Analytical Modelling of Frames with Composite Beams and Steel Columns

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ABSTRACT

Finite element models are proposed for investigating seismic behavior of sub- frames consisting of properly detailed steel-concrete composite beams and steel columns. The results indicate a considerable increase in sub-frame strength and elastic stiffness in case of composite beams compared with steel ones under both positive and negative moments.

Keywords: Slab Force Transfer Mechanism, Composite beam, Ansys

1. INTRODUCTION

Few experimental and analytical investigations about frame mechanism of steel-concrete composite beams connected to steel H-shaped columns have been carried out so far. In this paper, sub-frames consisting of steel-concrete composite beams and steel H-shaped steel columns have been modeled analytically and a monotonic increasing load has been applied to investigate the nonlinear behavior of the sub-frame.

2. SLAB FORCE TRANSFER MECHANISM

Fig. 1 shows a composite beam under gravity loading. Assuming that all of the slab depth is in compression, related force transfer mechanism in the slab has also been depicted. The compression stresses in concrete slab decrease with increasing distance from centerline of the beam, where shear connectors exist, and all of the stresses are oriented toward the mid-span of the composite beam

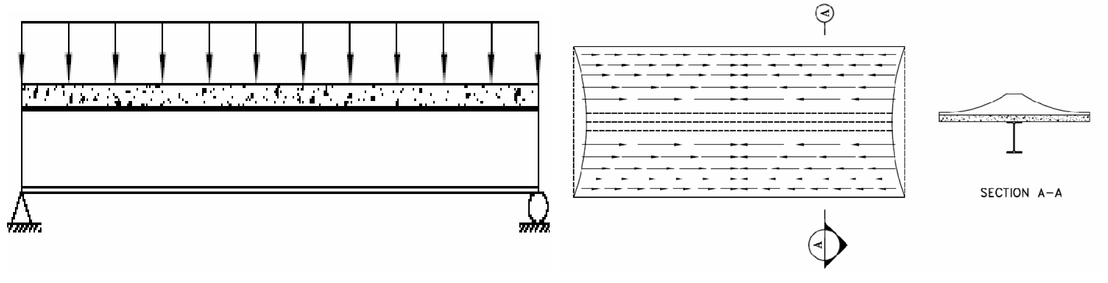

Figure 1. Composite beam under gravity loads and related slab force transfer mechanism

Now, we investigate how a composite beam, as a part of a moment-resisting frame, behaves under lateral forces. In Fig. 2 a sub-frame subjected to lateral loading is shown. Related force transfer mechanisms in the slab from elevation and plan views have also been depicted. A crack forms at the face of the column at the tension side and the compressive stresses in the slab at the compression side orient toward the column. The tensile stresses in the reinforcements at the tension side transfer to the slab at the compression side due to reinforcement continuity. In other words, the column behaves as a support for all compressive and tensile stresses and finally all forces act on the column through bearing contact of concrete slab to the steel column

3. THEORY OF MODELLING :

Seismic performance of the connection is in close relation with the sub-frame components i.e. beam, column, panel zone and connectors behavior. In sub-frames with composite beams, strength and stiffness of the beams are related to the amount of force which may transfer from the composite slab to the column. This force depends on beam span length, column cross section shape and dimensions, bearing contact conditions of the slab to the column and detailing of the slab around the column. In other words, developing strength and stiffness of composite beams is highly dependent on column properties and slab detailing around the column, as well as the beam span length

