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FE modeling and numerical investigation of shallow cellular composite floor beams

Toi Limazie, Shiming Chen *

School of Civil Engineering, Tongji University, Shanghai 200092, China

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ABSTRACT

The behavior of shallow cellular composite floor beam is normally governed by the shear transfer mechanism at the contact interface between the concrete slab and the encased steel beam, thus by the influence of the two materials. A detailed finite element modeling approach in investigating the structural behavior of shallow cellular composite floor beam is presented. The shear bound at the contact interface between the concrete slab and the steel beam is simulated by using the contact modeling and considering the adhesion, the friction and the local compression at all the contact zones. Both the material and geometric nonlinearities are considered in the FE modeling of the shallow cellular composite beams. The FEA results are calibrated and validated against the test results and the comparisons indicated that the FE analysis procedures with the contact modeling agree well with the test results, and can accurately predict the flexural behavior and the load bearing capacity of the composite slim floor beam. An extensive parametric study is further conducted to investigate all the likely influences of the parameters such as geometric dimensions and the web openings size and spacing on the structural performance of the shallow cellular composite floor beam.

1. Introduction

Shallow cellular composite floor beam (SCCFB) is a new type of composite floor beam which is usually composed of the deep steel decking, the concrete slab and an encased steel beam with regularly spaced opening performed within the web post, resulting in a flat appearance (Fig. 1). It offers important benefits in terms of cost such as the construction flexibility and speed, long spanning capabilities without or with fewer secondary beams, shallow floor depth, and inherent fire resistance [1–3]; [4], as well as other advantages offered by ordinary composite beam construction. Due to its merits, composite slim floor systems have been successfully used in many modern building projects such as commercial and residential buildings, hospitals, and schools. However, compared to other conventional steel and concrete composite constructions, application of the composite slim floor has been limited in many countries due to the lack of design specifications and practical analysis procedures.

The structural performance of a shallow cellular composite floor beam is governed by the shear transfer mechanism within the composite beam as well as by the performance of the concrete slab and the structural steel beam. To achieve the desired composite action and the desired load bearing capacity, the longitudinal shear forces within the composite beam have to be effectively transferred between the concrete slab and the steel beam. For an ordinary composite slim floor beam, the transfer of the longitudinal shear forces is achieved through the mechanical interlock mechanism, while for the shallow cellular composite floor beam (SCCFB) the shear transferring is achieved by the shear bound at the contact interfaces and the shear connection systems which consist of the cast-in-place concrete passing through the steel web opening combined with an embedded reinforcing bar. Besides, the structural behavior and desired composite action of a composite slim floor beam would be also influenced by the geometric and material characteristics of both the concrete slab and the steel beam.

Experimental investigations on integrated slim floor beams have been conducted in the Helsinki University of Technology; and the influences of the parameters such as reinforcement ratios and types of loading on the behavior of composite slim floor beams were investigated by Bernuzzi et al. [5]. Mullett [6] also conducted tests on slim floor beams using the hollow core precast units and proposed a design guidance for Slimflor beams. The design guidance was in accordance with the BS5950: Part 1: 1990 [7]. Slimflor beams using the profiled deep decking were also investigated by Mullett and Lawson [8] and some design tables and worked examples were given. A full-scale slim-floor beam test was presented by Mullett, where the shear transfer between the steel section and the concrete slab was provided by the shear bond at the interface between the concrete slab and the steel beam [9]. Wang [10] presented an experimental study of slimfloor beams using deep decking with fixed end connection to a column frame. Also, four full-

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* Corresponding author.
E-mail address: chensm@tongji.edu.cn (S. Chen).

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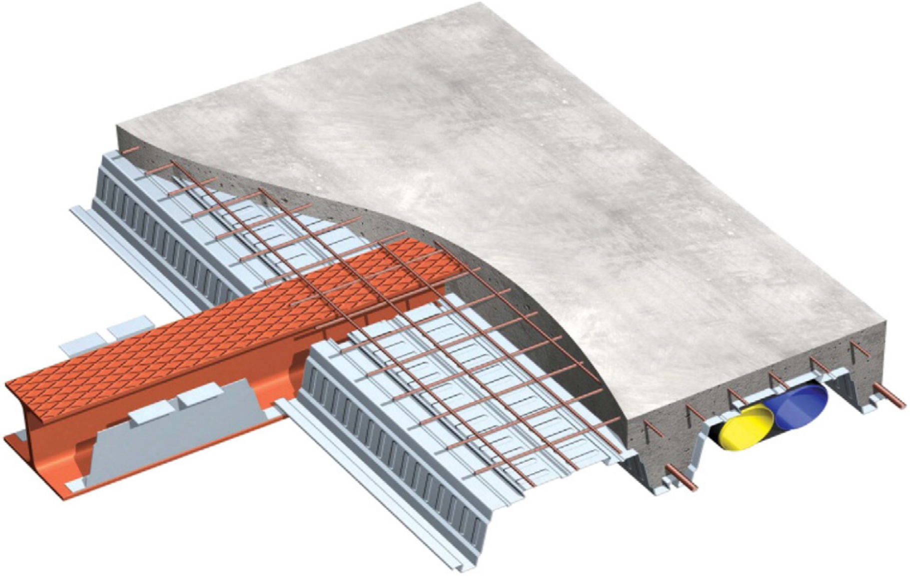

