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REAL SCALE EXPERIMENTAL ANALYSES OF CIRCULAR HOLLOW SECTION MULTI-PLANAR STEEL TRUSSES

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Abstract. *The main objective of this work is to develop innovative models of tubular connections in order to decrease the trusses total manufacturing cost and assembly time, making its use more economically viable. The truss joints were verified according to international codes and publications, and a commercial software of structural analysis was used to verify the truss bars resistance. The innovative tubular connections proposed are joints between the diagonal and chord using a single bolt and a plate, and one internal tube with bolts to link the chord bars. To analyze the truss global behavior and the developed connections, real scale experimental analyses of circular hollow section multi-planar trusses were carried out, with 30.0 meters of span, and 2.0 meters of height. The final results demonstrate the proposed connections efficiency and the truss good behavior, with low weight and manufacturing cost, besides a quick assembly.*

1 INTRODUCTION

The use of hollow steel sections in structures has been growing in recent years, because they result in lighter structures with technical and aesthetic advantages. One of its possible applications is the roof systems, which typically have small execution times and large spans due to need of large free internal spaces. Many researchs of this type of structure are being developed around the world, as this study of multi-planar tubular trusses, which are steel joists with low weights used as purlins for large spans.

To allow the use of these trusses in roof systems, an initial analysis was realized to determine the best geometry and tubes for obtaining a light truss which resists the loads that usually act on the warehouse roofs. New types of connections were also developed allowing an easy truss transportation and quick structure assembly, besides to lowering the trusses manufacturing cost, since the tubular connections are complex and expensive, which sometimes make difficult their use.

To check the multi-planar truss overall behavior, two real scale experimental analyses were conducted, also allowing analyzing the efficiency of the proposed connections. Some experimental analyses results were compared with computational analyses results.

This study continues the work of Requena, J. A. V. [1] and Freitas, A. M. S. [2], and was carried out with the support of Faculdade de Engenharia Civil, Arquitetura e Urbanismo – FEC of the Universidade Estadual de Campinas – Unicamp, and Vallourec & Mannesmann Tubes (V&M do Brasil) Company.

2 CHS MULTI-PLANAR TRUSSES

The experimental analyses were performed for trusses with 30.0 m of span, since the objective of this study is to analyze the behavior of multi-planar trusses in situations of large spans for use as purlins in roof systems, like figure 1. To define the best geometry to be used for the trusses, computational softwares were used such as AutoTruss, developed by the partnership between FEC-Unicamp and V&M do Brasil S. A., and the commercial software for structural analysis SAP2000. The loads used in this study are those that are commonly applied in warehouses, which often require covering for large spans.

The action of wind suction load is a critical situation for purlins, and therefore was considered for the trusses tubes design and for the experimental analyses. The loads acting in this situation are: the truss self weight, permanent load of 0.10 kN/m² and wind suction load of 1.03 kN/m².

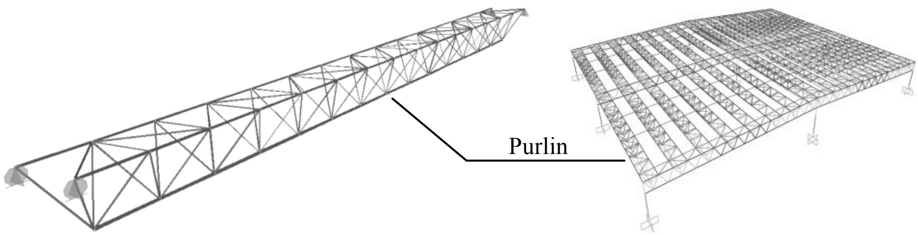

Figure 1: Multi-planar truss and the roofing system.

2.1 Truss geometry

The initial analyses were based on international standards such as Eurocode [3] and AISC [4], and demonstrated that the best truss geometry for the examined situation is the Warren truss, presenting lower weight and fewer connections than other types such as Pratt and Howe. The trusses dimensions and its tubes are presented in figure 2, noting that the loads were considered distributed in the trusses upper chords.

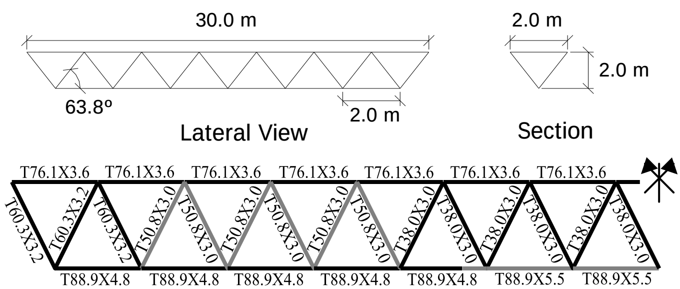

Figure 2: Trusses dimensions and its tubes.

