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Three-Dimensional FE Modelling of Simply-Supported and Continuous Composite Steel-Concrete Beams

F Tahmasebinia, G Ranzi*

School of Civil Engineering, The University of Sydney, Australia

Abstract

Composite steel-concrete beams represent an economic form of construction used in both building and bridge applications. The composite action is usually provided by the presence of shear connectors welded to the top of the steel joist and embedded in the concrete slab. The flexural response is strongly dependent on the rigidity provided by these connectors. Initial studies in this area highlighted that their deformability needs to be evaluated and included in the modeling for an accurate structural representation. For this purpose, different types of push-out tests have been proposed to date to describe the load-slip relationships of shear connectors. These relationships are usually used in numerical simulations when modeling experimental tests or performing parametric studies. In this context, the finite element model proposed in this paper intends to provide a representation of the composite behaviour of floor beams without the need to rely on constitutive relationships obtained from push-out tests. The model is validated against experimental results available in the open literature carried out using simply-supported and continuous static configurations and based on composite beams with solid and composite slabs.

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Keywords: Composite beams, concrete, connectors, finite element method, steel.

* Corresponding author and Presenter
Email: gianluca.ranzi@sydney.edu.au

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1. Introduction

Composite steel-concrete beams are widely used in building and bridge applications. In this form of construction the composite action is provided by the presence of shear connectors welded to the top of the steel joist and embedded during the pour in the concrete. Initial studies on the behaviour of composite beams highlighted the importance of accounting for the deformability of the shear connectors when describing the service and ultimate responses. The analytical model describing this partial interaction model is usually referred to Newmark model (Newmark et al. 1951). Since then extensive research has been carried out in this area. In recent years there has been an increasing amount of attention devoted to three-dimensional finite element models. Such models tend to represent the shear connectors in three dimensions to avoid the need to rely on experimental data obtained from push-out tests. Examples of such contributions include (e.g., El-Lobody and Lam 2003, Lam and El-Lobody 2005, Ellobody and Young 2005, Chung and Sotelino 2006, Queiroz et al. 2007, Fu et al. 2007, Nguyen and Kim 2009, Queiroz et al. 2009, Mirza and Uy 2010), and a comprehensive review of the state-of-the-art in this area can be found in (Spacone and El-Tawil 2004, Leon and Viest 1996).

This paper presents a finite element model capable of describing the response of a composite beam without any knowledge on the load-slip relationship of the connectors usually obtained from standard push-out tests. The proposed model is validated against a wide range of experimental results considering different static configurations, i.e. simply-supported and continuous beams, and both solid and composite slabs. For the purpose of this paper, the results reported by Ansourian (1980), Nie et al. (2008) and Ranzi et al. (2009) have been used.

2. Finite Element Model

The proposed finite element model is developed using the commercial software Abaqus. The concrete slab, the steel section, profiled sheeting, and shear connectors are modeled using the three-dimensional eight-node brick element C3D8R which possesses reduced integration and hourglass control.

The constitutive behaviour of the shear connectors, profiled sheeting, and the steel reinforcement is based on an elastic-plastic model with isotropic hardening. The concrete in compression is described with an initial linear-elastic range up to 40% of its compressive strength after which it is represented by means of the “Extended Drucker - Prager“. Its tensile behaviour is initially linear-elastic followed by a softening response after the occurrence of cracking. An overview of the assembled and meshed model is depicted in Figure 1. The nonlinear analysis is carried out using the RIKS-Static option available in Abaqus relying on the arc-length control procedure.

