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Slab effect of composite subassemblies under a column removal scenario

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ABSTRACT

This paper presents an experimental and computational study on the behavior of two composite subassemblies under a column removal scenario. The two specimens, designed as beam-joint-beam (B-J-B) subassemblies with reinforced concrete slabs on top of steel beams, were extracted from a prototype steel frame building with composite floor systems. One subassembly with the joint above the removed column was loaded under sagging deflection, and the other with the joint adjacent to the removed column was loaded under hogging deflection, simulating a center column removal scenario at a two-span beam-column subsystem. Detailed finite element models were also developed and analyzed for the two composite subassemblies. The observed failure modes were captured by the numerical models, and the computed load-versus-displacement curves agreed reasonably well with the measured data. To investigate slab effect, test results of the test specimens and steel subassemblies similar to the test specimens but without slab were compared. It showed that the load carrying capacities of the composite subassemblies were >63% higher than the steel subassemblies. Under sagging deflection loading, the composite subassembly showed a greater initial stiffness than the steel subassembly. Unlike the steel subassemblies, notable compressive axial forces were developed in beams of the composite subassembly subjected to sagging deflection at the early loading stages, indicating arching action contributed to the load resistance at small deformation as well as the initial stiffness. Contributions to the load capacity by resistant mechanisms, e.g. flexural action, arching action and catenary action were characterized and discussed.

1. Introduction

In recent decades, great effort has been made in preventing progressive collapse which could cause a substantial casualty to building structures and human lives. Many abnormal loading conditions, such as fire, blast and vehicle impact may induce progressive collapse. The spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it is commonly defined as progressive collapse [1]. The ASCE 7 Standard [1] recommends that resistance to progressive collapse be accomplished either implicitly, by providing minimum levels of strength, continuity, and ductility; or explicitly, by (1) providing sufficient strength to structural members that are critical to global stability or (2) providing alternate load paths so that local damage is absorbed and major collapse is averted through adequate connections and ties. When a major load-carrying member is damaged, an alternative load path is formed around failed structural members.

A series of testing programs have been conducted by the National Institute of Standards and Technology (NIST) to study the performance of moment-resistant frame assemblies under a column removal scenario [2]. Liu [3] studied behavior of semi-rigid HSS beam-to-column connections through experimental and numerical analysis. Yang and Tan [4] carried out experimental tests on steel joints of simple and semi-rigid connections, such as web cleat, top and seat angle, flush end plate and extended end plate. Khandelwal and EI-Tawil [5] investigated catenary action in moment resisting steel frames through computational simulations. Yang and Tan [6–8] studied the mechanical behaviors of bolted-angle beam-column joints under a column removal scenario. These studies show the dominant resistant mechanism of frame structures changes from flexural action at small deformation to catenary action at large deformation. For hollow section columns with non-flat surfaces (e.g. CHS), outer diaphragms are usually welded around the column. The adjacent open section (e.g. H-section) beams are connected to the column via the diaphragms using either bolted or welded connections (or a combination of the two approaches). Li and Wang [9] investigated the behavior of two types of outer-diaphragm connections under column removal scenario, with the welded-web and the bolted-web respectively. The test demonstrated the bolted-web connection is more redundant in strength and deformability. SHS/RHS column may hold the benefit of their flat surfaces, where a more straightforward connection detailing with internal diaphragms may be employed. Li and Wang [10] studied the effect of beam web bolt arrangement in H-beam to RHS column moment connection with internal diaphragms in resisting

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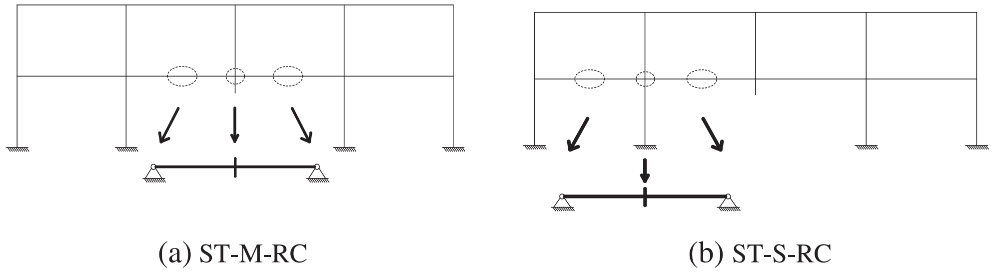

Fig. 1. Beam-joint-beam subassemblies.

