Numerical analysis of circular hollow section bar with stiffened flattened ends

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Abstract. Circular hollow sections are usually used in long-span roof truss systems. One of the typology for connecting elements in such structures involves the flattening of bar ends, in order to provide a simpler and more economical connection. A new flattening typology called stiffened flattening is proposed, characterized by a non-flat geometry. A study was carried out on the behavior of a plane truss composed of circular hollow sections, in which diagonal bars have stiffened flattening ends. This work presents the numerical analysis of an isolated circular hollow section bar with stiffened flattening ends under compression, which is like to the most requested diagonal of the truss. The numerical analysis using finite elements method was developed through ANSYS software with the Parametric Design Language (APDL), in which parameters such as geometry, material, element type, finite element mesh, boundary conditions and loads are specified. A non-linear analysis was performed using shell element on the bar. The numerical analysis result satisfactorily represented the structural behavior of the isolated bar, it was possible to observe the buckling effect of the circular hollow section bar under compression and the effect of the axial load eccentricity due to the stiffened flattening of bar ends.

Keywords: steel structures, numerical analysis, circular hollow sections, stiffened flattening.

1 Introduction

Steel structures composed of hollow section, widely used in structural trusses, mainly for large areas, are increasingly used in civil construction due to the advantages offered, such as excellent capacity to the axial loads (tension and compression), torsion and combined effects (Roquete et al. [1]).

The application of trusses composed by hollow section in roof systems translate an aspect of boldness and modernity, enable the construction of long spans with reduced self-weight, present good structural performance combined with economical solutions with fast execution and assembly (Araújo et al. [2]).

Several types of connecting systems have been developed and used in truss structures. Souza [3] presents the types usually used in Brazil, including the "typical node" where the end flattened bars are connected by a single bolt, as shown in the Fig. 1.

Maiola [4], Souza [3] and Casanova [5] highlighted that the "typical node" corresponds to a simple and economical solution, but has disadvantages, such as the generated eccentricity force and reduction of the bar stiffness due to the end-flattening process. This fact can compromise the efficiency of the connection and cause the structure to collapse.

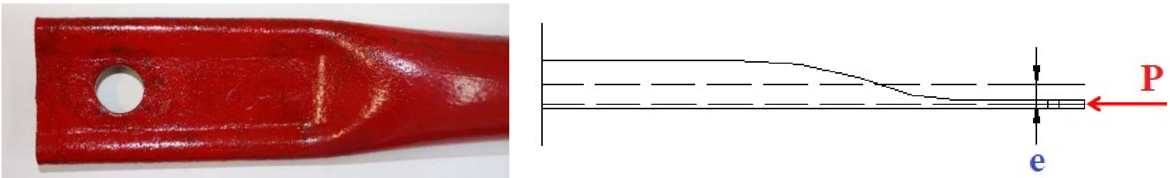
Figure 1. Typical node (Silva [6])

According to Souza [3], Sampaio [7] and Dundu [8], most standards do not provide prescriptions for sizing of flattened end circular hollow sections. The inconsistency between calculation models and the real behavior of structures can compromise the safety in determining the resistant capacity of its elements, causing partial or total collapse of the structural system.

Researches that focus on the study of isolated flattened end bars under compression, such as Malite et al. [9], Souza et al. [10], Dundu [8] and Cruz et al. [11], observed a reduction in the resistance capacity concerning the compression in the bars due to the influence of the flattening.

Studies carried out by Silva [12], Souza [3], Andrade et al. [13], Souza et al. [14], Bezerra et al. [15], Freitas et al. [16], Freitas et al. [17], Silva et al. [18] and Vital et al. [19] analysed the structural behavior of steel space structures using flattened ends hollow sections bars and evaluated the use of structural reinforcements in order to increase the resistant capacity of the structures.

Mazon [20] proposed a differentiated flattening, characterized by a non-flat geometry, with the creation of stiffeners on the lateral edges of the flattened ends, called stiffened flattening, Fig. 2(a). The stiffened flattening causes an eccentric compression load on the bar, Fig. 2(b), where “e” represents the eccentricity of the load “P”.



(a) (b)

Figure 2. (a) Stiffened flattening (Mazon [20]); (b) Load Eccentricity (Adapted from Mazon [20])

A theoretical, numerical and experimental studies on the behavior of a plane truss with parallel chords composed of circular hollow section was carried out by Mazon [20] and Mazon et al. [21]. The connecting typology consists of connecting plates welded to the chords where the diagonals with stiffened flattening ends are fixed using a single bolt. In Figure 3 a general view of the truss is shown.

