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Experimental study about composite frames under an internal column-removal scenario

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ABSTRACT

During the past decade, numerous research works have been conducted about building structures against progressive collapse. Among the conducted beam-column joint tests, normally it was assumed that the inflection point was located at the middle of the beam span. However, from the composite joint tests conducted by the authors, it was observed that this assumption may not be correct. In this paper, a series of experimental tests has been conducted to estimate the structural behaviour of composite frames under a middle column loss. The bending moment distribution among the middle and the side joints was investigated at the frame level. Two types of connections, namely web cleat and flush end plate connections were both studied. The experimental results show that the internal composite frames can form catenary action well. Also, it is found that the load-carrying capacities of the internal composite frames would be reached when beam-column joint failed. In addition, flexural action and catenary action can be formed more significantly if more reinforcing bars were used in the composite floor system. The bending moment distributions among middle and side joints are identified. In addition, according to UFC 4–023-03 published by DoD, all the horizontal tie forces should be carried by slab, since none of steel connections can reach the rotation angle of 0.2 rad. According to this suggestion, more reinforcing bars were used in composite slab in the conducted experimental tests and the effectiveness of the enhanced tie forces was investigated in this study. Also, the rotational capacities of composite beam-column joints were obtained.

1. Introduction

During the past decade, numerous research works have been conducted about building structures against progressive collapse. Recently, more experimental tests are presented since the test data about building structures under such extreme loading conditions is still limited.

About steel and composite structures, the experimental tests cover steel beam-column joints, composite beam-column joints, composite frames and three-dimentional composite floor systems. Lew et al. [9]) studied the behaviour of steel beam-column assemblies against progressive collapse by experimental tests. Two types of commonly used welded connections were tested in their study. Oosterhof and Driver [12]) tested many types of steel shear connections under tension as well as shear forces. Jamshidi and Driver [6]) conducted the experimental tests of composite joints against progressive collapse. Johnson et al. [7]) studied the performance of 3D floor system under column-removal scenarios by experimental tests. Hull [5]) presents the experimental results of 3D composite floor system to prevent progressive collapse. Yang and Tan [14]) studied the performance of different types of bolted steel beam-column joints to resist progressive collapse by experimental tests. Yang and Tan [15]) conducted experiments on bolted-angle beam-column connections under a column loss condition. Yang and Tan [16]) conducted an experimental tests of bolted-angle connections under pure tension and a component-based model of bolted-angle connections was proposed. Yang and Tan [18]) presented an experimental programme about composite beam-to-column connections against progressive collapse. Five tests including double angle and end plate joints were conducted. Liu, Tan and Fung [11]) presented experimental and numerical studies about the dynamic behaviour of shear connections under column loss scenario. Guo, Gao and Fu [4]) conducted a pseudo-static test of a composite frame with flush-endplate connections under the loss of middle column. Li et al. [10]) investigates the catenary behaviour of welded unreinforced flange-bolted web connections in plane frames against progressive collapse by experimental tests and numerical simulations. Stoddart et al. [13]) studied the static and dynamic behaviour of fin-plate connections by experimental tests. Fu [3]) built a 3-dimensional finite element model to study the behaviour of a multi-storey steel frames against progressive collapse.

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Also, for reinforced concrete structures, there are many tests conducted in recent years. Lew et al. [8]) conducted experimental tests about the performance of two reinforced concrete beam-column assemblies to resist progressive collapse. Dat and Tan [1]) conducted an experimental program to study the behaviour of reinforced concrete structures under a penultimate-external column removal scenario. Yi, Zhang and Kunnath [19]) conducted the experimental tests of reinforced concrete flat slab-column structures against progressive collapse.

Fig. 1 indicates that the middle and side joints are under positive and negative bending moments, respectively. It can be found from literature review that among the conducted joint tests, normally the inflection point was assumed to be at the beam middle span. Yang and Tan [18]) conducted an experimental programme about isolated composite beam-to-column connections under a column loss condition. The experimental results indicates that the bending moment resistances and ultimate resistances of middle and sides joints are significantly different with each other. It means during the whole loading process, the inflection point may change its position, which is not consistent with the test set-up assumption. Thus, the performance of the composite frames under column loss may be different from the behaviour of the isolated composite joints, which has been studied by Yang and Tan [18]). In this paper, the performance of composite frames will be assessed.

It is stated in DoD [2]) that "unless the structural members (beams, girders, spandrels) and their connections can be shown capable of carrying the required longitudinal, transverse, or peripheral tie force magnitudes while undergoing rotations of 0.20-rad (11.3-deg), the longitudinal, transverse, and peripheral tie forces are to be carried by the floor and roof system". Also, DoD [2]) specified the rotation capacities of various types of steel connections, and it can be found from DoD [2]) that none of steel connections can reach the rotation angle of 0.2 rad. It means for steel structures, all the horizontal tie forces should be carried by slab, since none of steel connections can reach the rotation angle of 0.2 rad according to DoD [2]). In this study, both web cleat and flush end plate, which belong to ductile connections, will be tested and the rotation capacities of these connections will be obtained [17]. In addition, in order to enhance the tie forces carried by floor system, which is suggested by DoD [2]), more reinforcing bars will be used in the slab and the effectiveness of the enhanced tie forces will be investigated in this study.