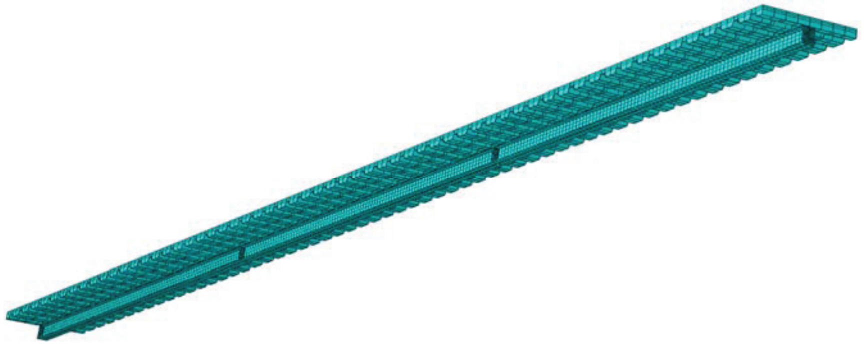


Figure 1: Proposed finite element composite model.

A surface to surface contact is provided for the interaction between steel joist and concrete slab. The shear studs are embedded in the concrete slab to provide the composite action.

3. Validation of the Developed Models

3.1. Ansourian (1980)

The proposed finite element model has been validated against the experimental results measured by Ansourian (1980) on six continuous composite beams. For illustrative purposes, the results related to beam CTB3 (Figure 2) are provided in Figures 3 and 4 as representative of the comparisons carried out also on the other samples. CTB3 is a two-span beam with a total length of 9 m subjected to mid-span point loads. The experimental and numerical values for the load versus mid-span deflections are shown in Figure 3. The accuracy of the finite element model are also verified considering curvatures measured at the mid-span and at a distance of 150 mm from the internal supports respectively and these are plotted in Figure 4. Overall, the numerical results are in good agreement with the experimental ones.

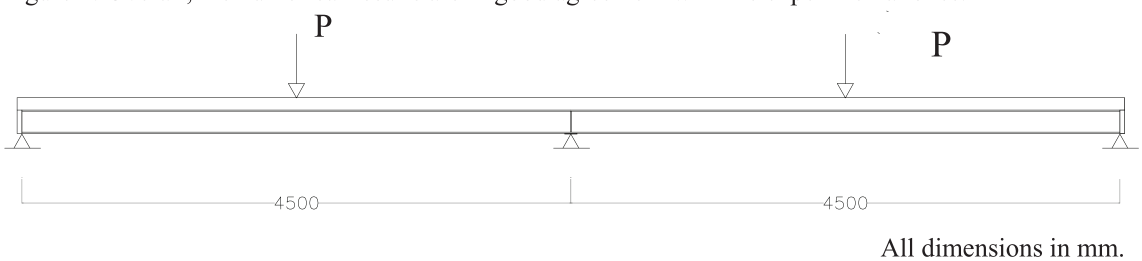


Figure 2: Layout of beam CTB3 (Ansourian 1980).