All trusses tubes have 300 MPa of yield stress and 205000 MPa of elasticity modulus. The chords and lateral diagonals tubes are hot rolled, while the superior plane bracing tubes are cold formed. The total weight of each truss is 1224.0 kg.

2.2 Connections

Two types of innovative connections were proposed in this paper. The first relates to the connection between the truss chords and diagonals, composed of a plate welded on the chord tube top, to which the diagonals with flattened ends will be fixed using only one bolt, as shown in figure 3. The plate thickness is 4.75 mm and the bolt has a diameter of 15.90 mm. The other proposed connection is a tube sleeve used to join the chord tubes, composed of an inner tube with a less diameter than the tube chord, which is connected to the outer tubes by bolts passing by both tubes, as shown in figure 4. A total of six bolts with 15.90 mm of diameter were used for the sleeve tube connection.

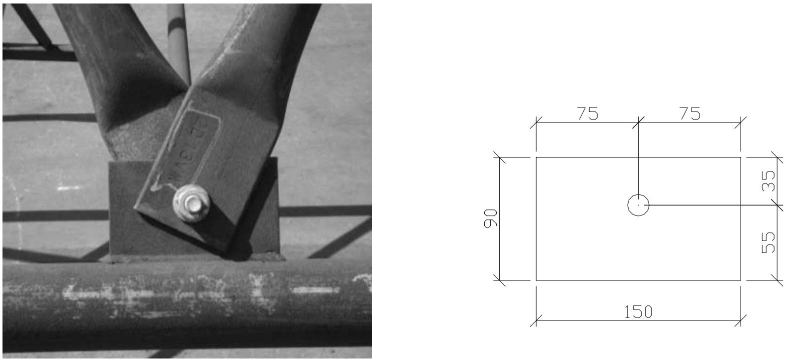

Figure 3: Connection between chord and diagonals (dimensions in mm).

Figure 4: Tube sleeve connection.

These connections were properly designed with adaptations to the conventional criteria of international codes as Eurocode [3] and AISC [5], besides specialized publications such as CIDECT [6], Packer [7] and Rautaruukki [8]. They can be used to replace the welded connections between diagonals and chords and the flange connections, in order to decrease the trusses fabrication cost, and make quicker and easier their assembly. Another advantage of these proposed connections, especially with respect to the connection between the diagonals and the chords, is the possibility to transport the truss disassembled, performing the assembly on site, since the connections are bolted. This fact makes the transportation more economical, since a multi-planar truss disassembled occupies a smaller space than an assembled.

3 EXPERIMENTAL ANALYSES

Two experimental analyses of trusses with 30.0 m of span were carried out, both with the diagonals proposed connection, but one with the tube sleeve connection and the other with the traditional flange connection. Thus it was possible to compare the two experimental analyses and check the tube sleeve connection influence in the truss global behavior.

The trusses were inverted, with the upper chords in bottom position and the lower chord in top position, and their nodes were numbered as in figure 5. Therefore, gravitational loads can be applied in the upper chords nodes, simulating the wind suction loads. To define the experimental load value, the permanent load and twice the truss self weight were subtracted from the wind suction load, since the truss was inverted and its self weight already act in the same direction as the suction load.

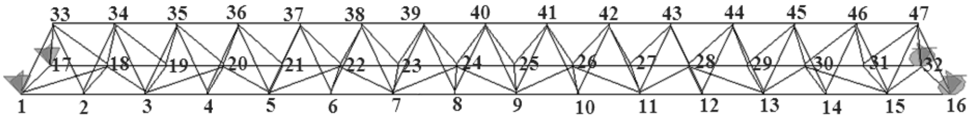

Figure 5: Inverted truss and numbered nodes.

The loads were applied at the upper chords nodes of the trusses, divided into six steps as shown in table 1, and at step 4 the load reached the value for which the trusses were designed. Thus, in step 5 was applied a load greater than the one for which the truss must resist, removing the tubes coefficient of resistance. Supports were fixed at the nodes for the load application, and the trusses at the experiment were isostatic. Figure 6 shows one of the trusses prepared to begin the experimental analysis.

Table 1: Table of loads (kN).