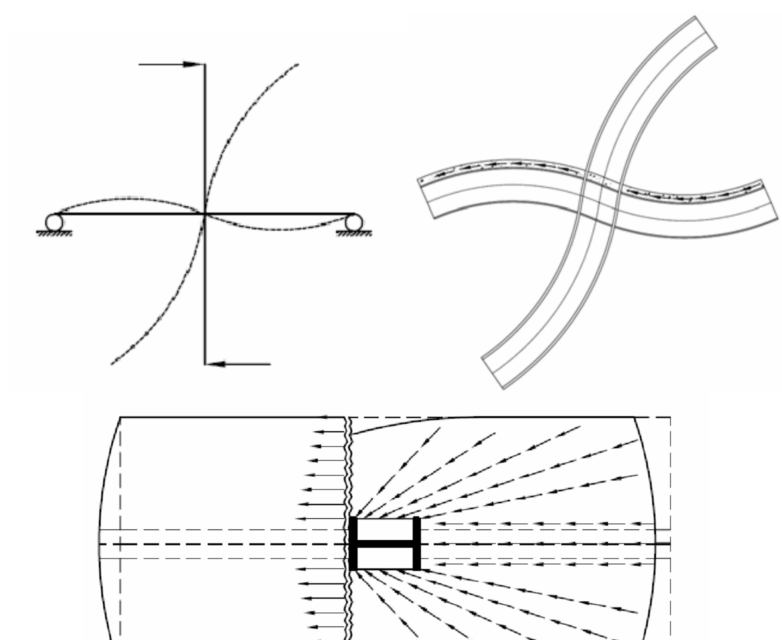

Figure 2. Composite beam under lateral loads and related slab force transfer mechanism

Exaggerated deformation of a composite beam in positive moment is shown in Fig. 3. If shear connectors are not used between column flange face and the end of probable plastic hinge zone, in order to avoid beam flange fractures when the hinge undergoes large cyclic strains at negative moment, one may assume a zone which has axial behavior between plastic hinge location and column face. In the case of using shear connectors in this zone, also an approximately axial behavior can be assumed. In Fig. 4 this zone has been shown from plan view. Induced stresses point to the column because the column elements play the role of support for them. In Fig. 5 these supports schematically have been shown with springs and in Fig. 6 for simplicity these springs have been replaced by restrained supports and deformed shape is also schematically depicted

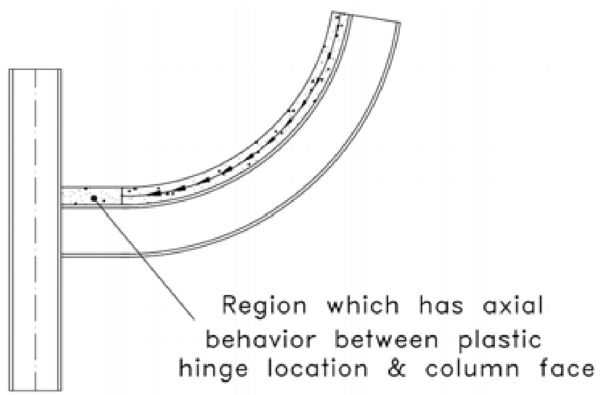

Figure 3. Exaggerated deformation of a composite beam in positive moment

As shown in Fig. 6, transverse reinforcement is required perpendicular to beam in order to control local bending stresses in concrete. In other words, to develop the slab forces and transfer them to the column, as shown in Fig. 7 a proper detailing around the column is needed (Fig. 8). Similar force transfer mechanism in slab has been investigated before for partially restrained composite connections (Leon R.T. 1998)

