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Behavior of a new shear connector for U-shaped steel-concrete hybrid beams

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ABSTRACT

This paper presents an investigation of the behavior of a new type of shear connectors used in U-shaped steel-concrete hybrid beams. Besides the role in transferring the force between concrete and steel material, this new type of shear connectors, welded on the upper flange of the U-shaped steel beam, serves to maintain the shape of the steel cross-section during concrete encasement. Several forms of shear connectors can be used such as L-shaped or square cross-section. The experimental investigation of the behavior of these shear connectors using asymmetrical push-out tests is presented in this paper. A finite element model has been developed in order to identify the stress behavior of the connectors and the surrounding concrete. The FE model is validated by comparing its results against experimental data and then used to perform a parametric study. Based on the parametric study results, an analytical formula for calculating the force transfer capacity of the shear connector is proposed.

1. Introduction

In composite construction, profiled steel sheets have been successfully used as permanent and integral formwork for the underneath of reinforced concrete slabs [1–3]. Profiled steel sheets serve not only as a concrete formwork during construction but also as principal tensile reinforcements for bottom fibers of the composite slab, offering an economic design solution over a plywood formwork. Acting compositely with reinforced concrete slab, profiled steel sheets produce a considerably stiffer and stronger floor system than many others. Consequently, the weight and size of primary structures as well as foundations can be reduced. Over the last few years, the profiled steel sheet has been introduced as permanent formwork and integral shuttering for the sides of reinforced concrete beams [4–7]. More recently, a U-shaped steel profile with infill concrete has been developed [8]. This new composite configuration can be considered as one of the most recent developments in steel-concrete composite beam construction which provides several advantages: more ductility compared to reinforced concrete beams with the same flexural strength, increase in shear strength and shear ductility, increase in span to depth ratio, reduction of concrete creep and shrinkage, and decrease in site labor costs. This new type of beam can be considered as a combined solution of steel-concrete composite and reinforced concrete beam. Indeed, the infill concrete in the U-shaped steel profile mitigates the local buckling of the webs of the steel profile and improves strength and stiffness of the beam. Besides, with this new configuration, longer beam span can be achieved with a significantly reduced beam height compared to reinforced concrete beam one. Moreover, fire resistance of this new composite beam can be assured without any protection of U-shaped steel profile by designing reinforcing bars, embedded in the concrete beam, against the applied design load in fire situation. However, corrosion resistance needs to be ensured by protecting U-shaped steel element.

The overall behavior of composite steel-concrete members strongly depends on shear connection between steel and concrete encasement which may be accomplished by three main shear transferring mechanisms: chemical bonding (bond between cement paste and surface of the steel), friction (assumed to be proportional to the normal force at the interface) and mechanical interaction (due to embossments, ribs or shear connectors). The role of shear connection is essential; without it there is no collaboration between steel and concrete material. It limits the slip that may occur along the steel-concrete interface. Thus, ensuring a resumption of longitudinal shear, it allows to obtain a composite section with two components working together. However, superposition of force transfer mechanisms is not generally permitted. The experimental data indicate that direct bearing or shear connection often does not initiate before the direct bond interaction has been breached. Moreover,

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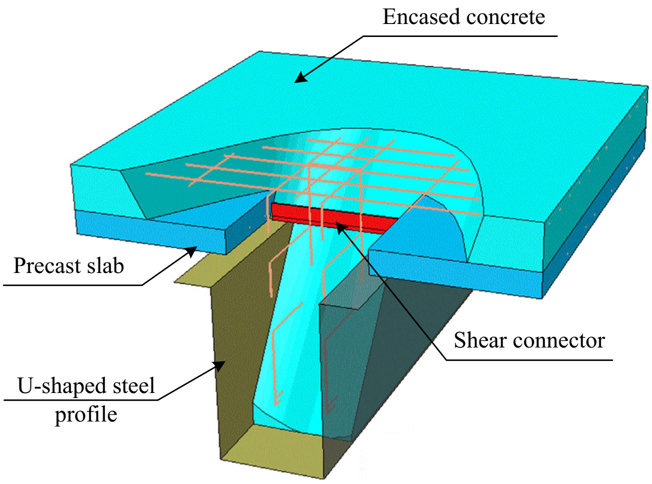

Fig. 1. U-shaped steel-concrete hybrid beam (USCB).

limited experimental data is available regarding the interaction of direct bearing and shear connection via steel anchors. Therefore, the shear connection between the two materials is supposed to be ensured only by the mechanical devices, commonly headed studs. The behavior of headed stud shear connectors has been investigated by numerous researchers worldwide by conducting push-out experimental tests [9–11] and/or by numerical simulation [12–14]. Although the common type of shear connector is headed stud, some older generations of shear connectors such as channel, angle or square bar shear connectors have been increasingly interested by many researchers [15–23] over the last decade. The installation of these older generations of shear connectors is not expensive since the procedure is similar to that used for beam stiffeners or connection components, where a specific welding equipment with high voltage is not required [18]. Recently, angle connectors have been used in steel-concrete composite beams with U-shaped steel girders [8]. However, no analytical models were readily available yet for calculating the shear force transferring capacity of this shear connector type, used in this new composite beam configuration.

