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Experimental study on progressive collapse resistance of steel frames under a sudden column removal scenario

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ABSTRACT

A comprehensive experimental apparatus for the progressive collapse testing of steel frames has been developed. The apparatus is suited for the testing of planar steel frames to study the load transfer process and the progressive collapse resistance of steel structures under a column removal scenario. In order to simulate a sudden removal of a middle column at the ground storey of the frames, a removable column unit has been designed to allow for an instantaneous knock-out by a pendulum hammer during the test. To avoid the out-of-plane instability of the planar steel frames, an out-of-plane restraining system has been designed and integrated into the test apparatus. Weights simulating the desired gravity loads were attached to the test frame through holding baskets, which were designed to minimize unwanted shaking and ensure that the suspended baskets moved together with the deformed steel frames during the tests. Experimental results showed that the column removal mechanism in the test apparatus was effective. Using this apparatus, the dynamic behaviour of three planer steel frames under a column removal scenario was investigated. Based on the measured deformations and strains, the dynamic response, collapse modes, load transfer path of the steel frames after the removal of the middle bottom column are studied.

1. Introduction

Among major civil engineering incidents, progressive collapse triggered by a local structural failure is generally recognized as one of the most devastating types of structural failures. According to ASCE-7 [1], progressive collapse represents "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". Studies have shown that most of the past progressive collapse cases were attributable to external event including blast and impact [2,3].

The process of progressive collapse of a structure subjected to blast and impact types of loadings may be divided into two different stages: a) abrupt failure of one or more load carrying members due to the direct loading effect, i.e. development of the local failure, and b) the structural response to the local failure, leading to either a rebalanced system or the collapse of the whole or a large part of the structure. Generally speaking, progressive collapse is complex as it involves dynamic response, inelastic behaviour, large deformations and contact-impact of structural members [4,5]. Prevention of progressive collapse and improving the capacity of structures in withstanding local failure has become a key area of research in structural engineering.

In recent years, considerable amount of efforts has been devoted into studying the behaviour and load transfer mechanisms of frame structures during the progressive collapse. On the numerical simulation front, different approaches have been studied for modelling the structural behaviour in a progressive collapse scenario. For instance, Krauthammer [6] used the finite element code DYNA3D to investigate the influence of the structural concrete and steel connections on the robustness of blast resisting structures. Lee et al. [7] investigated two nonlinear methods for the analysis of the resistance of welded steel moment frames, using the four-node quadrilateral shell elements in ABAQUS. Bao et al. [8] used a macro model-based approach, available in the nonlinear FE software DIANA, to numerically simulate the potential for progressive collapse of a typical reinforced concrete (RC) moment frame structure. Kripakov et al. [9] used finite-element ADINA models and studied a simplified approach to assess the structural stability of underground mine structures. Brunesi and Nascimbene [10] employed an open access procedure using a fiber-based model to simulate the dynamic response of RC buildings subjected to a sudden column loss.

On the experimental front, numerous studies have been performed using a quasi-static testing method. Yang and Tan [11] studied the performance of bolted steel beam-column joints under a central-column

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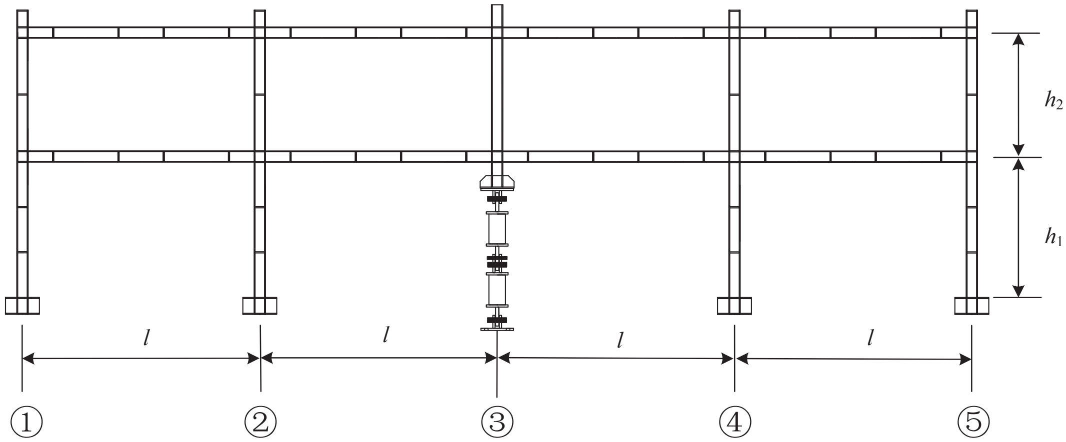

