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Composite steel joist analysis using experimental stiffness factor from push-out tests

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A R T I C L E I N F O

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A B S T R A C T

The stud anchor stiffness coefficient is vital for computing the deflections of composite steel joists (CSJ), although the way to capture this value can be challenging. A commonly used experimental method to compute this coefficient is the push-out test presented in EN-1994. However, the method does not address the incorporation of the steel metal deck currently used in the vast majority of composite decks. In order to tackle this problem, we present a modified version of the push-out experiment to better determine the stiffness coefficient when the stud anchor is placed in the weak or strong side with respect to the steel deck stiffener. Furthermore, 13 mm and 16 mm diameter studs are used in order to investigate lower capacities and to compare with the standard 19 mm diameter connector. An analytical solution of the CSJ system which incorporates the stud anchor stiffness coefficient is utilized to predict the overall system deflection when the effective composite moment of inertia of the joist is included. Results demonstrate the effectiveness of placing the stud in the strong side, and the accuracy of the enhanced push-out test.

1. Introduction

Truss-shape joists together with concrete slabs have become a very promising and useful alternative to I-shaped steel members in spans greater than 10 m [1]. The joist configuration provides accommodation for mechanical ducts and piping, reducing the floor-to-height distance. In consequence, the CSJ system can offer a number of advantages including reduced joist depth, better plenum space use, and the reduction on the overall building cost from weight savings [2]. However, there is still significant research need in the aspects of shear stud anchor behavior and the incorporation of the steel deck profile in the composite system. For instance, the SJI CJ-Series [3] provides a shear stud capacity conservatively assuming that all shear studs are placed on the "weak" side of the deck center stiffening rib, i.e. on the side of the deck stiffening rib closest to the point of maximum bending moment for the joist span. Moreover, the catalog considers the shear force to be derived from push-out tests generally oriented for composite beams. As a consequence, the catalog presents conservative values to the structural engineer to be used in their building design.

Researchers have studied and improved several aspects of the push-out test configuration. Chinn [4] performed 10 solid slab push-out tests using normal and lightweight concrete to predict the stud performance. Slutter and Driscoll [5] related the ultimate flexural strength of a beam to the ultimate strength of the stud by testing 9 push-out specimens and 11 push-out tests from other sources. Davies [6] studied a scaled push-out test version to study number, spacing, and pattern of welded studs. The author concluded that the stud ultimate strength varies linearly with the longitudinal stud spacing. Ollgaard [7] derived the stud capacity varying concrete compressive strength, stud diameter, number of connectors per slab, and concrete material characteristics. Results showed that the average shear strength of a stud is almost proportional to the cross-sectional area of the stud for specimens with similar concrete properties, but it decreases when the concrete strength decreases considerably. Oehlers and Johnson [8] analyzed 110 solid slab push-out tests to derive an equation to predict the strength of the studs in beams. Robinson [9] performed 49 push-out tests with 51 mm and 76 mm deep metal deck, and one or one pair of studs welded on each side of the specimen. Slips at ultimate load with pairs of studs were about 1.36 times slips than a single stud, and the strength of a pair of studs was 1.3 times stronger than a single stud. Sublett [10] performed 24 push-out tests to determine the strength of studs in composite open web steel joists. The author concluded that the strength of the concrete can highly influence the stud ultimate strength, and he recommended that the stud anchor position should be included as an influencing parameter to the

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stud shear strength formula given by the current AISC code. Easterling et al. [11] identified the position of the shear stud relative to the stiffener in the bottom flange of the deck as an important parameter to consider when calculating the shear stud strength. “Strong” and “weak” position concepts were defined on the basis of where the connector is located relative to the steel deck stiffener. Later, Rambo-Roddenberry [12] concluded that if the shear studs were located on the side of the deck stiffening rib closest to the ends of the joists, the shear stud capacity increases approximately 20–30 %.

This effect has not been included in the SJI catalog. Xue et al. [13] conducted 30 push-out tests on stud shear connectors to investigate the effect of different parameters, i.e. stud diameter and height, concrete strength, stud welding technique, steel beam type, and the amount of transverse reinforcement. Three failure mechanisms were found: splitting failure of concrete, stud shank failure, and welding seam failure. An expression to calculate the ultimate slip capacity was derived, and a new expression of stud load-slip relationship was proposed. Wang et al. [14] performed 12 push-out tests on stud connectors with large diameters and high strength. All the specimens failed by shear in the connector. No cracks were visible around the stud. It was found that the shear resistance and the shear rigidity increase as the diameter and the tensile strength of the studs become bigger. However, the increased use of high strength concrete during the past two decades can lead to different stud failure mechanisms, therefore providing a good justification for the study of other studs diameters.

In this work, we used a modified version of the standard push-out tests presented by EN-1994 [15] to include the effect of the steel deck profile. A double-angle steel section is used to replicate a typical steel joist top chord as Fig. 1. The modified version of the push-out experiment is used to better determine the stiffness coefficient when the stud anchor is placed in the weak or strong side with respect to the steel deck stiffener. Moreover, 13 mm and 16 mm diameter studs are used in order to investigate their behavior and to compare with the standard 19 mm diameter connector.

