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An experimental investigation of the progressive collapse resistance of beam-column RC sub-assemblages

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HIGHLIGHTS

- Experiments on 1-column 2-bay beam RC sub-assemblage with sliding pin connections.
- 3-Column 2-bay beam RC sub-assemblages tested with fixed pin connections or pantographs.
- Growth of vertical cracks analyzed with Digital Image Correlation technique.
- Rebar strength and beam height influence the progressive collapse resistance of structures.
- Closed form solution predicts the yield force of the RC beam-column sub-assemblages.

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ABSTRACT

The aim of the present paper is to evaluate the eventuality of progressive collapse of beam-column reinforced concrete (RC) structures employing a column removal scenario. An experimental program has been carried out to study the behavior of 5 types of laboratory-scale RC structures composed of one or three columns and two beams. The growth of damage within the concrete structure is analyzed using a Digital Image Correlation (DIC) technique. Two diameters of rebar (8 mm and 12 mm) and two beam lengths (180 and 240 mm) are considered to investigate the influence of the reinforcement ratio on the fracturing and bearing capacity of the one column-two beams structures. Sliding and pin connections are considered to evaluate the influence of the boundary conditions for structures consisting of three columns and two beams. The experimental results provide a failure scenario in four steps: elastic behavior, structural hardening with propagation of cracks through cross-sections of beams, yielding of rebars and growth of plastic hinges at beam-column joints, and the failure of longitudinal rebars. Finally, an analytical method based on the principle of virtual work is employed to calculate the structural resistance of the tested sub-assemblages and is compared to experimental data existing in published literature.

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1. Introduction

Reinforced concrete structures that are based on an assembly of beams and columns are widely utilized by civil engineers throughout the world. Accidental or intentional events, such as earthquakes, explosions and localized failures due to accidental overload, may induce localized structural damage leading to a loss of the load bearing capacity of an individual column [1].

This type of localized damage may lead to a chain reaction of failures of crucial structural members that may not even be associated with the initial damage, and lead to more widespread failure of the surrounding individual structural members causing partial or complete collapse of the entire structure [2,3].

During the last few years, experimental research programs have been developed all over the world to investigate the mechanical response of RC beam-column sub-assemblages and the risk of progressive collapse in a case of single column removal scenario. Among these studies, Yi et al. [4] performed an experiment in order to observe the procedure of progressive collapse of a reinforced concrete frame. In this work, the beam-column reinforced concrete frame is composed of five columns and three beam levels. This specimen is a third-scale model of the lower three stories of real structure. The details of the four-bay/eight-story RC frame structure are shown in Fig. 1a. This experiment was performed in two stages. For the first stage, the vertical load is applied on the top of the middle column by a servo-hydraulic actuator to simulate

