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Behavior of steel–concrete partially composite beams with channel type shear connectors

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ABSTRACT

This paper summarizes the findings of an experimental study investigating the flexural behavior of partially composite beams incorporating channel type shear connectors. Results from monotonic load testing of four full-scale steel–concrete composite beams and a steel beam are presented. The main effort focused on identifying the variation of strength and stiffness properties of beams with various degrees of partial composite action. Behavior of channel shear connectors in the composite beam specimens is related to those previously obtained from push-out tests of similar connectors. Finally, recommendations of the related AISC Specification on the strength and stiffness of composite beams are used for the assessment of the influence of the degree of partial composite action on flexural behavior. The experimental results revealed that even for beams with relatively low degree of partial composite action, major improvement on moment capacity and stiffness was obtained as compared to the steel specimen. The measured moment capacity of both the partially composite and fully composite beams agreed acceptably with the calculated capacities. The effective moment of inertia and the lower bound moment of inertia as specified by the AISC Specification were observed to overestimate the measured flexural stiffness of beams for all degrees of partial composite action investigated.

Introduction

Structural systems incorporating steel–concrete composite beams have been widely used throughout the world for building and bridge structures. Such composite beams are formed by a steel beam, a concrete slab, and mechanical shear connectors that are responsible for horizontal shear force transfer at the steel–concrete interface. Welded headed shear stud is by far the most common type of mechanical shear connector used in steel–concrete composite flexural members mainly due to their relatively faster installation process by utilizing a special welding equipment. Alternative mechanical shear connector geometries have been proposed [1], and among these alternatives, channel type shear connectors have been investigated in the past [2–8]. Unlike headed shear studs, channel type shear connectors are welded on steel beams using conventional welding equipment, and the size of the connector can be adjusted so that the required horizontal shear force capacity at steel–concrete interface can be achieved with less number of connectors than headed shear studs.

The main design parameter that affects the structural behavior of a steel–concrete composite beam is the amount of horizontal shear force transferred between the steel beam and concrete slab. Depending on the level of horizontal shear force transfer, a full composite action or a partial composite action is obtained. A full composite action is achieved when sufficient strength is provided at steel–concrete interface to enable the concrete slab or the steel beam to reach their capacity. In a typical partially composite beam, on the other hand, the shear connecters are expected to fail at the interface without utilizing the full capacity of the other components. In certain cases, using beams with only partial composite action becomes more economical than using fully composite beams due to substantial reduction in the number of mechanical shear connectors to be provided at steel–concrete interface.

Majority of the studies conducted in the past focused on partially composite beams with headed shear studs used as mechanical connectors [9–16]. While the channel connectors are potential alternatives to headed studs, little is known about their behavior in partially composite beams. In comparison with headed studs, a reduced number of connectors is needed when channels are used, resulting in high localized force and displacement demands. A two phase research project has been undertaken at Atilim University to investigate behavior of channel connectors. The first phase of the study, which is outlined by Baran and Topkaya [8], aimed at evaluating the capacity of channel connectors using push-out tests. The test results were used to develop an equation that can be used to predict the shear capacity of channel connectors. The second phase of the study aimed at investigating the behavior of these mechanical connectors when used in partially composite beams. Pursuant to this goal an experimental program on testing of full scale composite beams was developed. The experimental program consisted

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of destructive tests of a steel beam specimen and four composite beam specimens with various degrees of partial composite action. The main effort focused on identifying the variation of strength and stiffness of beams with various numbers of shear connectors placed at the steel concrete interface.

In this paper the recommendations of the Commentary to the AISC Specification for Structural Steel Buildings AISC360-10 [17] on calculating the strength and stiffness of partially composite beams are reviewed first. Later the findings of the first phase of the research program are revisited. The details of the experimental program are given to outline the design of test specimens. Finally, the test results are presented from a strength and stiffness point of view.

Recommendation of the commentary to the AISC specification for structural steel buildings

There exists a complex interaction between the steel beam and the concrete slab in composite beams due to the presence of mechanical connectors at the interface. In general, the mechanical connectors do not provide a perfect connection, resulting in slip of the two components relative to each other. Therefore, calculation of strength and stiffness for an applied loading should take into account the effects of slip at the interface. While the behavior is complex and difficult to determine for a particular value of the applied action, the ultimate strength and stiffness of composite beams can be predicted fairly accurately using simplified models.

