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Experimental and theoretical analysis of shear bolted connections for tubular structures

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ABSTRACT

In this paper, numerical and experimental investigations devoted to the evaluation of the bearing resistance of tubular members, with gusset plates and through-all long bolts, are presented. Unlike lap shear joints, the analysed connection shows a limited confinement of the bearing area associated with the use of long bolts and the presence of a gap in the member, which can lead to a reduction of the bearing resistance. In order to investigate the behaviour of shear connections composed by thin or thick SHS (Square Hollow Section) profiles and long bolts, experimental tests on 24 specimens and FE simulations have been conducted. Both experimental and FE results have confirmed the influence of local instability of the hole in bearing on the resistance of thin profiles and the poor accuracy of the available standards for this specific joint typology. In particular, the performed comparisons have shown that, for thin profiles, EC3 model is likely to overestimate the resistance, while for higher thickness of the SHS conservative predictions are obtained. The paper presents the conducted experimental and numerical investigations highlighting, at the end, the need for a proper formulation able to account for the local instability effect on the bearing resistance.

1. Introduction

Tubular members are currently used in many structural typologies and they are often preferred to other shapes when particular structural or architectural issues are under concern. In particular, they are selected when a high equivalent stiffness is required in two main directions, such as in case of columns, trusses or bracings. Hollow sections are also strongly used in racking structures where they are in many cases adopted to realize the uprights or the elements of the bracing system. In last years, several studies have been undertaken to investigate the behaviour of connections for racking structures [1] and, due to their significant impact on the global behaviour, many works have been devoted to the influence of connections on the structural stability [2]. Lately, construction companies have also considered the possibility to employ alternative solutions in view of a simplification of the joints details, trying to reduce the fabrication and assembly costs. In fact, the hooked connections normally employed in racking structures require a costly manufacturing of beam and column and, as a consequence, alternative solutions consisting in connections with long bolts and gusset plates are becoming very common in practice [3–5,35] (Fig. 1). However, albeit very practical, this connection typology cannot be properly designed simply following the rules proposed by the relevant design standards. Indeed, the currently available codified equations make typically reference to the case of lap shear connections in single-sided or double-sided configurations [6–8], where the plates are always in direct contact with the bolt head or nut, thus assuming the development of a strong out-of-plane confinement of the bearing area (Fig. 2a). Conversely, in case of connections with hollow sections and through-all long bolts, due to the lack of installation space, the bolt head and nut can confine the bearing area only outwards, while inwards the tube walls are free to buckle or curl. Clearly, the decreased confinement of the area ahead the bolt shank can lead to a reduction of the bearing strength with respect to the values calculated with the codified equations calibrated on overlapped connections, such as those proposed, for instance, in Eurocode 3 part 1.8 and part1.3 [6,7].

Recently, in several works, the bearing resistance of bolted connections has been investigated aiming to extend the range of applicability of EC3 equations to cases not yet covered by the code, such as connections with high strength [9–11] or stainless steel [12,13] or connections made of cold formed strips and hot rolled steel plates [14]. Other relevant technical literature which has been considered is the set of works carried out by different authors [17–20] constituting the background documentation of AISI S100 [14] or the works recently published by Teh et al. [15,16]. Nevertheless, also in case of AISI S100 standards or other literature models, the available equations are not specifically devoted to connections with tubular members and through-all bolts. The only exception in the standardized design rules is represented by

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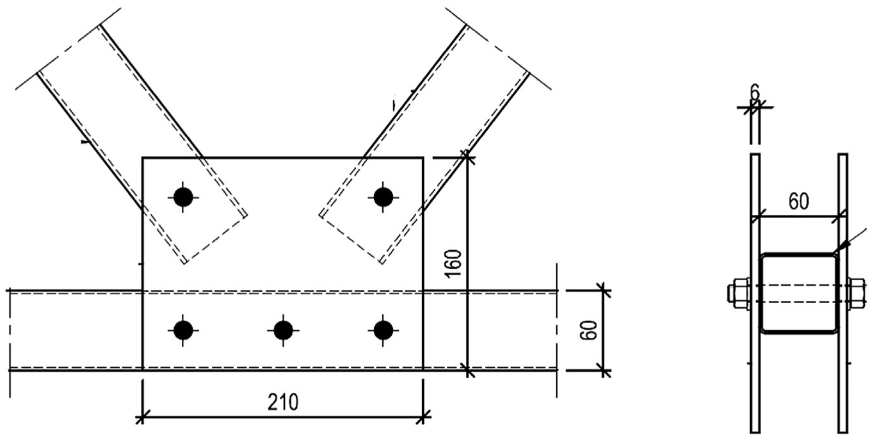

Fig. 1. Typical configuration of a joint with tubular elements and gusset plates employed in the bracing system of a racking structure.

equation (J7-1) suggested by AISC 360-10 [21], which is, anyway, a conservative extension of the equation for pins in bearing. Therefore, in general, all the current standardized calculation procedures, disregard the possible development of out-of-plane or curling [22] phenomena that may occur due to a lack of confinement of the bearing area (Figs. 1, 2b).