Solid mechanics procedures have been used extensively to derive the governing differential equations of a composite system [16–18]. The stiffness coefficient used to define the shear force vs. slip at the concrete-joist interface can be directly related to the number of stud anchors, therefore resulting in a reduction of the flexural strength [19,20]. Prakash et al. [21] designed a modified push-out test to study load-slip behavior and to determine the design strength and stiffness of stud anchors. The author concluded that the average strength of the stud connector was comparable with the EN-1994 [15] values and the average static stiffness equal to 53.3 kN/mm. was found to be closer to the mean value given in literature. However, only 19 mm shear stud anchor were used. Here, the shear stud anchor stiffness coefficient is used in an analytical solution of the composite system. Predictions of the overall system deflection when the effective composite moment of inertia of the joist are included, and compared to typical values presented in the international standards and codes.

2. Modified version of the push-out configuration

Full-scaled CSJ systems remain a costly and time-consuming option to investigate the shear stud anchor behavior [22]. As a consequence, many recognize the benefits of predicting the stud anchor behavior by conducting small-scale tests. Although various codes and guidelines exist regarding the strength of a single shear stud anchor, it has been reported the inadequacy of the push-out test setup presented [21]. The limited shape, size, and strength of the concrete, the steel section profile, and the use of steel deck can be inconvenient when the higher concrete strength, steel joist profiles, and different steel deck dimensions are used.

In the present work a new push-out test configuration is proposed. Twenty-four push-out tests are planned and tested to predict the linear behavior of the shear connector embedded in a concrete slab when a steel sheet profile is used. Variations in stud diameter (13 mm and 16 mm) and stud position relative to the deck stiffener (strong and weak) are studied. The novelty of this proposed setup is the utilization of stud anchors of 13 mm and 16 mm in diameter welded through a steel deck sheet. As a consequence, the effect of the weak and strong side stud position can be studied.

Details of the modified push-out specimen are shown in Fig. 1. Two concrete slabs of dimensions 610 mm wide, 660 mm long, and 114 mm thickness are connected to a pair of steel angles to form a push-out specimen. A 2.0CD/20 steel deck profile was used as a formwork and reinforcement for the concrete. Since the nominal dimensions of the steel deck profile were longer than the required dimensions, the deck

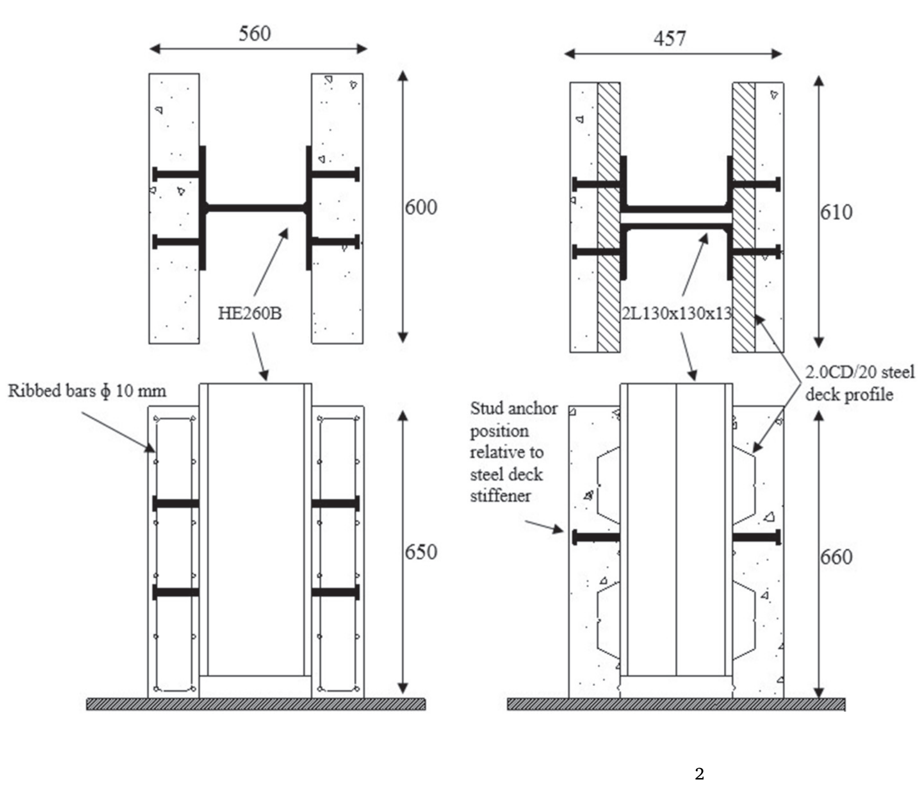

Fig. 1. Details of the standard and modified push-out test setup.