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Finite element modelling of steel-concrete composite beams with profiled steel sheeting

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ABSTRACT

Steel-concrete composite beams have been widely used in modern construction industry, where headed shear stud connectors are commonly welded through profiled steel sheeting to ensure full/partial composite action between the beam and the composite slab. For such composite beams, there are complex interactions between different components, leading to different failure modes. Finite element (FE) analysis could be used to understand the fundamental behaviour of such beams. But previous FE models have adopted various assumptions to simplify the modelling of some complex interactions such as the interaction between the shear studs and concrete. Accordingly, those FE models have limitations to capture certain types of failure modes. Meanwhile, the actual forces carried by the studs and profiled steel sheeting have not been quantitatively determined. In this context, this paper aims to develop a detailed FE model for composite beams with profiled steel sheeting by considering realistic interaction between different components, fracture of the shear studs and profiled steel sheeting, as well as tensile and compressive damage in concrete. The developed FE model can satisfactorily predict the full-range load–deformation curves of the composite beams and the shear force–slip relationship of the embedded shear studs. The predictions agree very well with a wide range of test data reported in the literature.

1. Introduction

Steel-concrete composite beams with profiled steel sheeting have been widely used in steel framed building construction. Full-scale tests of such composite beams are highly sophisticated, time-consuming and require large testing facilities [1]. Therefore, it is very expensive to investigate the effects of various parameters through experiments. Finite element (FE) modelling is a viable alternative approach to understand fundamental behaviour of the composite beams. However, modelling of composite beams, in particular with profiled steel sheeting, can be very challenging due to the corrugated shape of the profiled steel sheeting, numerous contact surfaces and nonlinear behaviour of steel and concrete materials.

There have been extensive efforts in the past to develop FE models for composite beams [2–5] and for push test specimens [6,7] as specified in Eurocode 4 [8] to determine the relative slip between the steel and concrete continuously during loading. But due to the high computational cost and/or intention to avoid numerical convergence issues, the shear studs in composite beams were normally simulated either as "embedded constraints" [2,3] or by using "connector elements" [4,5]. When a stud is fully embedded in the concrete by using "embedded constraints", the relative movement between the stud and concrete is prevented and the actual slip behaviour of the stud will not be revealed. Meanwhile, possible fracture of the studs might not be captured using this simplified method. To cope with this drawback, some researchers embedded only part of the stud in the concrete [3,6]. However, the specified embedment interaction is somewhat arbitrary. On the other hand, when "connector elements" are used, the shear force–slip relationship of the studs needs to be defined using either a simplified model or information from push tests. For example, the classic shear force–slip model developed by Ollgaard et al. [9] is a widely used model by previous researchers in simulating composite beams. One shortcoming of this model is that its shear force–slip curve does not have a descending branch to represent the actual full-range shear force–slip relationship of shear studs. This can only be improved if the effects of concrete failure and shear stud fracture are fully understood and properly incorporated into the model. Furthermore, this model was directly derived from results of push tests, where the shear studs were embedded in solid rectangular concrete slabs without the presence of the profiled steel sheeting. In addition, the behaviour of shear studs observed from push tests may not represent the actual behaviour of shear studs in composite beams [10,11]. This is because in the push test there is an absence of beam curvature and normal force resulting from the floor loading [12]. This has been confirmed by comparing test results of full-scale composite beams with those of companion push tests [11,12]. In general, shear

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studs exhibited higher ductility in composite beam tests than in push tests. Because of the aforementioned reasons, FE models using either "embedment interaction" between the stud and concrete or "connector elements" representing shear stud behaviour also have limitations in predicting the behaviour of composite beams.

In structural analysis and design, it is favourable to use simplified models incorporating realistic shear force–slip behaviour of shear studs in composite beams. However, an accurate shear force–slip model can only be developed based on the full understanding of the complex interaction between different components in composite beams. This task could be effectively addressed through developing an accurate and versatile three-dimensional (3D) FE model, which is the major focus of this paper. From the developed FE modelling, the shear forces carried by the studs and axial force carried by the profiled steel sheeting can be quantitatively determined. In the FE model to be developed for composite beams with profiled steel sheeting, realistic interaction between different components will be considered to capture different types of failure modes, such as shear failure of the studs, concrete crushing failure, steel beam failure and rib shear failure. It should be noted that the rib shear failure refers to the splitting of concrete inside the rib of the profiled steel sheeting resulting from the internal longitudinal shear force [13]. The prediction accuracy of the full-range load–deformation curves of composite beams and slip behaviour of shear studs will be verified by a wide range of test data reported in the literature.