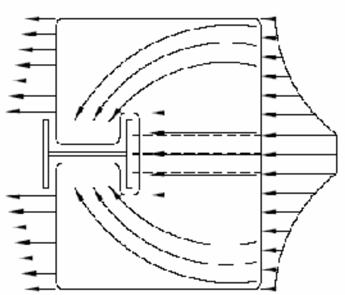

Figure 4. Force transfer path in slab

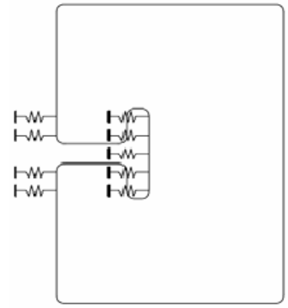

Figure 5. Slab axial zone assumed support conditions

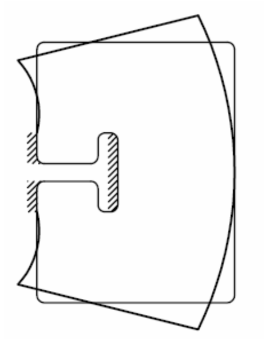

Figure 6. Slab axial zone deformed shape

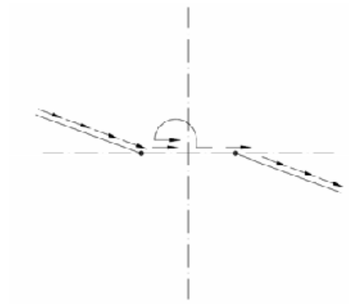

Figure 7. Slab force transfer path

As shown in Fig. 6, transverse reinforcement is required perpendicular to beam in order to control local bending stresses in concrete.

4. ANALYTICAL-MECHANICAL MODELING

According to the concept introduced in the previous section, three sub-frames each with a different type of connections i.e. cover plate connection; reduced beam section connection and bottom haunch connection have been modeled. These sub-frames are taken from a real moment- resisting frame with beam span length of 6000 mm and column height of 3200 mm.

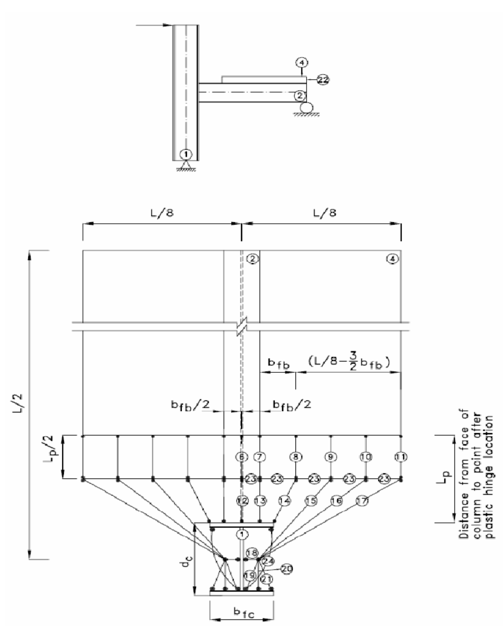

Figure 8. Second finite element model components

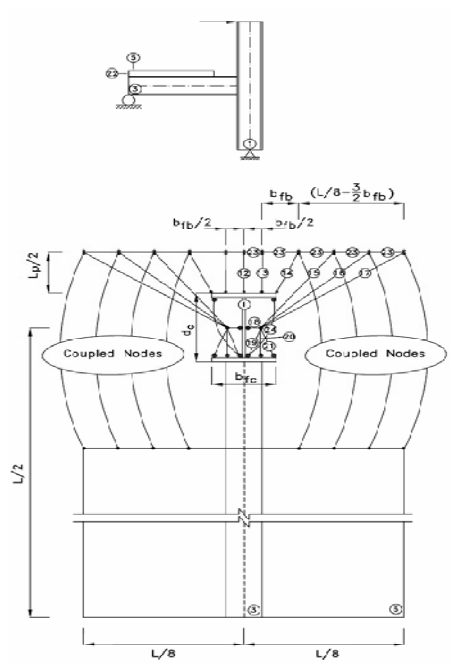

Figure 9. Third finite element model components

For each type of connections, three distinct finite element models have been prepared. The first model consists of steel alone beam, the second consists of composite beam under positive moment and finally the third one consists of composite beam under negative moment. In Fig. 8 the second model and in Fig. 9 the third models are shown.

Various components of these models which have depicted in Fig. 8 and 9 are described as below:

Component No. 1 is the H-shaped steel column.

Component No. 2 is the I-shaped steel beam in the second model. Component No. 3 is the I-shaped steel beam in the third model. Component No. 4 is the concrete slab in the second model.

Component No. 5 is the equivalent reinforcing shell in third model representing steel reinforcement of the slab. The cross section area of this shell is equal to the steel reinforcement of the slab.

Component No. 22 is the steel shell representing shear connectors. The cross section area of this shell is equal to the sum of shear connector's areas which have designed for full shear transfer. All of the above components have been modeled with shell elements.

Component No. 23 is the steel link representing lateral reinforcement. This component has been modeled with link element with area equals to lateral steel reinforcing.

