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Push-out test on the web opening shear connector for a slim-floor steel beam: Experimental and analytical study

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ABSTRACT

In slim-floor construction, the web opening of the steel beam is proposed as WO shear connectors of different shapes; square (WSO), rectangular (WRO) and circular (WCO) connectors were considered to evaluate the ultimate shear strength, failure mode and ductility performance. Six push-out tests were conducted under static loading. Finite Element (FE) models using ABAQUS software were validated using test results, and then, further models were developed. The effective parameters include web thickness of the steel beam, opening size, compressive strength of the concrete slab and group arrangement for WO connectors. The test result indicates higher shear strength for the WSO shear connector compared with WRO and WCO. FE analysis presents notable shear achievement of WSO and WRO connectors because of the larger effective width of the square and rectangular openings incorporated with infill concrete. Thicker web steel beam associated with larger opening enhanced the compressive and tensile resistance area of the infill concrete in all cases. The effective spacing between group WCO shear connectors was found to be 250 mm, and it was found to be 300 mm for WSO and WRO to achieve maximum shear strength. Finally, the ultimate shear resistance of the WCO and WSO/WRO shear connectors were predicted and validated with COV of 0.032 and 0.021, respectively.

1. Introduction

Recently, focus on slim-floor systems in Europe has increased in light of the emphasis on economical steel-framed building construction [1,2]. This system is an innovative steel-concrete composite floor product with a minimum depth, where the slab is supported on the lower flange of the steel beam [3–5]. The steel beam placed in the slab depth results in a flat appearance; the product has other advantages, including fast construction, decreased floor height, and building service passages, as shown in Fig. 1. This system has high stiffness and strength, which are more advantageous to either reinforced concrete or steel construction [6–8]. The circular web opening arrangement of slim-floor steel beam enabled the in-situ concrete to pass and fill the opening and enhanced the interaction of the concrete slab with the web post of the steel beam to transfer the applied shear load by means of a web opening (WO) shear connector. Concrete strength, web thickness, and opening configuration are effective factors on the shear transferring mechanism of the WO shear connectors, as investigated experimentally by Huo, and D'Mello [9]. The variables considered are the different sizes of the web circular opening (WCO) and the different compressive strengths of the infill concrete. For the concrete, compressive crushing of the infill concrete is accomplished by the web of the steel beam in the direction of shear load combined with tensile splitting failure in the transverse direction. Within this system, in which most of the beam is embedded in concrete, various methods for the arrangement of the shear transferring device are used to supply information in relation to their shear behavior and resistance. Concrete in composite beams has fire resistance, compressive strength, and smooth floor surface, whereas steel provides high tensile strength that causes proper ductility. The design of the composite beam is dependent on shear transfer mechanism that is provided by shear connectors between the steel beam and concrete slab. In recent years, a considerable number of tests have been conducted for transferring concrete dowel technology, which is known for its use in filler beam bridges, to slim floor construction. By placing the shear connection in the web of the hot-rolled steel section, the stiffness of the beam is enhanced significantly with no enhancement in the depth of beam or

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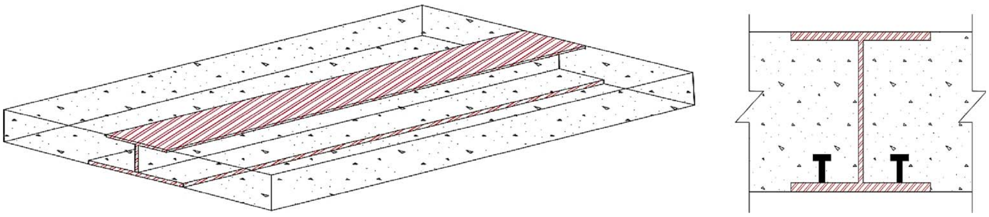

Fig. 1. Slim-floor integrated beam system.

a) WCO b) WSO c) WRO

Fig. 2. Steel beam and opening configuration.

Table 1
Test specimen configuration.

Specimens label	Connectors	[a]Dimension (mm)	f_{cu} (MPa)	f_t (MPa)	[b]Length (mm)
WCO-C25-8.6	Circular opening	Ø 140	25.34	2.25	8.6
WCO-C40-8.6	Circular opening	Ø 140	40.28	3.23	8.6
WSO-C25-8.6	Square opening	125 × 125	25.34	2.25	8.6
WSO-C40-8.6	Square opening	125 × 125	40.28	3.23	8.6
WRO-C25-8.6	Rectangular opening	100 × 150	25.34	2.25	8.6
WRO-C40-8.6	Rectangular opening	100 × 150	40.28	3.23	8.6

[a] The dimensions were considered Ø for circular and B * H for rectangular and square opening.
[b] The web thickness of steel beam was considered as the Length of web opening connectors.

thickness of floor. A well-prepared method ensures that the composite action results in effective application of the material with no addition to the cost or intricacy of fabrication and erection [10–16].

The effect of the opening geometry has not been studied in WO shear connectors. Such study would develop shear transferring behavior that considers the ideal shape of the opening in addition to the slim depth for the slim-floor steel beam. This study conducted six experimental push-out tests on WO shear connectors subjected to direct monotonic shear force. The varied effective parameters are considered to evaluate the behavior of tested shear connectors. The slip value was measured as downward movement of the steel beam in load direction. The parameters investigated are square, rectangular, and circular geometry of the opening. In slim floor flooring system, pre-cast slab panel usually erected with the unit resting on the bottom flange plate which welded to bottom beam flange. In situ structural concrete is typically used as infill material to partially surrounds the beam section. Hence, the WO shear connector can be easily adapted for various methods of construction. However, concrete strength of infill material will affect the shear capacity of the introduced connection system. Therefore, various compressive strength of the infill concrete is needed to be investigated in addition to opening geometry.

The load-slip behavior and failure of the WO connectors as well as the shape effect of the opening that considers the opening areas those provided. Push-out tests are frequently used to investigate the behavior of shear connectors, which are usually costly and limited to few parameters. As an alternative, finite element (FE) modeling has been be used to provide efficient information on the behavior of shear connectors [17–19]. Specifically, the results obtained from FE analysis have to be verified and compared with results achieved in experimental tests. The interaction of the steel part and concrete slab using shear connector through three-dimensional nonlinear behavior of the experimental specimens led to very intricate mathematical modeling similar to what has been studied in FE analysis in literature [20,21]. The shear transferring capacity, load-slip behavior, and failure mode of the connectors are well predicted by the FE model [19,22,23]. Hence, this research aims to study the shape effect of the web opening through an experimental test. A further FE analysis investigates the WO shear connector behavior by examining several parameters not considered in the experiment. These parameters include changes in the dimension of the web openings, the web thickness of the slim-floor steel beam, and the concrete compressive strength. The load-slip curve achieved through experiments was chosen for use in examining the validity of the FE models. The results obtained from FE analysis were used to propose and verify new empirical equations to calculate the shear resistance capacity of the web opening shear connector based on circular, square, and rectangular shapes of the opening.