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Numerical evaluation for the effective slab width of steel-concrete composite beams

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ABSTRACT

Although several studies in the field of steel-concrete composite beams reported that the effective concrete slab width depends on the loading stage of such beams (i.e. serviceability and ultimate stages), international codes have not considered it yet. In this respect, a nonlinear finite element model was developed using ABAQUS 6.10 and validated using three independent experimental research programs. The model was found capable of predicting the behavior of such beams and hence calculating a more accurate effective slab width. An extensive parametric study is conducted on 222 beams to evaluate the effective slab widths at service and ultimate loads. Different parameters related to beams geometry and concrete slab material were considered in this study. The results of this study showed that the effective width depends on the slenderness ratio (L/r_s) of the steel beam and the slab width-to-span ratio (B_s/L). In addition, it is found that the effective width at ultimate load is wider than that at service load. Finally, two sets of equations are provided to calculate the effective width at service and ultimate load. The provisions of the ANS/AISC 360–10 for the effective width were compared with the prediction presented herein.

1. Introduction

Structural members composed of two different materials attached together to act as one unit are widely used in various construction works. Steel-concrete composite (SCC) beams are a good example for this kind of structures. The high strength-to-weight ratio and the enhanced mechanical properties are considered to be the main structural benefits of using the composite action between two dissimilar materials. Steel beams attached to normal weight concrete (NWC) slabs are one of the commonly used composite structures in structural engineering. However, a lack of studies can be found for the use of lightweight concrete (LWC) slabs in SCC beams [1]. The major difference in the mechanical properties between NWC and LWC with the same ultimate compressive strength is their Young's modulii [2–4]. Lasheen et al. [1] conducted an experimental study on eight SCC beams to evaluate the validity of using LWC slab in SCC beams. It was found that the use of LWC slab has a minor effect on the ultimate load capacity of SCC beams compared to SCC beams with NWC slabs. SCC beam with LWC slab recorded only 2.2% reduction in ultimate load capacity compared to the counterpart beam with NWC. In addition, it was concluded that the effects of concrete slab thickness and modulus of elasticity are negligible on the effective concrete slab width. This is attributed to the close location of the concrete slab to the neutral axis of the composite section.

The concrete slab width of SCC beams is usually subjected to non-uniform longitudinal compressive stresses along the width of the concrete slab with high values over the steel beam that get smaller at the extremities [5]. This non-uniform distribution of the stresses along the concrete slab width results from the shear flow transfer between the concrete slab and steel section at the location of the upper steel flange, which is known as the shear lag phenomena [6,7]. The integration of this non-uniform stresses along the slab width leads to the determination of the effective slab width. Amadio et al. [8] carried out an experimental program on the evaluation of effective width for SCC beams. A new modification for the effective width based on the loading level under sagging and hogging bending moment was proposed. Moreover, it was found that the effective concrete slab width at the ultimate load is wider than that at service load, by up to 35%, even for wide slab width-to-span ratios [1–8]. On the other hand, ANSI/AISC 360-10 [9] provides only one effective width definition for both the serviceability and strength calculations. Thus, the need for an accurate determination for the effective slab width is very important for the calculations of deflection and ultimate load values of the SCC beams [1–10].

Past research studies [11 to 16] showed that the effective width depends on several parameters such as the available slab width, slab thickness, beam span and loading value. Lasheen et al. [1] revealed the

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significant contribution of the steel section size into the value of the effective slab width. It was reported that the effective width is inversely proportional to the slenderness ratio of the steel beam, defined as (L/r_s), where L and r_s are the beam span and radius of gyration of the steel cross-section, respectively. An equation for the effective width based on the steel section slenderness ratio was developed [1].

In general, shear connectors are used to reduce the slip value at the steel-concrete interface and consequently provide the necessary composite action between the steel section and the concrete slab. There are several kinds of shear connectors that are used to provide the composite action. The headed stud is considered to be the famous shear connector among these types due to the ease of installation. However, the rigidity of a channel shear connector is higher than that of a headed stud. Therefore, a few channel shear connectors can substitute a large number of headed studs.

In this respect, a numerical investigation is carried out to provide new equations for the determination of the effective concrete slab width at different loading levels. These equations would help structural engineers to accurately predict both the deflection values and ultimate load capacity. The provisions of the American Institute of Steel Construction "ANSI/AISC 360-10" [9] for the SCC beams is also used for comparison reasons with the results of the current study.