Step	Nodal Load	Total Load
Supports	0.48	13.30
1	0.95	26.60
2	2.02	56.59
3	3.02	84.56
4	3.96	110.80
5	4.83	135.26

Figure 6: Truss prepared to begin the experimental analysis.

The vertical displacement at the middle of the span was monitored during the experiment for the truss with the flange connection. The connection of the node 2 and the sleeve between the nodes 5 and 6 of the truss with the tube sleeve connection were instrumented with strain gauges, as shown in figure 7.

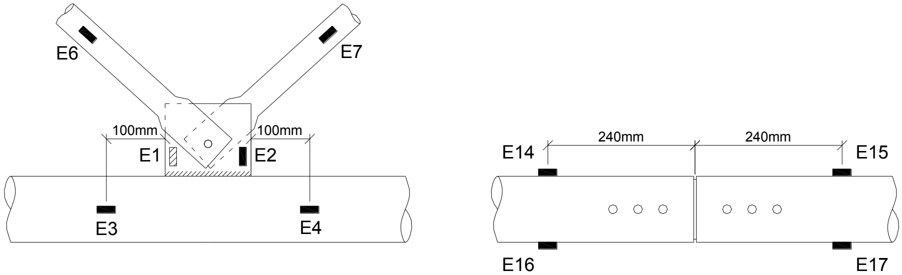

Figure 7: Instrumented connections.

4 RESULTS ANALYSES

Both trusses were monitored during the load application, presenting good behavior until step 4. After the step 5 load application the monitoring devices were removed, continuing the load addition to observe the trusses collapse mode. The truss with sleeve connections, which was experimented first, collapsed due to the connections of nodes 16 and 32, as shown in figure 8. The failure occurred at the expected location, because the extreme diagonals have the largest axial force, and after failure observation, the extreme diagonals of the truss with flange connection have been reinforced, as presented in figure 9. So, in the truss with flange connection, the failure after step 5 occurred at the connection of node 47, as it concentrates four diagonals with great axial forces, as shown in figure 10. As the failures occurred after the load application of step 5, the trusses and their connections resisted to the anticipated loads.

Figure 8: Connection failure of the truss with sleeve connection.

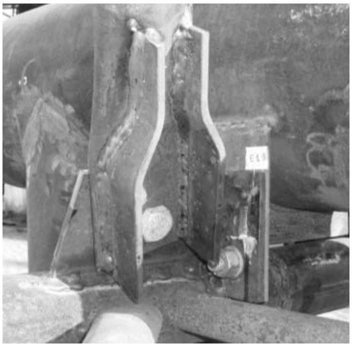

Figure 9: Diagonals reinforcements.

Figure 10: Connection failure of the truss with flange connection.

The vertical displacements observed in the experiment of the truss with flange connection were compared with those obtained by the computer analysis program SAP 2000, simulating an inverted truss with the same conditions and concentrated loads of the experimental analysis. In the computational model, the diagonals were released, which allow their rotation of ends, and the plate connection eccentricity was simulated with large stiffness bars. This vertical displacements comparison at the middle of the span of the truss with flange connection can be observed in table 2, which contains the values obtained by SAP 2000 and by the experimental analysis.

Table 2: Vertical displacements (mm).

Step	Computational Analysis	Experimental Analysis
Supports	9.51	10.27
1	19.01	20.45
2	40.45	44.74
3	60.44	69.52
4	79.20	108.35
5	97.47	133.79

The values are very close until step 2, getting distant from each other after step 3, indicating that for smaller loads, the diagonals rotations were similar to those of computational analysis, and the plates used in the connections presented a small rotation, consistent with the large stiffness bars rotation of the computational analysis. However, when the load was increased, there was a structure accommodation with a greater rotation of the diagonals, making the plates began to rotate more than the large stiffness bars of the computational analysis. Thus, the vertical displacements observed in the experimental analysis were higher.

The strain gauges results of the node 2 connection are showed in figure 11, while the strain gauges results of the sleeve connection between the nodes 5 and 6 are presented in figure 12.

