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Evaluation of the flexural behavior of composite beam with inverted-T steel girder and steel fiber reinforced ultra high performance concrete slab

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ABSTRACT

Huge efforts have been made to develop ultra high performance concrete (UHPC) and exploit its remarkable properties. Among the achievements, various solutions were proposed to achieve optimal composite beams using steel fiber reinforced UHPC. In order to increase the economy in material, a composite beam combining a slab made of UHPC and a steel girder without top flange is proposed. In this composite beam, the inverted-T steel girder requires the studs be arranged on the web for the composition with the UHPC slab. Considering the absence of studies evaluating the flexural behavior of this new type of composite beam, this study examines experimentally the flexural behavior with respect to the stud spacing and slab thickness. To that goal, eight composite beams with varying stud spacing and UHPC slab thickness were fabricated together with two additional composite beams using slabs made of normal concrete without steel fiber reinforcement for comparison. In addition, an analysis method considering the tension-softening behavior of steel fiber reinforced UHPC in the material model and the corresponding strain compatibility conditions of the beam member is proposed. The comparison of the analytic and experimental results reveals the good accuracy of the predictions indicating that the empirical tension-softening curve reflects reasonably the actual behavior of steel reinforced UHPC composite member.

1. Introduction

Modern concrete structures require materials with higher strength, higher performance and higher durability to deal with the ever-increasing height and length of structures and resist to harsher environmental conditions. However, conventional concrete is brittle and develops low tensile and compressive strengths. Therefore, studies were undertaken worldwide on steel fiber reinforced ultra high performance concrete (UHPC) with compressive strength higher than 180 MPa [1–3]. Compared to conventional concrete, steel fiber reinforced UHPC is known to exhibit improved deflection and flexural strength and post-cracking ductile behavior. The exploitation of UHPC in bridge deck is expected to extend significantly the lifetime and reduce significantly the weight of the structure [1,4–6].

A review of previous studies dedicated to steel composite beams using UHPC reveals that a European commission led by France and Germany developed a composite beam connecting an inverted T-shape steel girder and a UHPC deck by giving a puzzle shape to the top of the girder as shown in Fig. 1 [7]. The US Federal Highway Administration conducted studies on the connection of composite beams using an I-shape steel girder and UHPC waffle deck panels by installing various shapes of shear connectors at the top flange of the steel girder and by filling polymer concrete in the shear connectors at the top of the steel girder and the shear pockets arranged at the top of the precast waffle deck [2,8] (see Fig. 2).

From this survey, it appears that the top flange of the steel girder might be superfluous when the composite beam is formed by composing a UHPC slab with the steel girder considering the high stiffness developed by the UHPC deck and that the shear connector usually applied for the construction of composite beams can play the role fulfilled by the top flange of the steel girder. Based upon this observation, this study applies an inverted T-shape steel girder in which the upper flange of the girder is removed and replaced by shear connector for the composition of the composite beam shown in Fig. 3 [7,9–11].

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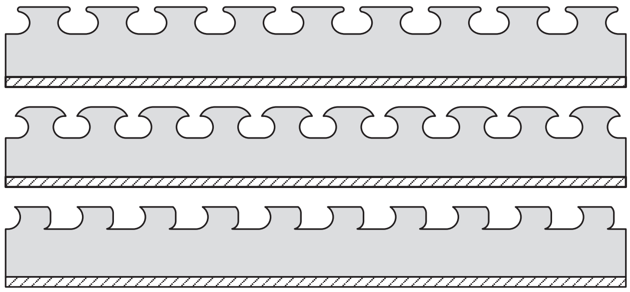

Fig. 1. Inverted-T steel girder with puzzle-shape [7].

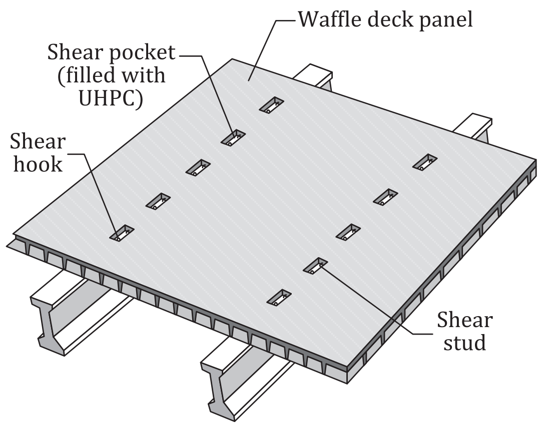

Fig. 2. Waffle deck UHPC panel system [2,8].