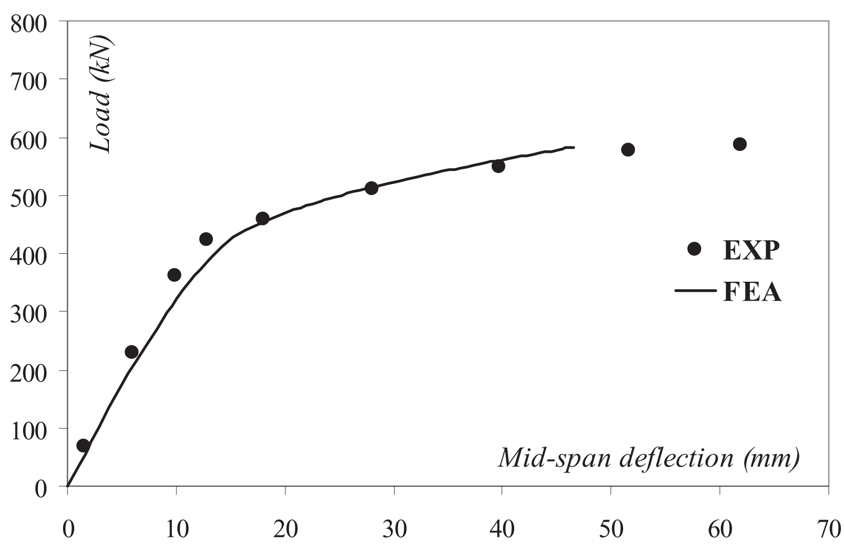
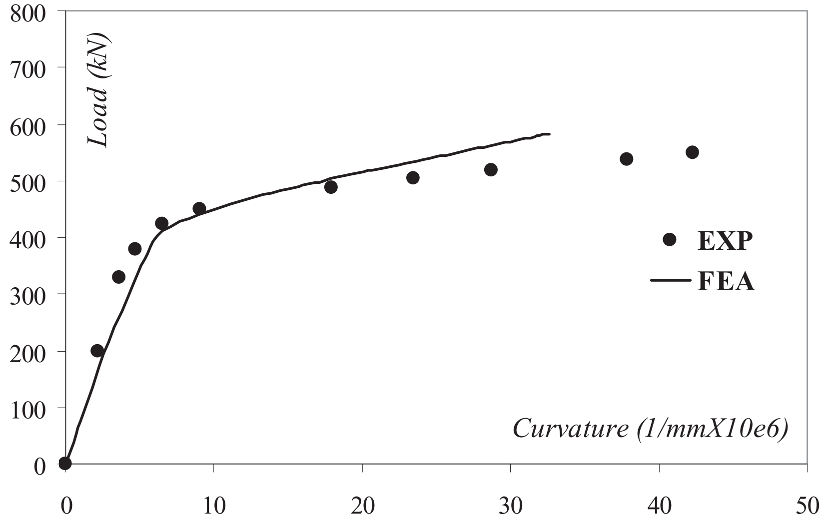
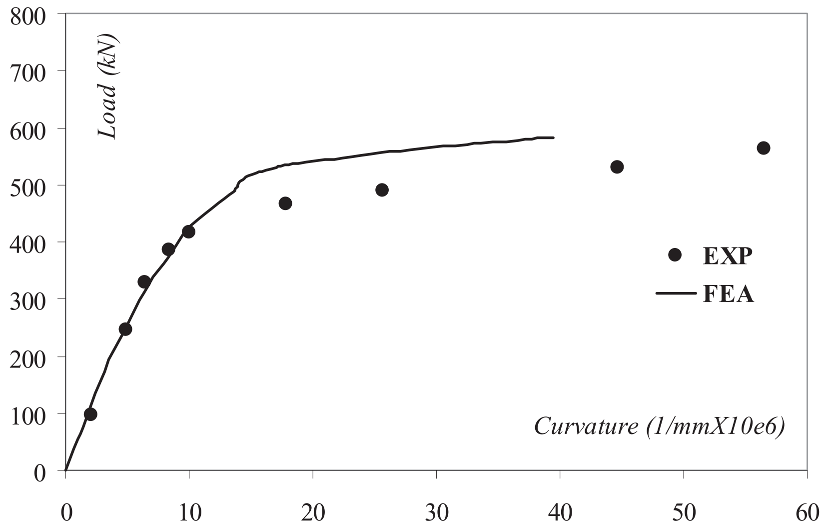


Figure 3: Comparison between experimental and numerical results for the load – mid-span deflection curve of beam CTB3 (Ansourian 1980).



