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Structural performance of light steel framing panels using screw connections subjected to lateral loading

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ABSTRACT

Screw connections have an important role in the performance of Light Steel Framing (LSF) construction systems. In this paper, the behaviour LSF panels using screw connections subjected to lateral load is discussed and further insights are provided on the behaviour of such panels by experimental tests and numerical analysis.

Therefore, the main aims of this paper are: (i) to provide a discussion on the analytical, experimental and numerical assessment of steel-to-steel connections, between cold-formed elements, and steel-to- Oriented-Strand-Board (OSB) connections; (ii) to discuss the results of the experimental tests carried out on braced and unbraced LSF panels subjected to lateral load; and (iii) based on a calibrated numerical model, to provide further insights into the behaviour of LSF panels.

The paper may be subdivided into two main parts. The first part of the paper addresses the behaviour of the screw connections; while the second part addresses the behaviour of braced and unbraced LSF panels, subjected to lateral loading.

The major conclusions of this paper are: (i) the results presented in this paper confirm a relevant contribution of the OSB board to the lateral stiffness of the LSF panel; (ii) the connections between OSB boards and the steel frame are the governing part of the panel resistance to lateral loading; and (iii) the significant contribution of the OSB board shows that it should not be neglected, as it is currently the case in the European standard EN 1993-1-3.

1. Introduction

Light steel framing (LSF) wall panels are increasingly being used, particularly in modular construction, not only due to its lightness and speed of assemblage but also due to its easy adaptability to most architectural and structural requirements. In the assemblage of LSF wall panels, screws are highly used given its efficiency, fast application and suitability for load bearing, fitting perfectly in the industrialized production philosophy. Due to the low thickness of cold-formed steel profiles, screw connections provide advantages such as simple design, fast installation [1] and low cost. For these reasons, they are often chosen by contractors. Only for high load bearing situations, they are not suitable due to its limited load capacity. In screw connections used in LSF, the connector is mainly subjected to shear load. Two main reasons may be identified for this type of application: i) most connections configuration consider this type of behaviour, it is the most suitable and easy connection in light steel framing; ii) the very limited resistance to tension forces of connections using screws, as the connecting layers are clamped only by the screw threads.

In this type of construction, screw connections are also used for the connection of non-structural elements or secondary members, as wood-derived boards. The latter are present in most LSF construction but often its contribution is disregarded for the design against lateral loads, such as wind and seismic actions. However, the contribution of these boards is clearly not negligible [2–4]. The lateral behaviour of sheeted cold-formed steel panels/structures is considerably dependent on the complex behaviour that occurs at each fastener location [5] and several studies are available in the literature showing the primordial role of connections in the overall performance of lightweight steel panels. Most of these studies are experimental [6–11] but also analytical [12,13].

Screw fasteners are easy to install, however their stiffness and strength contributions to the structural system are exceedingly difficult to quantify, this is due to complex kinematics related to, for example, screw head to plate contact and screw thread-plate interaction [14]. It is therefore very important to characterize and to control the response of this type of connections for predicting wind and seismic drift. In order to provide a deeper understanding of the behaviour of screw connections and their impact on the frame response, this paper provides

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a discussion on the results of experimental tests and numerical simulations performed by the authors, both on screw connections and wall panels. It is observed that the research carried out in this paper focusses on the configuration of light steel framing panels that were developed for the modular construction system *CoolHaven®* [15].

In the first part of this paper, the behaviour of screw steel-to-steel and steel-to-OSB connections is investigated. The analytical evaluation of the screw connection behaviour focussing on the design standards [16,17] is discussed and the results of an experimental programme and of the numerical simulation of single shear screw steel-to-steel connection are analysed for a detailed characterization of the connection response. In addition, the connection between OSB board and steel is analysed based on experimental tests and on the analytical formulae proposed in the EN 1995-1-1 [18]. In the second part of the paper, the behaviour of cold-formed steel panels using screw connections subjected to lateral loading is investigated and discussed by means of analytical models, experimental tests and numerical simulations.

To enable the numerical simulations, a numerical model for the steel panel is developed. This model is calibrated and validated by the results of the experimental tests.

Then the numerical model is further used to evaluate the impact of additional bracing systems, like the use standard diagonal steel strips bracings. Therefore, the contribution of the bracing system is assessed by comparing the performance of the unbraced panel frame with the OSB board braced panel frame and panel frame braced using diagonal steel stripes.