2. Finite element modelling

In this paper, detailed 3D FE models were developed using ABAQUS version 6.14 [14] to predict the behaviour of steel-concrete composite beams with profiled steel sheeting. As shown in Fig. 1, a typical FE model consists of five types of components, i.e., the steel beam, shear

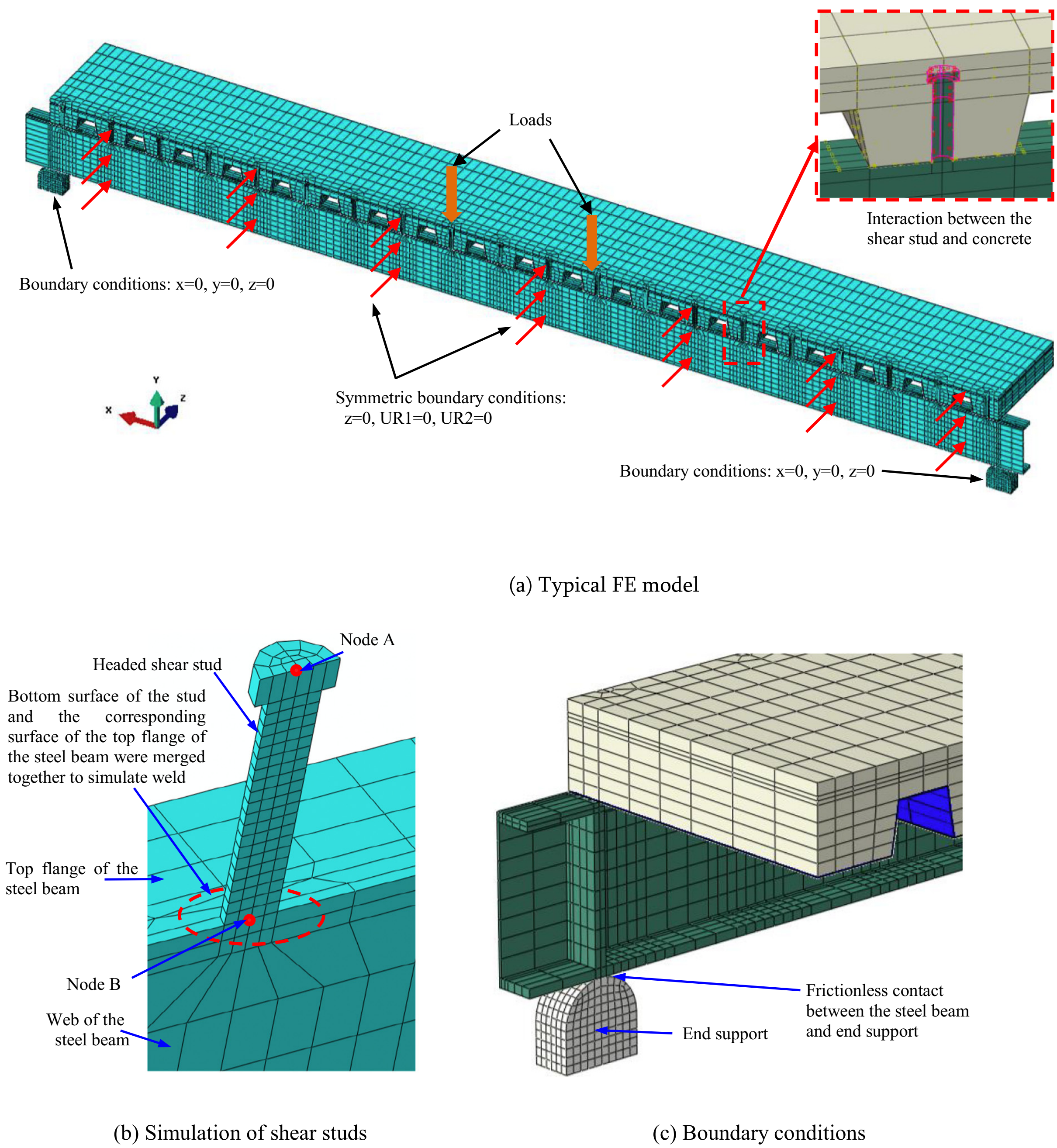

Fig. 1. Finite element model of a typical composite beam under positive moment.