The use of the stiffened flattening eliminated the failure mode in the connection region and induced failure mode by the buckling of the diagonal under compression. In relation to the theoretical values of Brazilian standards ABNT NBR 8800:2008 [22] e ABNT NBR 16239:2013 [23], a 60% reduction in the resistance capacity of the flattened end diagonal was observed. Figure 4 illustrates the buckling of the diagonal under compression at the end of the experimental test carried out.

The need to study the behavior of circular hollow section bar with flattened ends, both isolated and inserted into structures, is recognized to determine limits and criteria for use, as well as solutions involving low cost, structural efficiency, safety and ease of assembly.

Figure 3. Plane Truss (Mazon [20])

Figure 4. Buckling of the diagonal under compression (Mazon [20])

In the present work, a numerical study was carried out on an isolated circular hollow section bar with stiffened flattened ends under compression. This is similar to the most requested diagonal under compression of the studied plane truss composed of the circular hollow section with a diameter of 38 mm and a thickness of 3 mm.

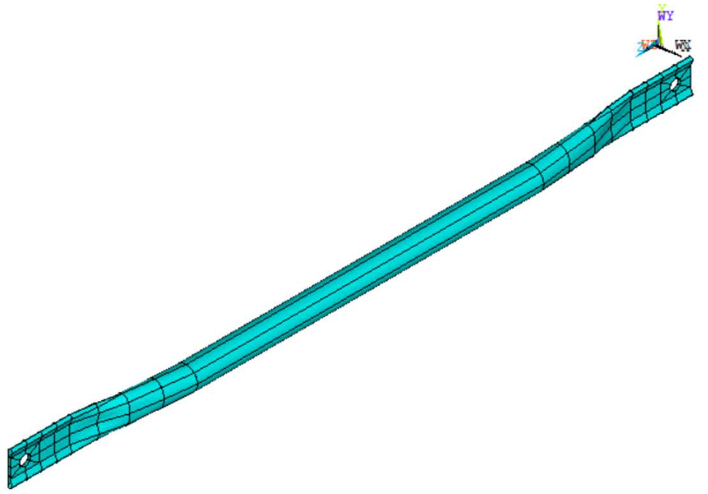
2 Numerical model of the bar

The numerical analysis of an isolated circular hollow section bar with stiffened flattened ends under compression was performed using finite elements with the ANSYS [24] software, through the ANSYS Parametric Design Language (APDL), where parameters such as geometry, material definition, element type, boundary conditions, loads and other characteristics of the bar are specified.

Figure 5 shows the numerical model of the circular hollow section bar with stiffened flattened ends with a diameter of 38 mm and a thickness of 3 mm. The total length of the bar considered is 1140 mm, with 1090 mm being the distance between holes, and 25 mm being the distance between holes and edges. The central region of the tube that is not geometrically influenced by the stiffened flattened is 580 mm long.

Figure 6 represents the region at the ends of the bar that is influenced by stiffened flattening. Five distinct cross sections can be observed, with S_1 the initial stiffened flattening part; S_2 à S_4 being the transition sections and S_5 corresponding to the original circular section of the bar.

The length of the stiffened flattened end, characterized by the distance between the two S_1 sections is equal to 100 mm and the distances between the sections S_2, S_3, S_4 and S_5 to the origin are equal to 140 mm, 180 mm, 230 mm and 280 mm, respectively. The diameter of the hole is 17.5 mm.



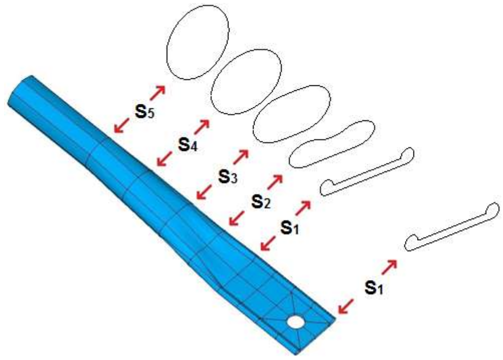


Figure 5. Numerical model of the bar

Figure 6. Geometry of cross sections (Mazon [20])

The element SHELL181 was used in the modeling of the bar, being a homogeneous structural element with four nodes and six degrees of freedom per node, which allows irregular meshes and load application in all directions (Roquete et al [25]). The numerical modeling used the material with a nonlinear stress-strain relationship, with a bilinear diagram.