2. Finite element model

Eight specimens were modelled using ABAQUS 6.10 [17] to simulate the SCC beams that were tested in an experimental program by Lasheen et al. [1]. This was carried out to verify the FE models against the experimental results in terms of load-deflection, load-slip and load strain responses.

Only one-quarter of the specimen was modelled due to the symmetry in the geometry, loading and boundary conditions, as shown in Fig. 1. The coordinate axes X, Y and Z are represented as axes 1, 2 and 3 in the model, respectively. Fig. 1 shows also the symmetry planes.

The accuracy of the results mainly relies on the FE mesh, constitutive material models and the boundary conditions. Therefore, these aspects are accurately investigated in the proposed FE model. In the current study, brick elements (C3D8R) have been chosen with a maximum mesh size of 20 mm. The mesh intensity is kept the same for the whole concrete part of the model, as shown in Fig. 1. A regular structured hexahedral mesh is used, as shown in Fig. 1. Discrete reinforcement bars were defined using three-dimensional truss elements (T3D2) in linear order. This element was used for all reinforcement types with a maximum mesh size of 20 mm.

2.1. Material model

2.1.1. Steel modeling

Bi-linear model is used for steel material. The properties of the steel sections and shear connectors are modelled with the same properties as the tested beams [1]. The elastic properties of the steel beams were taken equal to 205 GPa for Young's modulus and 0.3 for Poisson's ratio. The yield and ultimate strengths are taken equal to 300 MPa and 520 MPa, respectively.

2.1.2. Concrete modeling

Concrete damage plasticity model is used to model the concrete slab in the current study. The compressive strength defined in this study for both the NWC and LWC is 27 MPa. The Young's modulii of the proposed NWC and LWC are 28 GPa and 14 GPa, respectively.

Tension stiffening is used to model the post-failure behaviour for direct tension across cracks, which allows the definition of the strain-softening behaviour for cracked concrete. The total strain at which the tensile stress equal zero is taken in many previous studies as 10 times the tensile cracking strain. However, it has been found that this value was not suitable for concrete slabs in SCC beams [18,19]. As reported by Liang et al. [20], a total strain of 0.1 is preferably used for reinforced concrete slabs in SCC beams.

2.2. Steel-concrete interaction

In this study, the interaction between the internal steel reinforcement bars and the concrete slab was defined using the truss in solid technique option that used in ABAQUS 6.10. This technique specifies the embedded elements as truss elements simulating the reinforcement bars while the host region was specified as the continuum solid elements simulating the concrete slab.

The surface-to-surface contact algorithm was used to model the contact surface between the concrete slab and channel shear connector, where the channel shear connector was selected as the master surface. The contact property was defined by tangential behaviour to consider the factors of friction and elastic slip and by normal behaviour to consider the factors of penetration and separation. Penalty friction formulation with a coefficient of 0.5 was selected to its tangential

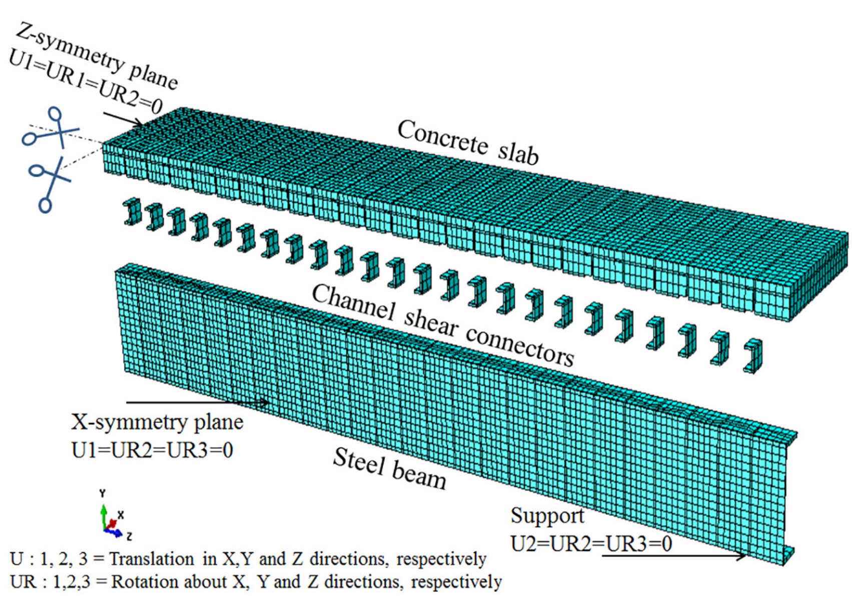

Fig. 1. Finite element mesh of one quarter of SCC beam.