Engineering Structures 147 (2017) 398–409

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Experimental and numerical analysis of the push-out test on shear studs in hollow core slabs

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ARTICLE INFO

Article history:
Received 18 August 2016
Revised 23 December 2016
Accepted 27 May 2017

Keywords:
Headed stud
Hollow core slab
Composite structures
Composite slim floor
Push-out test
Finite element method
Numerical simulation
Precast concrete

ABSTRACT

Prefabricating concrete slabs combined with the speedy erection of steel structures is a good approach to reduce the construction time and optimize construction processes. Composite action between a steel profile and a concrete slab is most commonly established by using headed studs welded to the flange of a steel profile. In this research, an innovative arrangement was proposed for a composite slim floor with the headed stud welded to the steel web inside the hollow core slab. This paper presents the results of an experimental program using push-out tests to determine the shear resistance of the headed studs. In addition, a numerical study of experimental results was conducted to analyse the composite action of headed studs and precast concrete hollow core slabs. The experimental results showed the proposed solution had good behaviour. Theoretical analysis presented safe side predictions of the connector resistance. The finite element model was created, and a satisfactory match with the experimental data was obtained. Parametric FE (Finite Element) analysis was performed by using the variation of the compressive strength of the concrete and yielding strength of the headed studs.

1. Introduction

The composite slim floor consists of the steel profile contained within the concrete slab depth and a range of benefits is provided such as the minimization the overall height of a building for a given number of floors, or the maximization the number of floors for a given height of building. Additionally, the flat soffit is achieved because there are no interruptions found with down stand beams, which gives complete freedom for the distribution of services below the floor. The fire protection is also a characteristic of the shallow floor, besides to be an economical solution to reduce the costs with workmanship and to provide shorter construction time. Another benefit is that some forms of composite slim floor construction inherently achieve the composite interaction between steel beam and concrete slab, thereby enhancing structural efficiency.

The shallowness of the floors is achieved by using asymmetric steel beams with a wider bottom than top flange, which enables the slab to sit on the upper surface of the bottom flange with adequate bearing, rather than the upper surface of the top flange as found with down stand beams. The floor slab can have various concrete slab configurations or a composite slab with metal decking. The precast slab has been widely used [1,2] because it is a great option for increasing the quality and productivity of construction. To facilitate its assembly and concreting, the ends of the precast slab can be chamfered and only the steel profile requires shoring of each span [3]. The in situ concrete is used to provide a leveled topping and to fill the voids between the hollow cores and the steel profile, involving the shear connectors (Fig. 1).

There are several alternatives to promote this joint behaviour of steel and concrete. The best option depends on the knowledge of the shear connector's behaviour, the applicable failure modes, the design criteria and the cost. According to [5], the headed stud is subjected to shear and bending stress, which can lead to a failure in the connection between the connector and the steel profile. Moreover, the rotation of the connector's head generates cracks in the concrete that forms an embedded concrete section.

Determining the shear connector's behaviour in a steel-concrete connection is usually achieved by using push-out tests. This test is composed of a steel profile that is connected to two concrete slabs by the shear connectors to be studied and the slip between the slabs; then, the profile is measured. Several push-out tests were conducted on specimens, including trapezoidal profiled steel sheets and headed studs [6–9]. The experimental results concluded that the resistance of the through-deck welded headed studs cast in slabs with profiled steel sheeting will depend on the geometry

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http://dx.doi.org/10.1016/j.engstruct.2017.05.068
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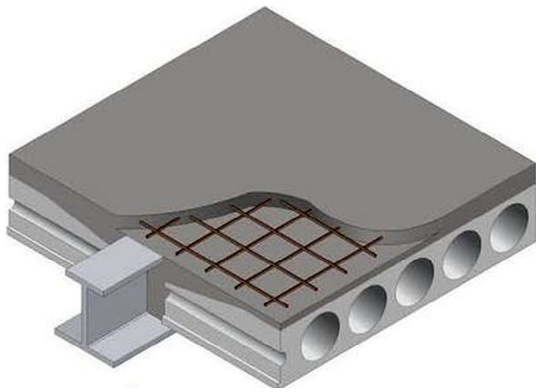

Fig. 1. Composite slim floor comprised by precast hollow core slabs and asymmetric steel beams [4].

of the sheeting and shear connector's height [7]. A three-dimensional nonlinear finite element model was developed to investigate the effect of transverse spacing in push tests with double studs placed in favourable and staggered positions. The results showed that the shear resistance of pairs of shear connectors placed in favourable and staggered positions was 94% and 86% of the strength of a single headed stud, respectively, when the transverse spacing between headed studs was 200 mm or more [8]. Under different fire conditions, the ultimate load and initial stiffness were generally decreased when the shear connector temperature increased [9].