All of the shells have been modeled with SHELL43 element of ANSYS (1992). This element has six degrees of freedom at each node and the deformation shapes are linear in both in-plane directions. For out of plane motion, it uses a mixed interpolation of tonsorial components. The element has plasticity, creep, stress stiffening, large deflection and large strain capabilities. All of the links have been modeled with LINK8 element of ANSYS (1992). This element is a uniaxial tension-compression element with three degrees of freedom at each node and no bending of element is considered. The element has plasticity, creep, swelling, stress stiffening and large deflection capabilities.

5. RESULTS

In Fig. 10 Moment vs. Total Rotation curves for three mentioned types of connections have been shown. In all three connections an increase in elastic stiffness, strength and strain hardening stiffness (which is named plastic stiffness) can be observed at both positive and negative moments. In Fig. 11 results have been shown on bar chart.

An approximate 50% increase in both elastic stiffness and strength at positive moment and 25% at negative moment were observed and also an approximate 300% increase in plastic stiffness at both positive and negative moments. This increase has come from strain built up in steel beam because of changing neutral elastic and plastic axis in the composite beam. None of the plastic strains have reached to the rupture strain limit of the steel and 60% of increase in plastic strains are observed in composite case in comparison with steel alone beams.

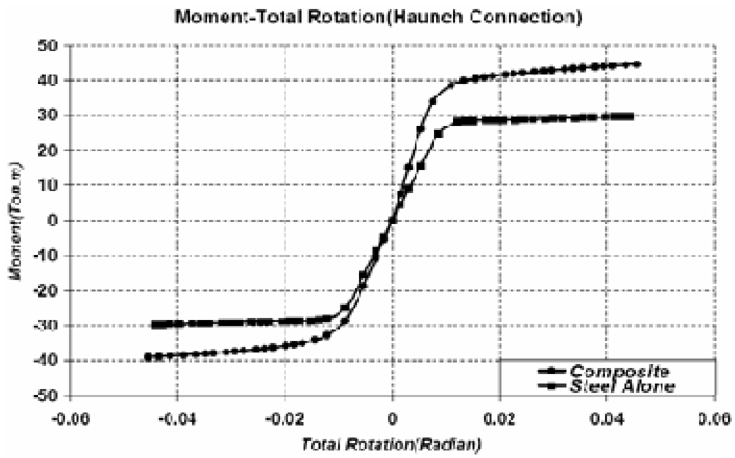

Figure 10. Moment vs. Total Rotation Curves

6. CONCLUSIONS

Effective width of properly detailed composite beams in moment-resisting frame mechanism is highly dependent on column characteristics such as column cross section shape and dimensions as well as the beam span length. Finite element analysis showed that an approximate 50% increase in elastic stiffness and strength of sub-frames at positive moment and 25% at negative moment may be attained. But in lieu we have an approximate 60% increase in plastic strains induced in tension flange of composite beam at positive moment

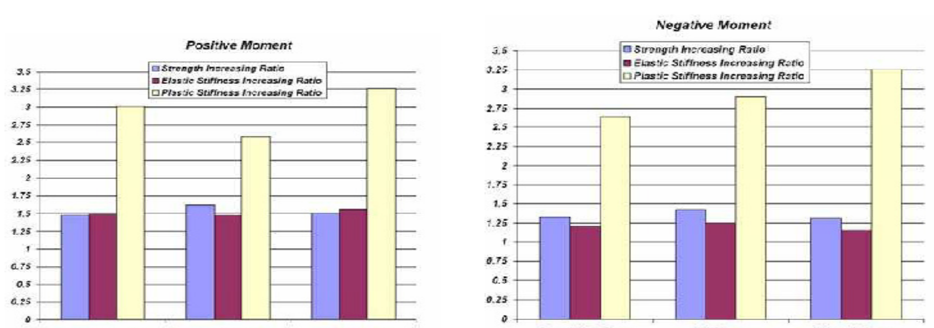

Figure 11. Strength and Stiffness Increasing Ratios

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