The Commentary to the AISC Specification for Structural Steel Buildings AISC360-10 [17] adopts the plastic stress distribution shown in Fig. 1 to calculate the ultimate moment resisting capacity of a composite beam. In this stress distribution, it is assumed that all fibers of the steel beam reach to the yield stress (F_y) and the stress on the concrete slab is represented by an equivalent rectangular stress block with intensity equal to 0.85 times the nominal compressive strength (f'_c). The portion of the concrete slab subjected to tension is assumed to carry no stress. The depth of concrete slab which is subjected to compression (a) is determined by considering the degree of partial composite action. For fully composite beams the neutral axis can pass through the steel section or the concrete slab depending on the relative strengths of these two components. When the net tensile strength of steel section determined by $A_s \times F_y$, where A_s is the total area of the steel beam, is smaller than the compressive strength of concrete slab determined by $0.85 \times f'_c \times A_c$, where A_c is the area of concrete slab within effective width, the neutral axis passes through the concrete slab. In this case the entire steel beam is subjected to tensile stresses resulting in a net tensile force equal to $A_s \times F_y$. From equilibrium the same level of force should develop on the concrete slab. If the compressive strength of concrete slab is smaller than the tensile strength of the steel section then the neutral axis passes through the steel section engaging upper part of the steel beam in addition to the entire concrete slab in resisting compressive forces.

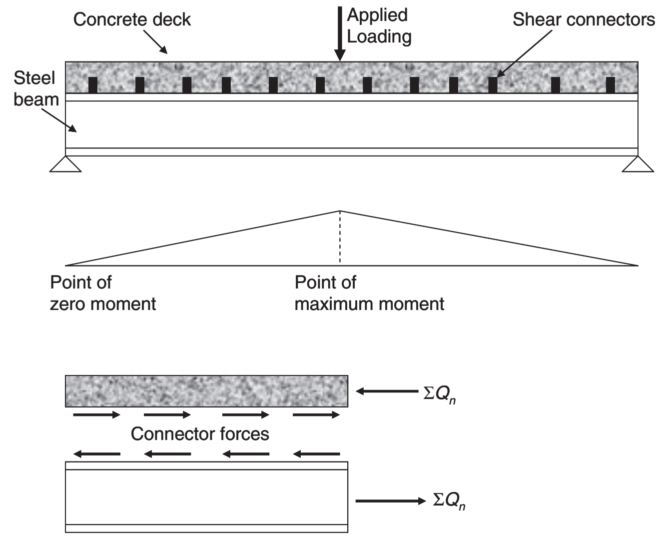

Fig. 2. Equilibrium of forces for a partially composite beam.

For partially composite beams, however, the net compressive force on the concrete slab is determined by the summation of the ultimate load carrying capacity of the connectors (Q_n) placed between the point of zero moment and maximum moment as shown in Fig. 2. Based on this discussion the depth of concrete slab subjected to compression for fully or partially composite sections can be found by:

$$a = \frac{\min(A_s F_y, 0.85\, f'_c\, A_c, \sum Q_n)}{0.85\, f'_c\, b} \tag{1}$$

where b is the effective width of the concrete slab. The distance between the resulting compressive force on concrete and the top of the steel section is usually termed as Y_2 and can be found as follows:

$$Y_2 = Y_{con} - \frac{a}{2} \tag{2}$$

where Y_{con} is the depth of the concrete slab.

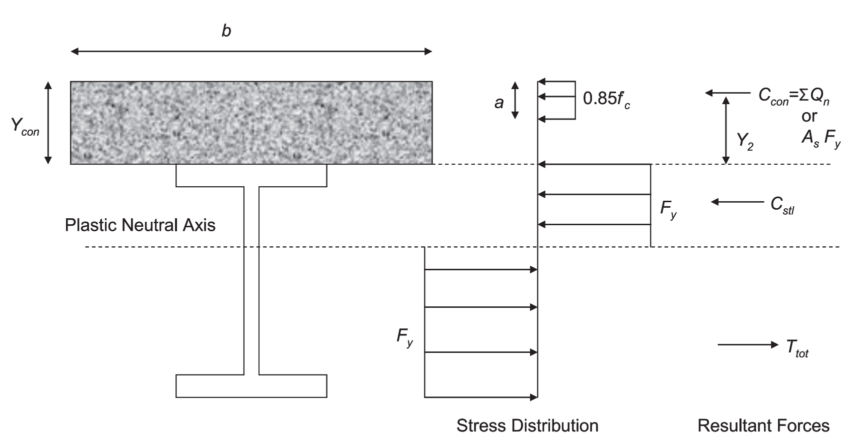

Fig. 1. Stress and force distribution on a typical composite section.