In push-out tests with different stud diameters and concrete strengths, the concrete's compressive strength was observed to significantly affect the shear resistance of the headed studs [10]. A numerical and theoretical comparison showed that the specifications in [11] and [12] usually overestimated the capacity of the headed stud [13], unlike the study of [14,15], which concluded that [12] is conservative. Other studies of the shear transferring mechanisms of composite shallow cellular floor beams have been developed, which are formed by the web opening with or without other additional elements, i.e., tie-bar or headed studs. In summary, the push-out tests showed that the shear resistance increased when the web opening diameter expanded with an increase in the concrete strength and the use of additional elements [16].

Finally, push tests on stud bolts in hollow core slabs were performed to determine the capacities of the stud bolts in conventional composite beams. It was concluded that the optimum gap width of 80 mm should be used for square-end hollow core slabs. The experimental results were analysed, and design equations for calculating the shear resistance of headed studs for this composite construction were proposed [17,18]. Parametric studies showed that the concrete strength had a notable effect on the shear resistance and load-slip behaviour [19]. Because the connections by adherence appear promising, new types of steel-concrete connections with embossments geometry have been adapted for use in precast slabs [20]. However, push-out tests on headed studs in a composite slim floor with hollow core slabs were not found in the literature.

In this paper, an innovative arrangement is proposed, for which the headed stud welded to the steel web inside the hollow core slab. Three push-out tests on headed studs in hollow core slabs were conducted to determine the capacities of the headed studs in hollow core slabs, and the results were compared with the design predictions. A three-dimensional nonlinear finite element model was developed, and a parametric study of push-out specimens with different headed studs and concrete strengths was performed. The numerical results were also compared to the code provisions.

Table 1
Mechanical properties of the steel elements.

Material	Yield stress (MPa)	Rupture stress (MPa)
Profile	345	450
Connector	345	430

2. Experimental program

The push-out tests were part of the experimental program of [21]. With the aim of studying the behaviour of the composite slim floor, the transfer of forces at the interface between the steel profile and the concrete slab was characterized by a proposed push-out test to evaluate the role of the shear connectors. Three push-out tests of the slim floor were conducted with displacement control to determine the shear resistance of the steel-concrete connection, an exemplar and two replicas.

2.1. Physical characteristics

The physical models consisted of pre-stressed hollow core slabs with a characteristic compression strength of 45 MPa and length of

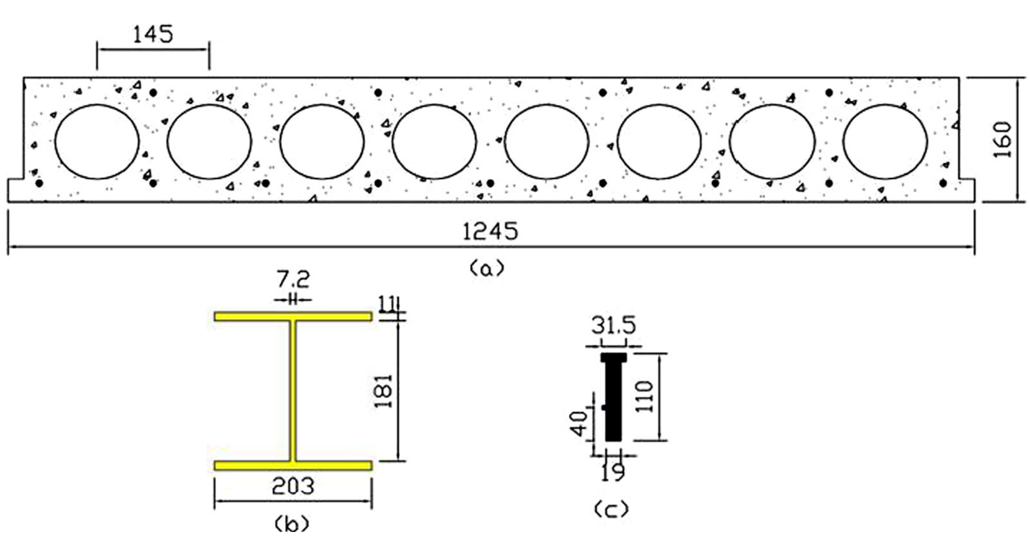

Fig. 2. Dimensions of the components of the push-out specimens (unit: millimetres).