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Development and design of a concealed splice joint configuration between tubular sections

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ABSTRACT

Tubular structures are structurally efficient; however, there were many limitations to their use in the past due to the difficulties associated with the design and execution of joints. Nowadays, this scenario is changing as design recommendations already exist for several tubular joint configurations and further research is being carried out. The aim of this study is to develop and assess the structural efficacy of an aesthetically agreeable configuration of a concealed splice bolted joint between tubular sections, using inner splice plates. Countersunk head bolts and socket head bolts were used in the development and design of these joints. The experimental behaviour of the joints analysed, namely the resistance and the failure modes, were compared with the corresponding design models in Eurocode 3, Parts 1.1 and 1.8. A numerical study was also performed to assess the influence of geometric variations on the structural behaviour of the joint. The ratio between the thickness of the outer tube and the height of the bolt head was the main geometric parameter investigated.

1. Introduction

Tubular steel structures have several advantages as they combine the structural efficacy and sustainability, which are often characteristics of steel structures, with their architectural and aesthetical value. Such characteristics are potentiated by the geometry of these sections [1]. Tubular sections, whether square, circular or rectangular, provide compelling advantages when compared with open sections such as: (i) a high resistance to torsion; (ii) high resistance to buckling (flexural, torsional or lateral); (iii) ability to optimize the structure simply by varying the thickness of the section maintaining the outer geometry; (iv) the possibility of being reinforced either by filling the interior with concrete or water, improving resistance to axial compression and fire, respectively; (v) better resistance to corrosion due to the lack of free edges.

In general, structural hollow sections and tubes are produced by hot rolling in accordance with EN 10210-1 [2] or by welding in accordance with EN 10219-1 [3]; additional information about other processes can be found in a specialized bibliography [4].

Truss structures are traditionally used for tackling long spans as they provide a very effective structural solution, because they are lightweight and visually appealing. Yet, very large trusses require segments of appropriate sizes that must be transported to, and assembled on site, this assembly has to be taken into account during the design of the structure. As the solution of welding for this assembly has some technological and economic drawbacks, the use of bolts is a very reasonable and convenient solution. However, bolted splice joints in tubular structures, despite providing a high structural performance able to withstand axial forces as well as bending moments, are aesthetically poor, as illustrated in Fig. 1 [1]. Other configurations, such as the one illustrated in Fig. 1c, are aesthetically better because the bolts can be concealed. However, this configuration is only suitable for tension joints as its ability to ensure full continuity of the spliced members is limited [1].

Several alternative bolts, such as the flow-drill system or the hollo-bolt system [1] have been developed to respond to the lack of access to the internal face of the tubular sections. Nevertheless, these systems display a number of drawbacks in terms of structural efficiency. In order to simplify the joints and to improve their aesthetic appearance, other researchers [5] have proposed a splice joint configuration using inner plates connected to the outer section by long bolts placed across the cross section (glove bolted splice joint, see Fig. 2). This typology is less complex and has less visual impact than other more traditional bolted splice joints. However, the bolt head and the opposite end, nut included, protrude from the outer face of the section.

The research described in the present paper was intended to develop and improve a concealed bolted splice between tubular

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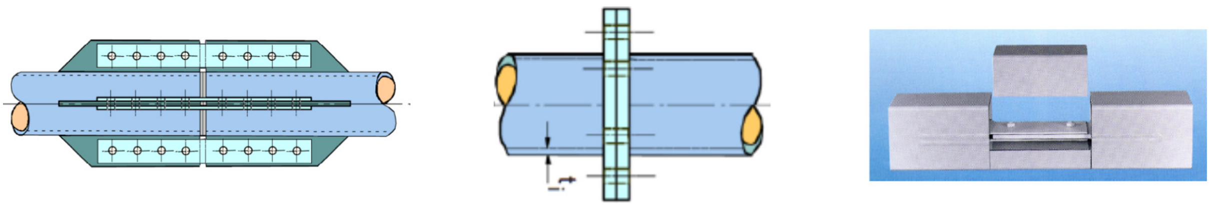

(a) Joint with lateral plates (b) Top flange joint (c) Concealed bolted joint

Fig. 1. Examples of splice bolted joints between tubular sections.

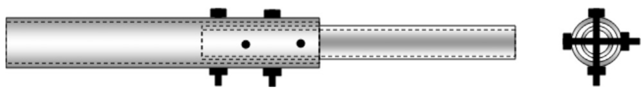

Fig. 2. Glove splice joints.

joints that efficiently tackles the drawbacks of the configurations shown above and is able to transfer axial forces (tension or compression) and bending moments between the spliced members. Although this study only addresses the behaviour under axial tensile forces, the results obtained suggest that a high performance under axial compressive forces and bending can also be expected.