(a) mid-span curvature

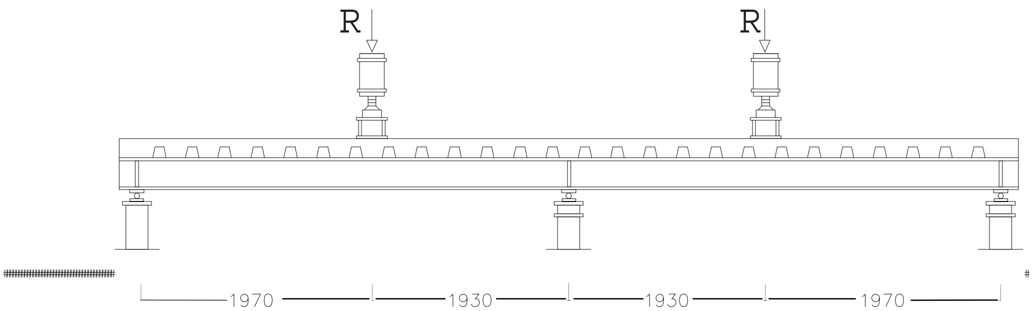


(b) curvature at 150 mm form the internal support

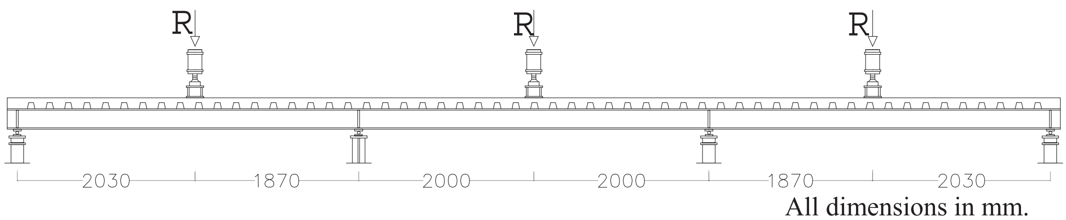
Figure 4: Comparison between experimental and numerical results for the load – curvature of beam CTB3 (Ansourian 1980).

3.2. Nie et al. (2008)

The second set of tests considered in this paper consists of the continuous ones reported by Nie et al. (2008). For illustrative purposes samples labelled as SB12 and SB13 are used for comparison purposes. These beams have total length of 7.8 m and 11.8 m, respectively. In these cases the slab is cast on a trapezoidal steel deck profile as outlined for the two specimens in Figure 5. The sheeting, designated as YXB60-200-600, has a thickness of 1 mm and ribs with a height of 60 mm spaced at 200 mm. During the preparation of the samples the throughs are placed perpendicular to the steel joist.



(a) layout of beam SB12



(b) layout of beam SB13

Figure 5: Continuous beams SB12 and SB13 (Nie et al. 2008).

One shear connector per trough is placed in the two-span beam SB12 while two connectors are inserted in the three-span SB13. Comparisons between the calculated and measured load-deflection curves for SB12 and SB13 are presented in Figures 6 and 7. For SB12 the deflection is measured at 1930 mm from the internal support while for SB13 these are recorded in the internal segment of the beam at mid-span. Good agreement between numerical and experimental results is observed for the samples reported by Nie et al. (2008).

3.3. Ranzi et al. (2009)

The two simply-supported beams reported by Ranzi et al. (2009) are used to further validate the finite element model when considering slabs cast on profiled sheeting. The two samples, referred to as CB1 and CB2, have a length of 8050 mm and slab width of 2000 mm. The composite slab has a thickness of 130 mm and the rib a height of 78 mm. The numbers of shear connectors inserted in each through in beams CB1 and CB2 are one and two, respectively. In the case of CB2, the two connectors are welded diagonally across the joist axis. Figures 8 and 9 illustrate the comparison between the experimental measurements and the calculated values for the mid-span deflections. Also in this case the numerical results provide a satisfactory match with the experimental ones.

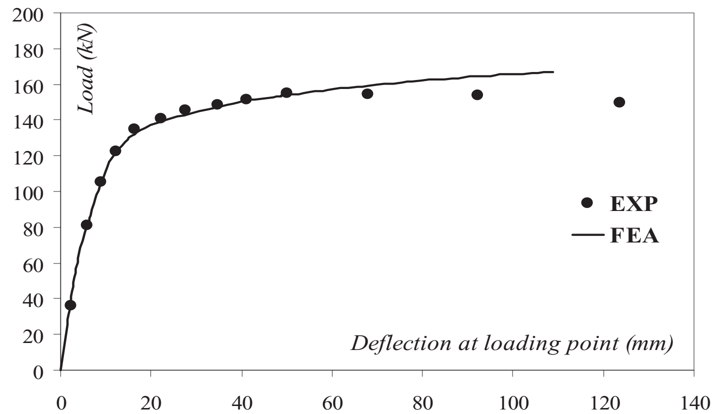


Figure 6: Comparison between experimental and numerical results for the load – deflection at loading point of the beam SB12 (Nie et al. 2008).