Fig. 1. Layout of the steel frame specimen.

removal scenario. Lew et al. [12] investigated the performance of beam-column assemblies with two types of moment-resisting connections under a column removal scenario. Tsitos et al. [13] tested two 1/3 scale three-storey, two-bay steel frames to evaluate the effectiveness of earthquake resistant design details in enhancing the progressive collapse resistance of steel frames. Yi et al. [14] conducted a 1/3 scaled progressive collapse test of a 4-bay and 3-storey plane reinforced concrete (RC) frame. A collapse resistance test of a 1/8 scaled 4-bay and 3-storey plane RC frame was performed by Sagiroglu [15]. Xie and Shu [16,17] carried out a space steel frame experiment

Table 1
Summary of the dimensions of steel frame specimens.

Specimen	Beam section	Column section	Storey height		Span length l
			h_1	h_2	
	mm	mm	mm	mm	mm
FRAME1	Middle bay: H54 × 50 × 4 × 4 Side bay: H80 × 50 × 3 × 4	H100 × 100 × 6 × 8	1227	1054	2100
FRAME2	H54 × 50 × 4 × 4	H54 × 50 × 4 × 4	1227	1054	2054
FRAME3	H54 × 50 × 4 × 4	H100 × 100 × 6 × 8	1227	1054	2100

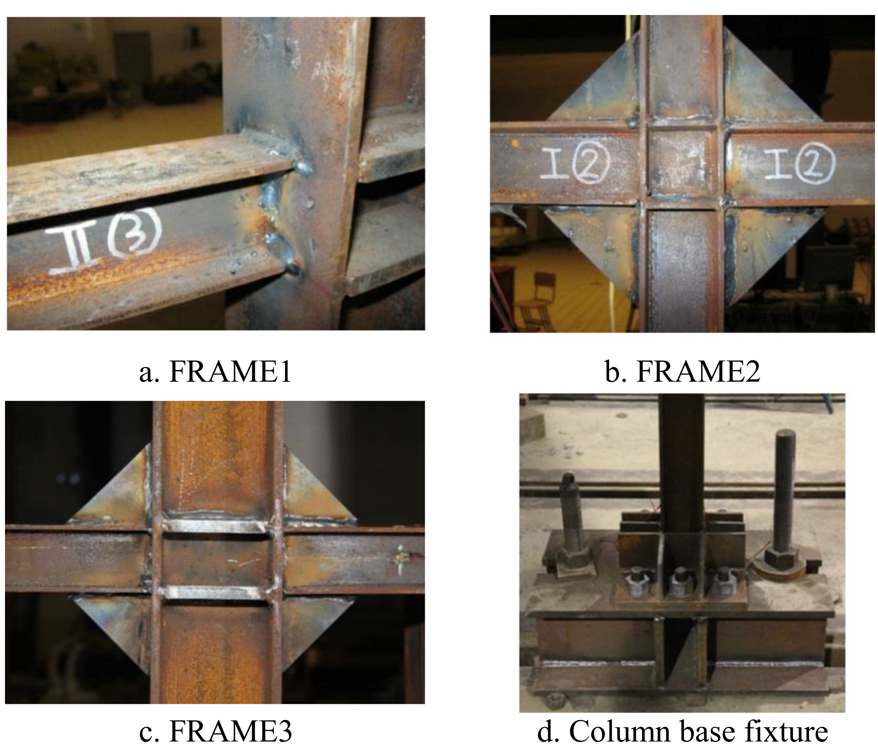

Fig. 2. Beam-column connections in different frames and column base fixture.