Fig. 1. Ordinary asymmetric slim floor beam configuration.

scale tests were carried out on two continuous span composite floor systems (6 m × 10 m) by Hegger et al., [11]. However, the structural mechanism of this integrated composite slim floor beam system has not yet been well understood. Investigating the longitudinal shear force as well as the influence of the geometric and material characteristics on the structural behavior of composite slim floor beams would require cumbersome experimental investigations that would result to expensive testing programs. Also, due to the semi-empirical nature of the experimental investigations, it would be difficult to obtain a clear picture of the physical behavior at the concrete interface between the concrete slab and the steel beam, as within the shear connection system.

During the last decade, attempts have been made to develop design and analysis procedures consisting of computer-based methods which can be used for the analysis of the composite beams, instead of the standard large-scale testing programs, aiming to move away from expensive experimental tests but taking into account all the parameters that could be ignored in the physical tests.

Numerical analytical and FE analyses are alternative methods in investigating the complex structural behavior of composite slim floor beam. Based on the principle of virtual work, Ranzi et al. [12–14] proposed an analytical formulation to analyze the generic multi-layered composite beams which were composed by n layers and interconnected by flexible interface connections between the adjacent layers. A multilayer laminated composite structure model was also proposed by Karama [15] to predict the mechanical behavior of the multi-layered laminated composite structures. Uy and Bradford [16] proposed a straightforward method to predict the moment–curvature relation of profiled composite beams using the nonlinear stress–strain relation of materials. Several other methods were also reported to investigate the moment–curvature behavior of a multi-layered composite beam. However, most of these methods would require cumbersome numerical calculations to ensure a convergence in the solution. Recently, Limazie and Chen [17] proposed a simple design method to predict the nonlinear behavior of a composite slim floor beam considering the effect of the composite action available within the composite beam system.

Compared with an experimental investigation, the FE analysis has the advantages of lower time consumption with lower cost and higher efficiency. The accuracy and reliability of the FE analysis have been demonstrated by many researchers in the past. For composite floors with shear bond interaction, various FE models have been proposed. Daniels and Crisinel [18] developed a FE procedure using the plane beam elements to analyzed single and continuous span composite slabs, in which the nonlinear behavior of the materials was well considered. Veljkovic [19] performed 3D FE analysis using software DIANA to investigate the behavior of steel concrete composite slabs, where the shear bond between the steel deck and the concrete was modeled using a nodal interface element. Abdullah and Easterling [20] also developed a procedure to generate the shear bond property from bending tests. The shear bond property or shear bond–slip curves were then applied to connector elements within the FE models to simulate the horizontal shear in the composite slabs. Widjaja [21] used two parallel Euler–Bernoulli beam elements to simulate the bending test of composite slab, but only one single typical longitudinal slice of the slab was considered in the model, and the vertical nodal displacements of the two parallel beam elements were forced to be the same. Ferrer and Marimon [22] simulated the pull-out tests of composite slabs using the FE method, in which the contact elements were implemented between the steel deck and the concrete, and various coefficients of friction were analyzed. Tsalkatidis and Avdelas [23] also proposed a model where the shear bond mechanism at the contact interface of the composite slabs was treated as a unilateral contact problem and simplified as a two dimensional contact model.

In this paper, a FE modeling approach is proposed to investigate the complex structural behavior of SCCFB considering the realistic shear transferring provided by the shear connection system and the shear bond at the contact interface between the concrete slab and steel beam. The shear transfer mechanism is modeled using the contact modeling considering the adhesion, the friction and the local compression at the contact zones between different components of the composite beam. The geometric and material nonlinearities are all considered in the FE modeling. The FE simulation results were calibrated and validated against the bending tests conducted by Chen et al. [24], and it was illustrated that the numerical simulation results agree well with the test results. An extensive parametric study, with the aim of providing design suggestion, was therefore conducted to further investigate all the likely material and geometric parameter influences on the overall performance of a shallow cellular composite beam, such as the load bearing capacity, stiffness and slip capacity.

2. The shear transferring system in SCCFB

The shear transferring mechanism in a shallow cellular composite floor beam is assumed to be achieved by the shear bond effect at the contact interface together with the shear connection system which is