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Bar fracture modeling in progressive collapse analysis of reinforced concrete structures

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ABSTRACT

Reliable evaluation of progressive collapse resistance of structures requires substantiated methods and techniques for analyzing the response of critical elements subjected to large deformations. Steel bar fracture is a significant event that can lead to progressive collapse of reinforced concrete (RC) structures. Given the sudden discontinuity associated with bar fracture, modeling of such an event in a continuum domain analysis is challenging. In this paper a method is proposed for finite element modeling and analysis of RC elements that accounts for bar fracture. It is demonstrated that such a modeling technique is capable of developing catenary action. Analytical results based on the proposed method show good agreement with experimental data. The underlying cause for a drop in beam vertical resisting force following the peak force is identified and explained.

1. Introduction

Structural systems subjected to man-made or natural hazards may experience large deformations to resist progressive collapse. Progressive collapse occurs when local structural damage causes a chain reaction of structural element failures disproportionate to the initial damage, leading to partial or full collapse of the structure. Over the last few years, a number of publications covering the subject of progressive collapse have appeared in the scientific literature [1–6], which cover both experimental and analytical studies. The General Services Administration [7], and the Department of Defense [8] provide threat independent methods and use different scenarios for initiation of local failure to examine the potential progressive collapse of structures. One of these scenarios is the instantaneous removal of a ground floor column located near the middle of exterior frames.

Following the column removal, the beams and floors start to deform and redistribute the gravity loads. This may lead to large deformation response of beams and in turn to steel bar fracture. For problems in which material failure takes place due to progressive damage resulting in the formation of either single or multiple fractures, the current position of computational modeling is not established well [9]. Although, bar fracture at a section results in the loss of section flexural strength, it does not constitute collapse of the element or structure. Therefore, in order to carry out reliable evaluation of progressive collapse resistance of reinforced concrete (RC) structures, there is a need to understand and model large deformation response of RC elements and steel bar fracture. In this paper, first, the results of an experimental program on large deformation response of an RC beam are presented. Then, a method is proposed to model bar fracture in a finite element analysis of structures. The main reasons for a drop in beam vertical resisting force following the peak force are discussed and explained. Experimental and analytical results are compared.

2. Experimental program

In order to study large deformation response of RC beams, first a seven-story building is designed. A typical plan of the building is shown in Fig. 1. The floor is a one-way joist system in the transverse direction. The span in the transverse direction is set equal to 30 ft (9.15 m) in order to have an economical joist floor system [10]. The total depth of the floor system is 20 in. (0.51 m) with a solid slab of 4.5 in. (0.11 m). The depth of all beams is equal to 20 in. (0.51 m; equal to the depth of the joist floor system) to minimize the formwork cost. For design purposes, reinforcement of grade 60 ksi (413 MPa) is used along with concrete with a compressive strength of 4 ksi (27.6 MPa). In the design of the building, the integrity requirements are satisfied [11]. The building is assumed to have ordinary RC frames and located on a site class C in Atlanta, GA.

In the experimental program, the response of the second floor exterior beam following the loss of column D3 in the first floor is studied (see Figs. 1 and 2). This is done by evaluating the response of the two-span exterior beam between axes *C* and *E* under a monotonically increased vertical displacement at the location of removed column. A 3/8th scaled model of the second floor

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