The definition of the finite element mesh can be seen in Fig. 7. A greater refinement was considered around the holes and in the stiffeners of the lateral edges of the stiffened flattened ends, being uniform along the length of the bar.

The ends of the bar received displacement restrictions in two directions (x and y), allowing movement only in the z direction, corresponding to the longitudinal direction of the bar. The compression loading was applied in the direction of the z axis, at 72 nodes at each end, belonging to the finite element lines that define the holes, with 36 nodes per flat face of each hole. It should be noted that the compression load was considered in the region of the holes, in order to simulate the bolt used to connect the bar with other structural elements. Figure 7 represents the detail of boundary conditions and the compression loading application in one end of the bar, with the other end being similar.

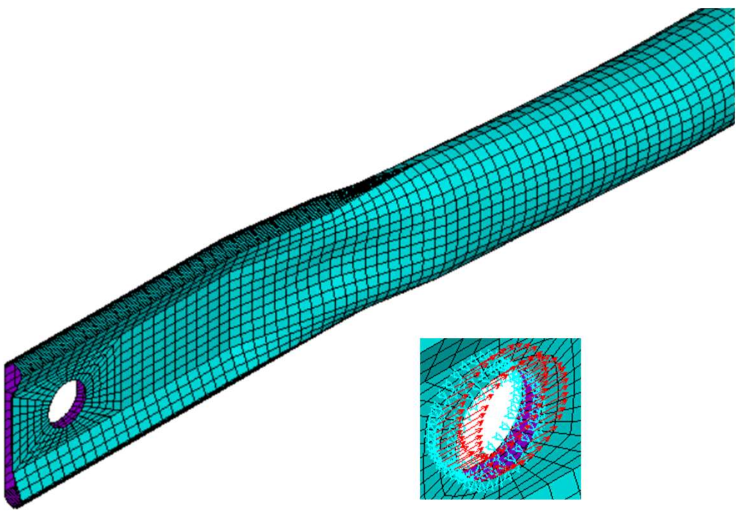
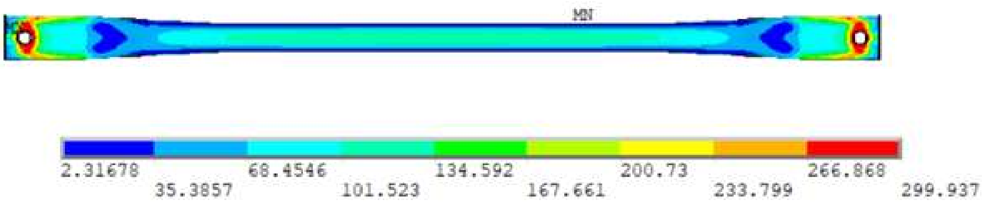


Figure 7. Representation of mesh and detail of loading and boundary conditions

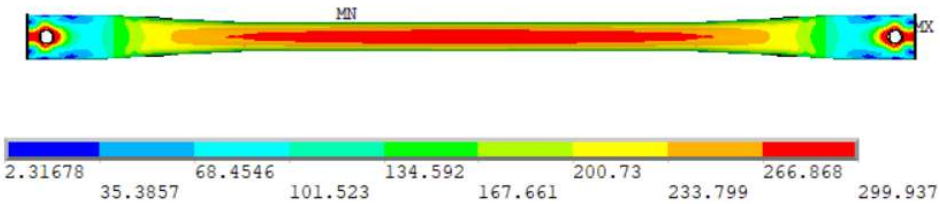
3 Results and discussions

Numerical analysis was carried out on an isolated circular hollow section bar with stiffened flattening ends under compression, similar to the most requested diagonal of the truss studied by Mazon [20]. The mechanical properties considered in the analysis are modulus of elasticity equal to 200 GPa, Poisson coefficient equal to 0.3 and yield strength equal to 300 MPa.

A total compression loading equal to 36 kN was applied at each end of the bar. Figure 8 present the results obtained for the von Mises stress distribution in the bar under compression for the load of 30.15 kN.



(a)



(b)

Figure 8. von Mises stress distribution (MPa) of the bar under compression for the load of 30.15 kN. (a) View of the region under tension of the bar. (b) View of the region under compression of the bar.