In this paper, the behavior of two types of shear connector for U-shaped steel-concrete hybrid beams (USCB), see Fig. 1 is investigated. Besides the role in transferring the force between the two materials, these shear connectors, welded on the upper flange of the U-section, serve to maintain the shape of the steel cross-section during concrete encasement. Several forms of the connector cross-section can be used such as L-shaped or square cross-section. The L-shaped angle connectors, in the absence of top flange, could be cheaper and more economical compared to the channel ones. In general, a hoop reinforcement should be provided for the L-shaped angle connector while being used in classical composite beams, in order to limit the uplift of the concrete slab [24]. However, it is not the case for L-shaped angle connectors used in U-shaped steel-concrete hybrid beams in consideration of the connector part fully embedded in the concrete. This new type of shear connection is not covered in present norms of composite structures and it requires an investigation on its behavior and on force transfer mechanisms. This paper presents the experimental investigation of the behavior of these shear connectors through asymmetrical push-out tests. Two different types of the shear connector cross-section are considered: square and L-shaped section. To get further insight into the force transfer mechanism while using L-shaped shear connectors as connector devices in USCB, a finite element model is developed. The latter is validated by comparing its results against four experimental data tests. Based on a parametric study using FE model, an analytical design formula for shear connectors is proposed.

2. Experimental program

An experimental program is developed to quantify the strength and deformation capacities of shear connectors as well as to gain an insight into the force transfer mechanism in the U-shaped steel-concrete hybrid beams. A modification of the typical push-out test setup proposed by Eurocode 4 [24], which is usually adopted for classic shear stud connectors, is made to represent the real situation of the U-shaped steel-concrete hybrid beams. Primarily, two experimental tests with two different types of connector cross-section are conducted in order to choose an appropriate connector type to be used in USCB; as stated earlier, the square and L-shaped connector cross-section are considered. Next, three additional tests are conducted for the selected appropriate connector type, L-shaped shear connector in this case. In the following, the detailed description of the experimental program is presented.

2.1. Geometric description of the test configuration

The test setup consists of a universal testing machine with a capacity of 1500 kN, a U-shaped steel-concrete hybrid beam specimen, reaction blocks and bracing systems, see Figs. 2 and 3. The actuator is fixed to one end of the steel beam. It is attached to a 40 mm-thick steel plate that serves as a platform for push-out test specimens. The 40 mm thick steel plate is welded to two 6 mm-thick gussets, which are connected to the webs of steel beam at one end via twelve 20 mm-diameter high-strength bolts. At the other end of the specimen, the back side surface of the concrete floor is put in contact with a rigid steel beam. The specimen is positioned horizontally on 2 vertical supporting steel columns where at the top surface of their end-plate (with slotted holes), two greased PTFE plates are placed, allowing the horizontal displacement of the steel beam to occur. This test setup is similar to the one used by Lowe et al. [25] and Topkaya et al. [26]. The advantage of this setup is that there is only one slippage interface, compared to two interfaces for a typical push-out test.

2.2. Test specimens

The specimen consists of a U-shaped steel beam, two precast-slabs, a reinforced concrete beam encased in a U-shaped steel beam

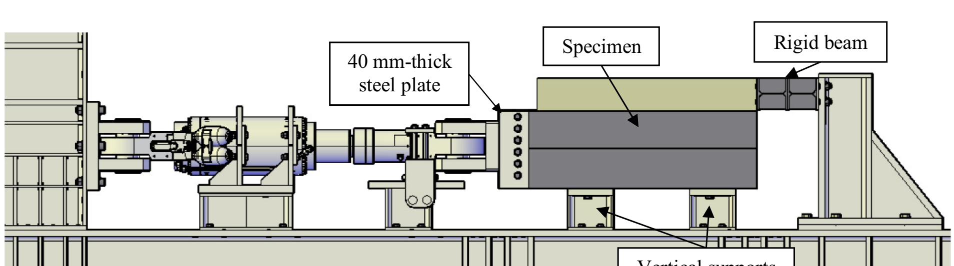

Fig. 2. Schematic of push-out test setup.