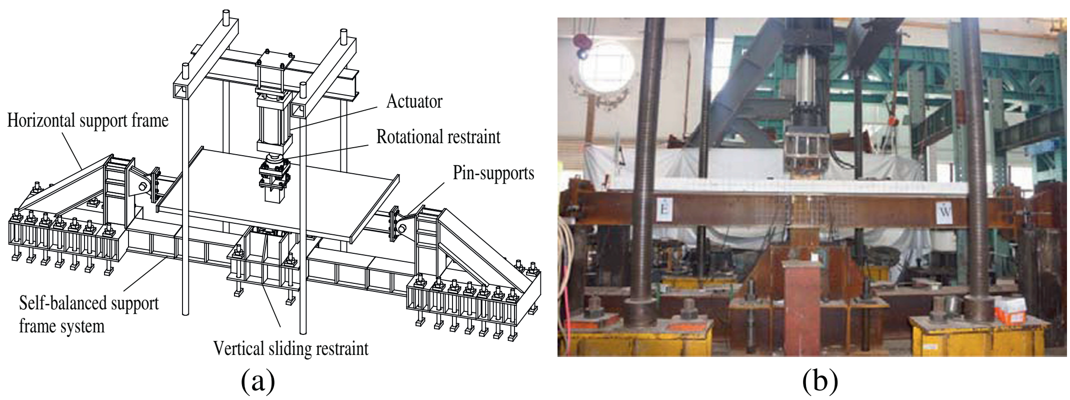

Fig. 2. Test setup.

progressive collapse. Results showed that arranging bolts in one row made the connection more robust than arranging bolts in two rows under column removal scenario. In order to achieve the convenience for fabrication, an alternative solution of internal diaphragms is to use short 'through diaphragms' (i.e. continuous plates 'cutting' through the column). In this case, the beam flange is directly welded to the edge of the diaphragm and the beam web can be bolted to the column with a normal shear tab connection. Qin and Wang [11] conducted experiments to investigate failure modes and load transfer mechanism in RHS column to H-beam connection with through diaphragms. The tensile force could be effectively retained after the beam flange failure, allowing the continuous development of catenary action.

Slab contribution to progressive collapse resistance has also been studied in recent years. Liew et al. [12] experimentally demonstrated rigid composite connections consisting of steel beams and reinforced concrete slabs developed a higher load-carrying capacity and better deformation ability than steel connections. Yasser Alashker et al. [13] used finite element models to investigate the progressive collapse resistance of steel-concrete composite floor systems with single shear tab connections. Sadek et al. [14] explored the robustness of concrete deck-steel beam composite floor systems through computational simulations. Yu et al. [15] conducted numerical investigation on steel concrete composite frames including pin and rigid joints in preventing progressive collapse and showed that a rigid connection could improve the structural capacity to prevent progressive collapse. Demonceau and Jean-François [16] conducted experimental tests to simulate the loss of a column in a substructure which was extracted from a composite building with semi-rigid joints. Yang and Tan [17] conducted experimental tests to explore the behavior of semi-rigid composite beam-column joints with steel profile decking under a middle-column-removal scenario. Although resistance of progressive collapse has been considered as an important design requirement in published design guidelines, such as GSA [18] and DOD [19], the contribution of slab to progressive collapse resistance is not taken into account explicitly in practice due to lack of sufficient

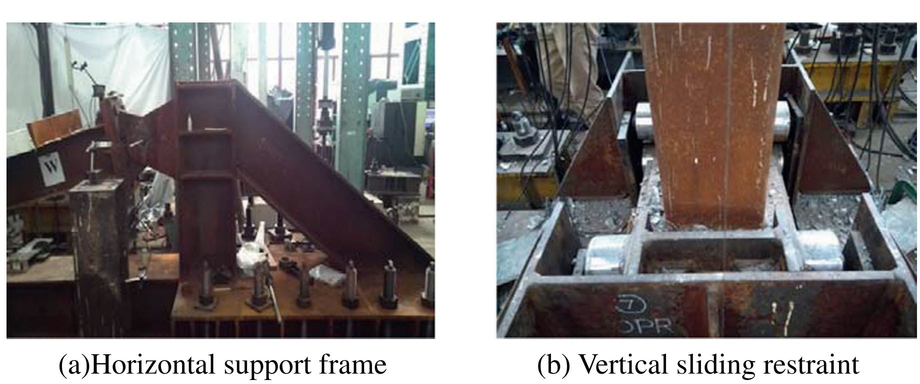

Fig. 3. Horizontal support system and vertical restraint.