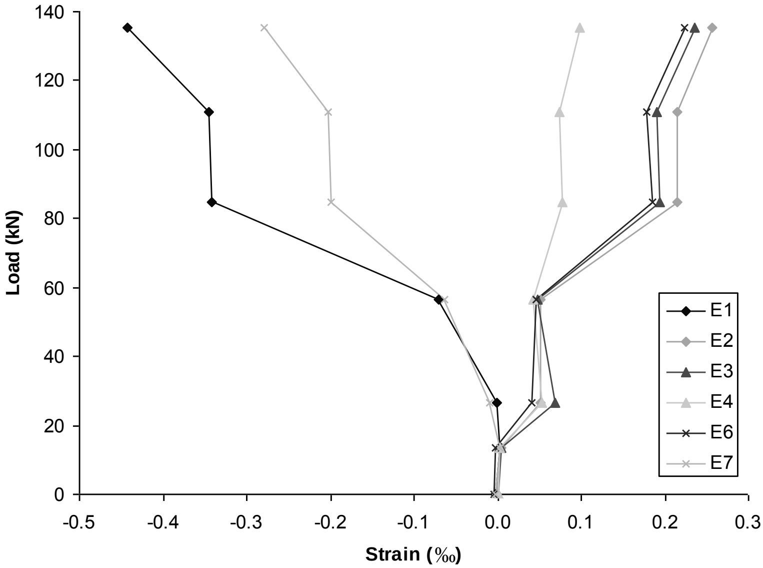

Figure 11: Strain gauges results of node 2 connection.

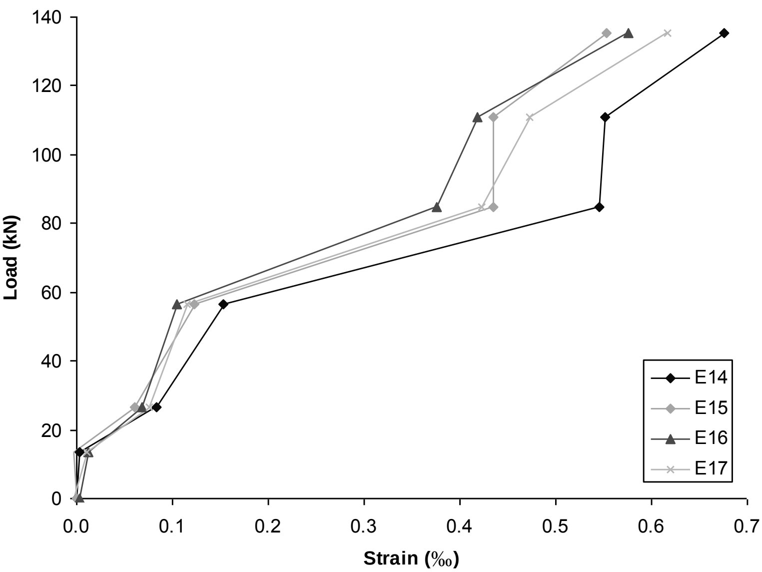

Figure 12: Strain gauges results of sleeve connection between nodes 5 and 6.

With respect to the node 2 connection, the diagonal with strain gauge E6 was tensioned while the one with strain gauge E7 was compressed. Thus, a plate rotation occurred due to the connection eccentricity, as shown by strain gauges E1 and E2, respectively compressed and tensioned. The chord strain gauges indicate that it is tensioned, with a greater stress in the region of the strain gauge E3 than in E4 region, due to the presence of bending moments.

No failure was observed on the sleeve connections at the end of the experimental analysis, attesting to the proper functioning of this type of connection. Figure 12 shows that the sleeve connection was tensioned, and the strain increase was constant for all strain gauges until the end of step 2, which has low loads. Then there is a change in the curve, with a smaller slope, indicating a truss accommodation due to its flexibility, causing diagonals and plates rotation. With the load application of step 4, the curves slopes become similar to those before step 2, indicating a truss stabilization again. Finally, with the load application of step 5, a new accommodation occurred, with a smaller curve slope, similar to that observed after the load application of step 3.

The same is true for the curves of node 2 connection in figure 11, which have two parts with higher slopes and other two with lower slopes, with the change of slope corresponding to the load application of steps 3, 4 and 5. This indicates that the truss accommodation influenced the strain and the displacement of the whole truss.

5 CONCLUSION

The experimental analyses demonstrated the good trusses global behavior, with great lateral stability and bars resistance to the forces for which they were designed, indicating that the multi-planar trusses are good solutions for large span roofs, without the need of external bracings for the trusses lateral stabilization. As the collapses at the connections of the diagonals with largest axial forces occurred only for loads greater than those assumed in truss design, the proposed connections demonstrated good performance and can be an alternative for welded diagonals and flange connections commonly used.

Further studies about the proposed connections are in progress, since they provide great flexibility for the trusses, causing accommodations of the trusses bars as the load increasing, as observed in strain gauges and vertical displacements results. The extreme diagonals connections should also be analyzed with attention, developing a special connection for this situation, as they have greater axial forces.

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