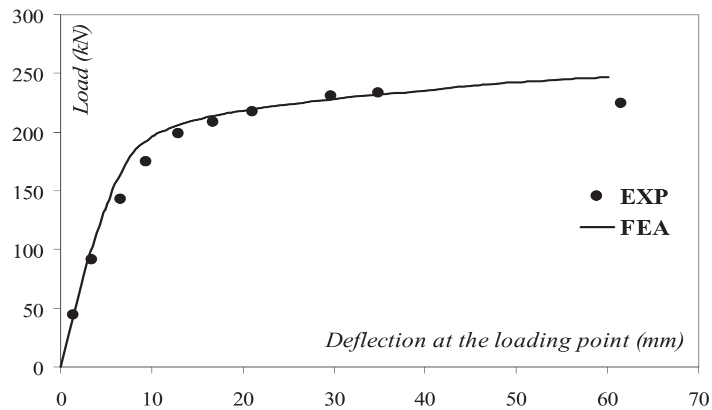


Figure 7: Comparison between experimental and numerical results for the load – deflection at loading point of the beam SB13 (Nie et al. 2008).

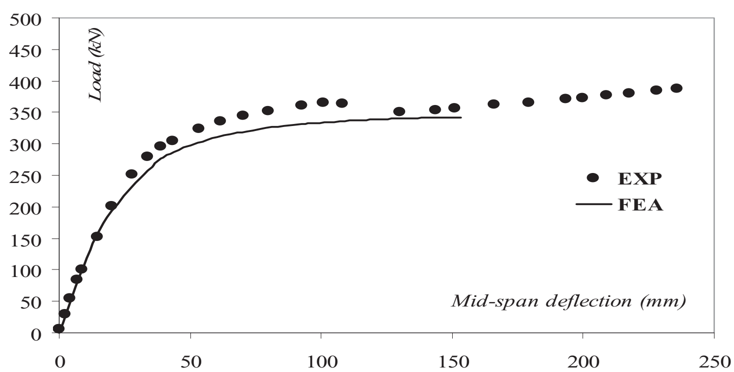


Figure 8: Comparison between experimental and numerical results for the load – mid-span deflection curve of beam CB1 (Ranzi et al.2009).

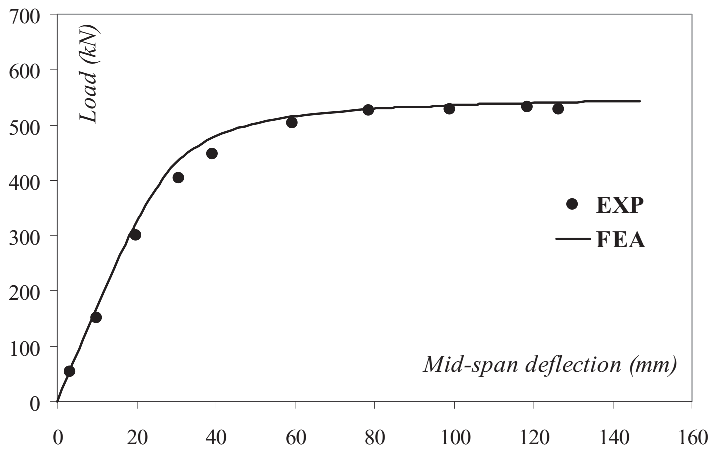


Figure 9: Comparison between experimental and numerical results for the load – mid-span deflection curve of beam CB2 (Ranzi et al.2009).

4. Conclusions

This paper presented a three-dimensional finite element model capable of predicting the response of composite steel-concrete beams up to failure. The particularity of the proposed model relies on its ability to model the shear connectors as solid elements, therefore not requiring the load-slip relationship to describe the nonlinear behaviour of the connectors. This aspect is particular important when dealing with trapezoidal steel decks for which different types of push-out tests have been proposed in recent years. The ability of the proposed model to well describe the composite behaviour has been verified against experimental results reported in the open literature of simply-supported and continuous beams considering both solid and composite slabs.

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