In this paper, the performance of composite frames under a middle column loss will be investigated. The load transfer mechanism and redistribution for composite steel frames after the loss of a middle column will be discussed and the effect of additional reinforcing bars in composite slab will be estimated.

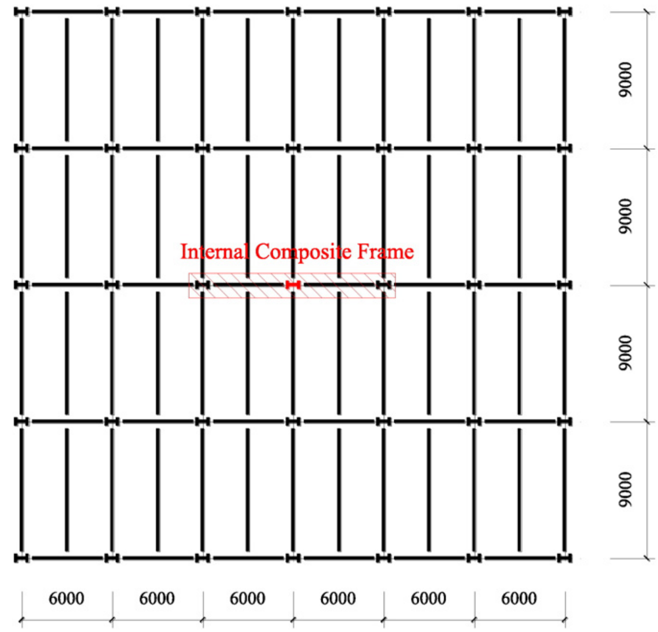

Fig. 2. Prototype composite steel frames.

2. Test programme

2.1. Test set-up

Fig. 2 depicts the prototype structure studied in this paper. Internal Composite Frames are horizontally restrained. Fig. 3 (a) shows the front view of the frame test set-up. From this figure, it can be seen that full horizontal restraints were used. The side columns and the extended beams were restrained by pin supports. One side of the specimen was constrained by an A-frame and the restraint at the other side was connected onto a reaction wall. The horizontal reactions at the column top and extended beam connections were measured by load cells. Strain gauges were attached onto column sections in order to obtain the horizontal reaction forces at the column bottom. Fig. 3 (b) depicts the set-up aerial view. Vertical forces were applied onto the middle column stud under out-of-plane restraint during the tests.

Fig. 3 (a) shows that the two side columns were under constant compressive forces applied by two hydraulic jacks. The purpose of this is to consider the influence of column compressive forces. Fig. 4

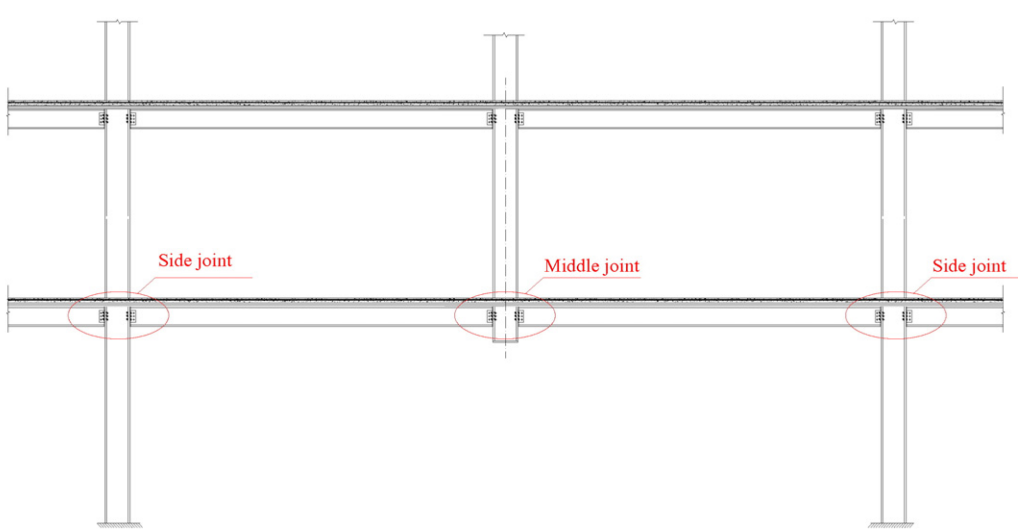

Fig. 1. Composite steel frame under a middle column loss.