According to the numerical result, it is observed that the points of greatest stress concentration occur in the region of the holes and in half of bar longitudinal length, in the region under compression, as a resul of lateral deflection. Due to the effect of buckling and the loading eccentricity, the first node in which the yielding stress is observed is located in the region under compression of the bar, which corresponds to the flat side of the stiffened flattened region, in half of bar longitudinal length, which characterizes the failure mode of the compressed bar. As the load increased, could be observed the plasticization propagates in the compressed region, which tends towards the ends of the bar.

In the analysis, can be observed that as the load increases, the stresses are redistributed around the holes, therefore, the stress concentration in this region is not the critical factor in the collapse of the bar. With continuity of loading, the buckling of the bar under compression is observed, characterizing instability and failure mode of the element.

The graph in Fig. 9 shows the numerical result of the compression load, P, versus von Mises strain at the node in which the yielding stress is observed, located in half of bar longitudinal length, in the region under compression. The strain relative to the yield stress in the bar of 1500 μm/m is represented by the vertical line.

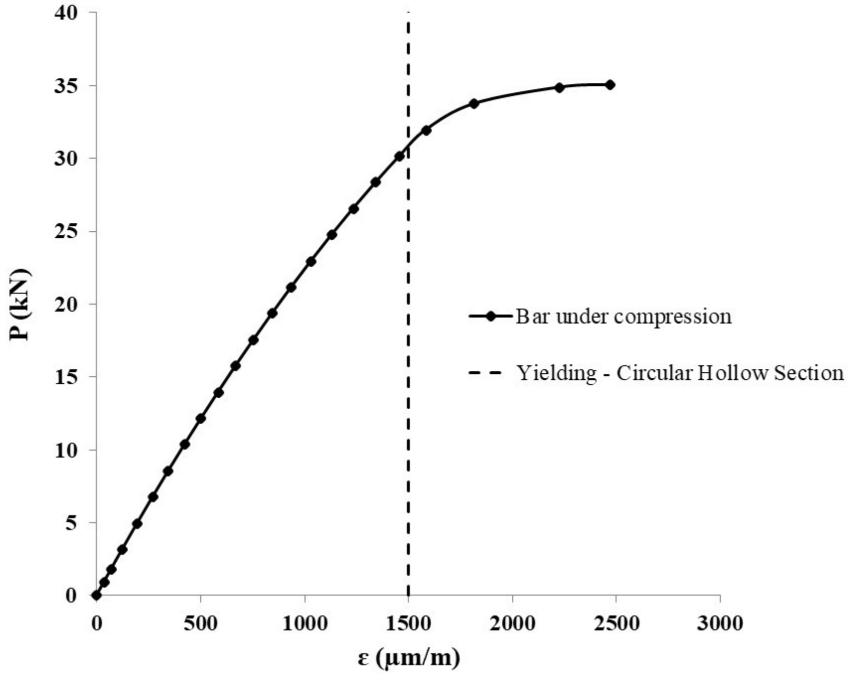


Figure 9. Graph of load versus von Mises strain of the bar under compression

It is observed, by analyzing the graph in Fig. 9, that the yielding stress occurred for the compression load equal to 30.8 kN, therefore characterizing the failure mode of the bar due to buckling and load eccentricity.

4 Conclusions

In this study, a numerical model was performed using finite elements with the ANSYS software, to evaluate the behavior of an isolated circular hollow section bar with stiffened flattening ends under compression, which is like to the most requested diagonal of the truss studied by Mazon [20]. The element SHELL181 was used in the modeling of the bar.

The points of greatest stress concentration occur in the region of the holes and in half of bar longitudinal length, in the region under compression, due to the lateral deflection. It was observed that as the load increases the stresses are redistributed around the holes, therefore, the stress concentration in this region is not the critical factor in the collapse of the bar. The failure mode of the bar under compression was characterized by instability due to lateral deflection. The numerical modeling satisfactorily represented the behavior of the bar under compression, as the effect of buckling and the compression load eccentricity were highlighted, in which yielding stress occurred in the region under compression, in half of bar longitudinal length.

It is noteworthy that the use of circular hollow section bar with stiffened flattened ends simplifies the structural design of plane and multi-planar trusses, due to cost reduction in manufacturing and transportation, and quick and practical assembly.

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