2. Development of the concealed configuration

2.1. Introduction

The objective was to develop and perform a comprehensive structural study of a concealed type of bolted splice joint (see Fig. 3), which is efficient in terms of structural performance, is economical, aesthetically appealing and provides an alternative to the conventional solutions.

In the envisaged joint, the load is transferred by means of inner splice plates and bolts orthogonal to the tube wall in a radial layout, further detailed in Section 2.4. The bolt heads are as discreet as possible, preferably countersunk.

2.2. Structural scheme for the load transfer

When compared with ordinary bolted shear joints the configuration proposed is different, mainly because the bolts are not accessible from the inside face of the tubular section, which means the fastening may only be done from the outside, making it impossible to use nuts. Nuts are of key importance when a conventional bolted joint is subjected to shearing as they allow the activation of contact pressure that prevents the bolt from rotating (see Fig. 4a). This is the main difference to a conventional joint with bolts experiencing shearing (see Fig. 4b).

In order to overcome the lack of nuts, the inner plates were threaded in order to have a similar behaviour to them. However, unless the geometry of the joint is the most appropriate, it may allow a certain bolt rotation, which would subject the bolt not only to a shear load but also an axial load. Thus, the efficacy of this system to replace the effect of the nuts was the principal aspect of the structural performance of the proposed joint configuration.

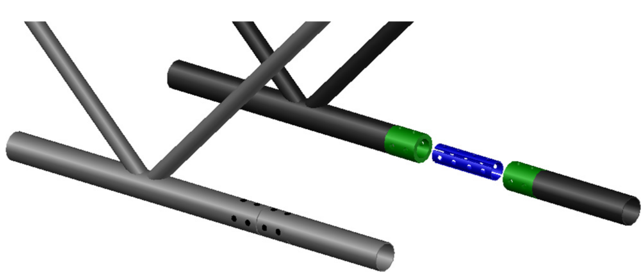

Fig. 3. The proposed splice joint.

2.3. Preliminary studies

The solution presented here is the result of several iterative/improvement studies [6]. The main objective was to establish a configuration that would replace the effect of the nut efficiently, thus preventing the rotation of the bolt leading to the conventional shear transfer. The geometry was further improved so that the joint elements would not condition the resistance of the tube. The study made it possible to identify the main parameters influencing the structural behaviour of the joint, namely the bolt type, the thickness of the tubular section and the thickness and geometry of the inner splice components. These studies covered different base configurations, such as: different bolt head types (countersunk - CS, button head - BH and hollo-bolt flush-fit - HB, see Fig. 5); three bolt diameters (8, 10 and 12 mm); two bolt steel classes (8.8 and 10.9) and inner splice components (inner tube or segments) with thicknesses varying from 6 mm to around 4 to 5 times the thickness of the tubular section to be spliced; a total of 16 bolts (8 on each side) was considered in all tests. Table 1 and Fig. 6 summarize the configurations tested.

A specimen with button head bolts, which was tested in previous studies, may be seen in Fig. 7; this figure also depicts part of the experimental setup, more precisely the measurement of the relative displacements.

Fig. 8 depicts the average load-displacement curve per bolt typology. In all tests the failure mode observed was bolts in shear, and in some cases accompanied by some bearing, close to the holes of the tubular sections. By observing the curves, one can see that the specimens with countersunk head bolts (CS) and hollo-bolts (HB) are characterized by a reduced stiffness, the ultimate resistance is achieved for high displacements. This behaviour compromises their possible application as an effective solution and it is fundamentally caused by the rotation of the bolt around an axis normal to its longitudinal axis (see Fig. 9a)). This rotation has two disadvantages, on the one hand it aggravates the local yielding of the tubular section hole, on the other hand the rotation produces tensile stress in the bolt, this stress is located in the thinnest part of the bolt heads set in the hexagonal holes needed to fasten them (Fig. 9b)).

In the tests with button head bolts (BH), the protruding head prevented the rotation of the bolts, thus failure occurred only when the bolts sheared. This reduced the overall displacement and improved the stiffness of the joints in comparison with the other bolt typologies. Despite the improvement in the mechanical behaviour of the joints, thereby providing satisfactory values regarding applicability, the protrusion of the button head does not meet the aesthetical objective.