Within this framework, this paper seeks to examine the influence of the particular connection layout on the bearing strength, using experimental and numerical approaches. To this scope, 24 experimental tests on connections with SHS and through-all long bolts have been first performed at the Material and Structure mechanic (M&S) laboratory of the University of Liege. Then, FE models have been calibrated and used to perform parametric analyses varying the geometrical properties. The experimental and FE results have been exploited to check the accuracy of the currently available provisions in predicting the ultimate bearing resistance (AISI S100, EC3 part 1.8 and part 1.3 and AISC 360-10) when straightforwardly applied to this joint configuration, knowing that, while AISI S100 provisions are considered accurate for lap shear connections, EC3 equations are considered conservative for simply overlapped connections [23–26].

2. Experimental investigation

In order to study the behaviour of the investigated connections, an experimental programme including 24 specimens was performed at the University of Liège. The layout of the specimens consists of a SHS profile fastened to a couple of gusset plates by means of a long bolt (Fig. 3). The specimens are subjected to a monotonic tensile load in order to generate shear in the bolted connection. The 24 tested specimens are divided into six groups, according to the bolt diameter, the thickness of the tube and the steel grade. In particular, two different steel grades, HX420LAD (f_y = min.420/max.520 MPa) and S235 (f_y = 235 MPa), three different tube thicknesses (2 mm, 2.5 mm and 4 mm) and two bolt diameters (M12 and M16) have been considered. All the bolts employed in the experiments were 8.8 class bolts and they were snug-tightened before executing the test. The specimens were connected to the jaws of the loading machine by means of steel plates, on one side welded to the tube and, on the other side, bolted to the specimen. Before executing the tests, the tubes walls were marked with a letter. In particular, the holed sides were called A or C and the two other sides were called B or D as illustrated in Fig. 3.

In Table 1, the actual material properties and the actual dimensions of all the specimens are summarized. In particular, in this table, the values of the parameters d_A and d_C, which are the minimum dimensions of the hole diameters (on the side A or C of the profile) and of the parameter d_N, which is the nominal diameter of the hole, are given. The experimental setup and the nominal geometry of the specimens are also summarized in Fig. 3a for the series of tests with M12 bolts namely HX-2-M12, HX-2.5-M12 and S235-4-M12, and in Fig. 3b for the series with M16 bolts, i.e. HX-2-M16, HX-2.5-M16 and S235-4-M16.

As reported in Table 1, the holes of the specimens were realized using drilling or punching techniques. Drilled holes were cylindrical (Fig. 4a); conversely, punched holes were conical or combined conical and cylindrical (Fig. 4b, c). As explained in the following, the shape of the hole can significantly influence the elastic behaviour of the connections. When reference is made to the numerical models called

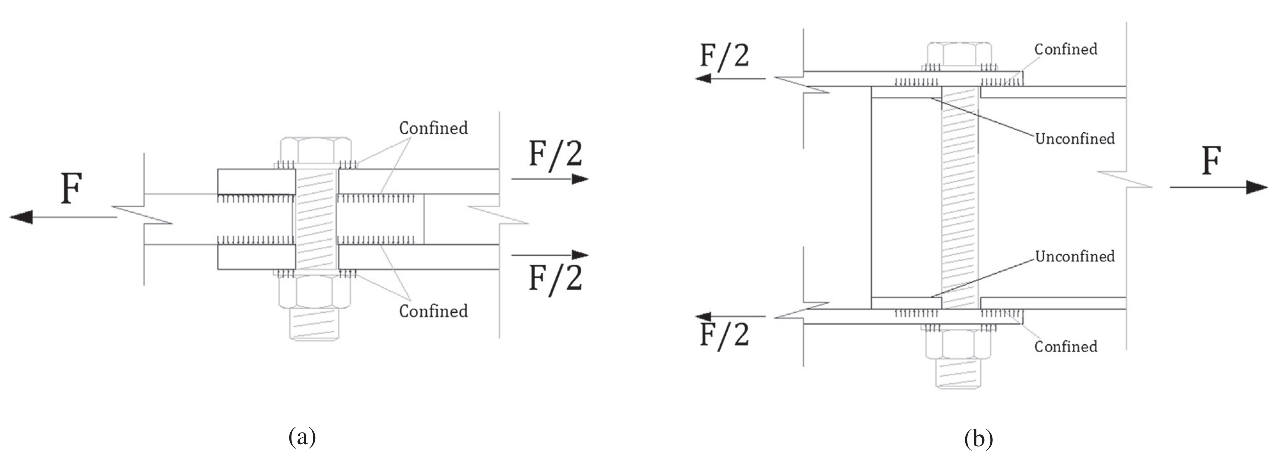

Fig. 2. Different configurations of shear connections.