2. Behaviour of screw connections in shear in light steel framing panels

2.1. Steel-to-steel screw connections

2.1.1. General

In LSF the behaviour of connection is strongly influenced by the thickness of the members (thin-walled), which are characterized by a small stiffness [19]. Consequently, design equations differ from those used in connections with thicker members. The main particularity of screw connections is that the screw works without nut (Fig. 1). This implies that the connection depends strongly on the mechanical interface between the thread and the connected plates. This type of connections has a significant screw rotation, especially when using a single screw, because the restrain, which could be provided by the nut, is not present. In connections using more than one row of screws, the screw rotation depends on the pitch distance [14].

The load transfer mechanism in screw connections is similar to shear bolted connections. The load is transfer between the connected members (here denominated as plate) through shearing of the screw. The failure modes that may develop are listed in Table 1. Though, the modes of failure are clearly identified, the behaviour of the screw connections is much more complex because of screw rotation. In single shear plane connections, the eccentricity of the loading leads to a rotation of the screw (tilting) and originates a pull-out force on the screw. This pull-out force is then compensated by the screw head pressure against the steel plate and consequently local bending develops on the plate. The higher the flexibility of the steel plate, the higher the rotation. A model to predict the fastener tilting based on the plate thickness and on the pitch distance is proposed in [14]. In the shear connections with eccentricity, as single shear plane connections, fastener tilting occurs and is coupled with tearing and/or with bearing. In the codes no distinction is made between these modes of failures being identified as a unique mode. Further discussion on the design prescriptions are given below. The shear failure of the screw occurs only in the case thicker plates are used. As in light steel framing, thin elements are often used, this failure mode do not occur so often. In relation to the net section failure, it mainly occurs in the case of connections with thin and narrow plates, for example when using extra plates to connect members. In the majority of the connections in light steel framing, this mode of failure do not occurs as connections are performed often between members directly where the cross-section is considerably resistant in comparison to the resistance of other modes of failure.

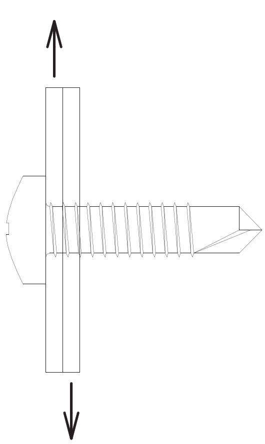

Fig. 1. Shear screw connection.

In the construction of panels, the screw connection between the members, vertical and horizontal studs, is often performed inserting the vertical studs (C or Ω shape type) in the horizontal studs (U shape type or C shape type with a notch), as illustrated in Fig. 2. This configuration is a shear connection type and failure may occur from one of the modes described in Table 1. In the case of braced panels, this type of connection is also used to connect the diagonal bracings or the OSB boards to the panel members (vertical and horizontal studs). Subsequently, the bearing capacity and the stiffness of the panels to lateral loading depend on the behaviour of this type of connections. Therefore, the characterization of the connection behaviour is important to evaluate the panel performance. In the next sections, the behaviour of shear screw connections in LSF is discussed based on analytical, experimental and numerical investigations.

2.1.2. Assessment of the response of single shear screw connections

The design of a screw connection is based on the evaluation of the individual failure modes listed in Table 1. In practical terms, the principles of the component method [20] are applicable. The connection may be represented by the mechanical spring model illustrated in Fig. 3. Each mode of failure is identified as a component and reproduced by a translational spring. The connection response results then from the assembly of four springs in series. In practice, the deformation of such connection is completely neglected and therefore the model is only used to evaluate the load capacity. Tables 2 and 3 summarize the design expressions to evaluate the resistance of screw connections according to the reference codes for the design of light steel framing structures [16,17]. The main differences between the design rules reproduced in these tables consist in the evaluation of the bearing and tearing failure. The EN1993-1-3 [16] approach is limited to the cases where the plate near the head of the screw is the thinnest. The other cases are not covered. This is not case in the AISI S100 [17] where all the situations are accounted for. In the latter, different design equations for the same mode of failure are given which are related to the design criterion (ASD – Allowable Strength Design; LRFD – Load and Resistance Factor Design; LSD – Limit State Design). The comparison between the analytical expressions proposed by the two codes, to evaluate these two modes of failures, is illustrated in Figs. 4 and 5. In the application of the analytical expressions, the following was considered: single screw, one steel grade, same screw diameter, no influence of edges and variation of plate thickness. Fig. 4(a) shows that in case of the EN 1993-1-3 [16], only for higher thickness of the steel plate t_1, bearing becomes the governing mode. In the case of AISI S100 [17], the governing mode of failure depends on the thickness of both plates,