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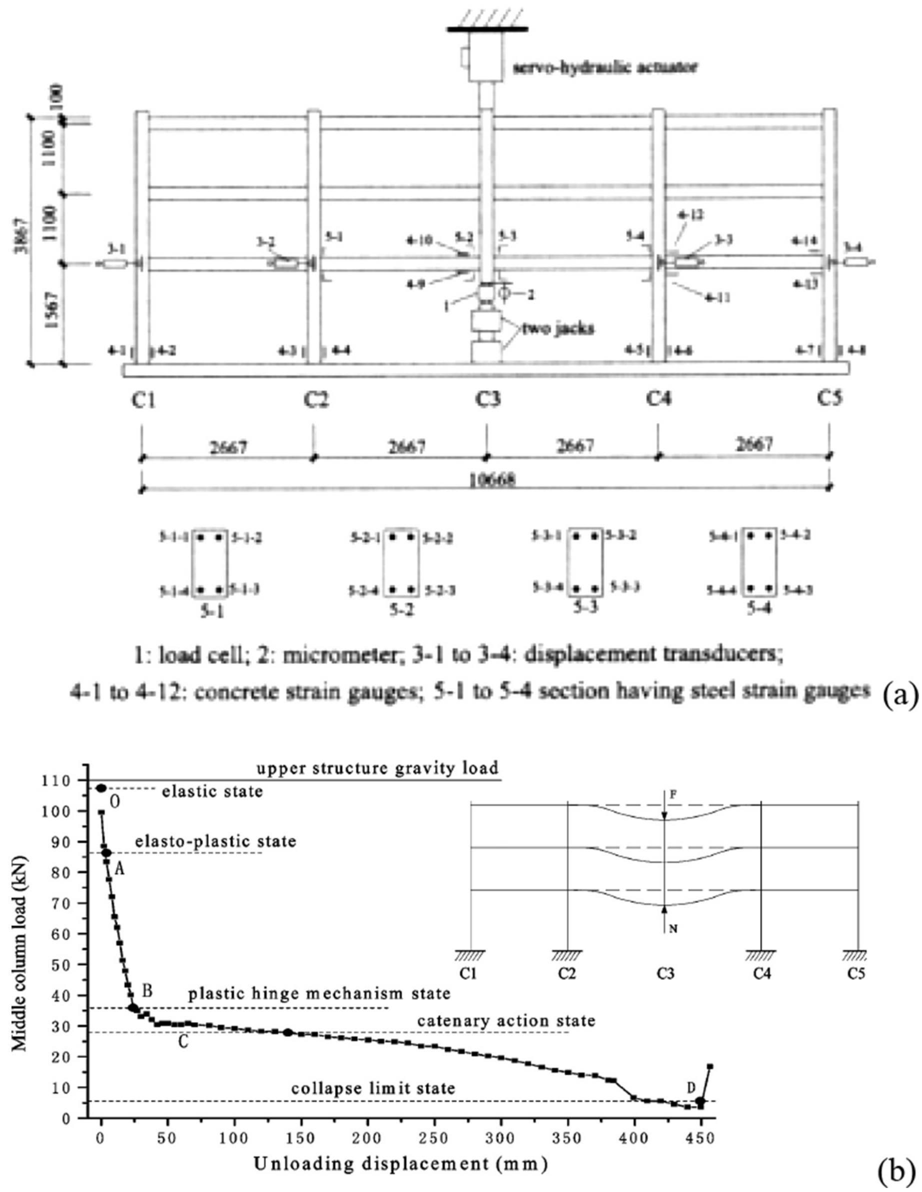

Fig. 1. Progressive collapse scenario of a five columns and three beam-levels RC frame structure by Yi et al. [4] (a) details of model frame and instrumentation layout, (b) Middle column load versus unloading displacement of failed middle column.

the gravity load of the upper frame, the load being transmitted to the lower jack through the middle column. In the second stage, the lower jack is bent down to artificially simulate the gradual failure of the lower story column. Four significant states are identified by the authors: the elastic state, a plastic hinge mechanism corresponding to the plastic deformation of reinforcing steel bars in the floor beams, the catenary action state which corresponds to tensile loading of steel bars in the floor beams, and the collapse limit state that corresponds to the failure of rebars in the first floor beam adjacent to the middle column as illustrated Fig. 1b. In addition, the horizontal displacement of columns at the first floor level is measured by means of linear variable differential transducers (LVDTs) which show that the side columns cannot be considered as purely constrained (the final displacement is about 20 mm) and the entire structure was contributing to the progressive collapse-resistant behavior of the RC frame. However, due to the size of the structures tested, experiments are costly and necessarily limited to a very small number of multi-bay/multi-story RC frames.

More recently, a number of publications investigate the mechanical behavior of three column-two beam sub-assemblages. However, due to restrictive constraints applied to the side-columns, two failure modes are superimposed which are joint failure at the beam-column interface, and a catenary action corresponding to a tensile loading of the rebar, leading to unrealistic bearing capacities of the tested RC structures compared to that of a real full scale structure. For instance, an experimental program was developed by He and Yi [5] to investigate the influence of a steel bar arrangement and loading-rate on the resistance-capacity of RC beam-column sub-structures. Five specimens were tested with fixed pin connections at both ends. The vertical load was applied on the top of the middle column with velocities set to 8 mm/s and 51 mm/s. The successive elastic, plastic and cate-

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