By adopting such configuration, the studs needed for the composition of the steel girder with the UHPC slab must be disposed in the web of the girder because of the absence of the upper flange. However, very few experimental and theoretical studies were dedicated to the behavior of the shear connectors welded on the web of the girder and to the behavioral characteristics of the composite beam with the inverted-T steel girder.

Accordingly, this study intends to evaluate the behavioral characteristics of the shear connectors and the flexural behavior of the composite beam using the inverted-T steel girder. To that goal, eight composite beams with varying stud spacing and slab thickness were fabricated and tested. Moreover, two additional composite beams using the inverted-T steel girder and slabs made of 50-MPa normal concrete without steel fiber reinforcement were also fabricated for comparison with the UHPC composite beams.

Table 1
Designation of test members and test variables.

Member designation	Slab thickness (mm)	Stud spacing (mm)
50-50	50	50
50-100	50	100
50-200	50	200
50-400	50	400
100-50	100	50
100-100	100	100
100-200	100	200
100-400	100	400
N50-100	50	100
N100-100	100	100

2. Test setup

2.1. Test variables and test members

The stud spacing and slab thickness are selected as test variables. Therefore, two thicknesses of 50 mm and 100 mm are adopted for the UHPC slab and, four different lengths of 50, 100, 200 and 400 mm are chosen for the longitudinal spacing of the studs leading to a total of 8 UHPC composite beam prototypes. In addition, two supplementary composite beams using the inverted-T steel girder and slabs made of 50-MPa normal concrete without steel fiber reinforcement are also considered. All the test members are fabricated with a span length of 2200 mm. The girder presents a bottom flange with thickness of 13 mm and width of 225 mm, and its web is 8-mm thick and 177-mm high. In addition, the UHPC slab is placed with thickness of 50 mm and 100 mm and width of 248 mm at 137 mm along the height of the web.

The slab thickness is selected as test variable to examine the effect of the embedment depth of the shear connector welded on the girder web. The change in stud spacing intends to evaluate the composite behavior of the composite beam and to derive the appropriate spacing for the configuration shown in Fig. 3.

Table 1 gives the designation of the test members according to the test variables. Fig. 4 indicates the dimensions of the test members. Figs. 5–7 present the girder installed in the steel form, the completed test members and a view of the loading test. In the sensor layout shown in Fig. 7(a), a total of 18 strain gages with 9 concrete strain gages and 9 steel strain gages are attached to the front and rear faces of the specimen and, two LVDTs (linear variable differential transformer) are installed at 1/2 and 1/3 of the span to measure the deflection. In addition, strain gages are also embedded inside the specimen and attached to the top and side faces of all the studs located inside the 400-mm wide area around the mid-span.

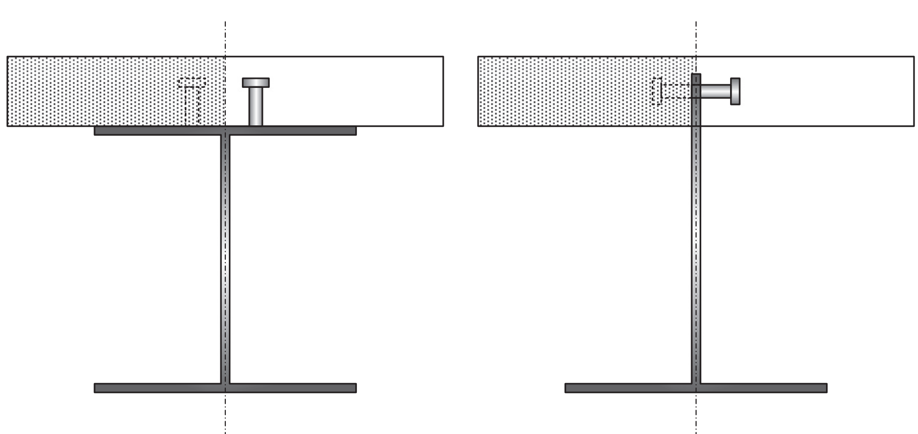

Fig. 3. Cross-sectional configuration of conventional composite beam (left) and composite beam with inverted-T shaped girder (right).