 265 N/mm². For these loads the model with three bolts showed a maximum von Mises stress of 414.39 MPa and a maximum von Mises strain of 58.7%. For the model with four bolts, the maximum stress was 414.40 MPa and the maximum strain was 41.7%. It should be noted that the von Mises strains were far above the 11% value associated with the ultimate strain defined for the outer tube, indicating that the collapse of the connection occurred when the von Mises strain exceeded the 11% threshold, before the final converging load step. The results for the load steps with a von Mises strain immediately above the ultimate strain can be found in *Table 3*.

Table 3. Numerical Results

Model	Load step (N/mm²)	Tension resistance force (N)	Outer tube maximum stress (MPa)	Outer tube maximum strain (%)
3 bolts	210	144935.7	391.9	11.7
4 bolts	240	165640.8	409.9	14.2

The tension values were used to determine a shear lag coefficient (*Table 4*) by dividing the force by the net area and the ultimate stress of the outer tube. The international standards do not provide a formula for calculating the shear lag coefficient for this type of connection; an analogous formulation, *Eq. (1)*, was proposed by AISC (2005) [11] and studied by Willibald et al (2004) [12], Saucedo et al (2009) [13], and Cheng et al (2000) [14] for a circular hollow section with a single concentric gusset plate. By way of comparison, the shear lag coefficient calculated using the AISC methodology is included in *Table 4*.

$$U = 1 - \frac{\bar{x}}{l} \tag{1}$$

where U is the shear lag coefficient,
$\bar{x}$ is the connection eccentricity,
l is the length of connection.

Table 4. Shear lag coefficients

Model	AISC	Ansys	Difference (%)
3 bolts	0.832	0.707	15.02
4 bolts	0.888	0.809	8.90

3 CONSIDERATIONS

The results obtained with Ansys v.10 (2005) [9] for the present work showed the suitability of both numerical models, allowing the collapse mode to be identified at the net area of the outer tube. In addition, the obtained tension resistance forces demonstrated the existence of the shear lag coefficients for this type of connection. While international standards do not yet include sleeve connections, the shear lag coefficients found in this study were compared to those obtained by the formulation of AISC (2005) [11] for a similar connection with gusset plate. However, since the coefficients found in the numerical analyses differed somewhat those obtained by the standard method, the AISC alone should not be relied on for sleeve connections. Thus, there is the need to develop a specific formulation to determine the shear lag coefficient for bolted tube sleeve connections. For this, further analyses will be carried out varying parameters such as the number and diameter of bolts, as well as the thickness and diameter of the tubes. Experimental analyses will also be made for some tube sleeve connections to compare with the numerical results. The ultimate goal of these numerical and experimental investigations will be the development of a specific formulation to assess bolted tube sleeve connections.

4 ACKNOWLEDGMENTS

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