Performance of Three-Dimensional Reinforced Concrete
Beam-Column Substructures under Loss of a Corner Column Scenario

Kai Qian, A.M.ASCE1; and Bing Li2

Abstract: The vulnerability of conventional RC structures to structural failure caused by the loss of corner columns has been emphasized over the past years. However, the lack of experimental tests has led to a gap in the knowledge for the design of RC building structures to mitigate the likelihood of progressive collapse caused by losing a ground corner column. Seven one-third scale RC beam-column substructures were tested to investigate their performance. The variables selected for the test specimens included beam transverse reinforcement ratios, type of design detailing (nonseismic or seismic), and beam span aspect ratios. Shear failure was observed to have occurred in the corner joint, and a plastic hinge was formed at the beam end near the fixed support in the nonseismic detailed specimens. However, plastic hinges were also formed in the beam end near to the corner joint for the seismically detailed specimen. Vierendeel action was identified as the major load redistribution mechanism before severe failure occurred in the corner joint, but a cantilever beam redistribution mechanism dominated after the corner joint suffered severe damage. The test results were compared with the Department of Defense design guidelines to highlight the deficiencies of the recently updated guidelines. DOI: 10.1061/(ASCE)ST.1943-541X.0000630. © 2013 American Society of Civil Engineers.

CE Database subject headings: Progressive collapse; Reinforced concrete; Beam columns; Substructures.

Author keywords: Progressive collapse; Reinforced concrete; Corner; Three dimensional; Beam-column; Substructures.

Introduction

ASCE SEI 7 (2010) defines progressive collapse as the spread of an initial local failure from element to element, which eventually results in the collapse of an entire structure or a disproportionately large part of it. In less technical terms, it is often thought of as the domino effect. The collapses of the Ronan Point Tower in London in 1968 and Murrah Federal Building in Oklahoma City in 1995 have demonstrated the disastrous consequences of a progressive collapse. To prevent progressive collapse, a structure should have continuity to offer an alternate path to ensure the stability of the structure when a vertical load-bearing element is removed. Design guidelines [Department of Defense (DoD) 2005; General Services Administration (GSA) 2003] have proposed design procedures to evaluate the likelihood of progressive collapse of a structure following the notional removal of the vertical load-bearing elements. Although significant improvements were implemented in the recently updated DoD design guidelines (2009) [for a detailed description of these updated points, please refer to Stevens et al. (2009) and Marchand et al. (2009)], a number of design criteria still need to be subjected to further analysis and verification with experimental data.

To better understand the performance of RC frames subjected to different missing column scenarios, several experimental and numerical studies have been conducted in recent years. Sasani et al. (2007) conducted an in situ test to study the performance of a RC building with one-way floor slabs supported by transverse frames when subjected to the sudden removal of one of its exterior columns. The behavior of a RC moment frame subjected to the loss of an interior column was also investigated by Yi et al. (2008). The efficiency of using carbon fiber–reinforced polymer (CFRP) retrofitting RC pre-1989 frames, which may be deficient in its continuity subsequent to the loss of an interior column, was investigated by Orton et al. (2009). The behavior of axially restrained beam-column subassemblies under the scenario of the loss of a column was studied by Su et al. (2010). The performance of exterior and interior beam-column subassemblies following the loss of one of the ground exterior columns was experimentally studied by Yap and Li (2011) and Kai and Li (2012a), respectively. However, most of the previous research studies were focused on the frames subjected to the loss of interior or exterior column scenarios, whereas limited studies have been conducted for the case of loss of corner columns. Mohamed (2009) investigated the implementation of DoD (2005) to protect against progressive collapse of corner floor panels when their dimensions exceeded the damage limits through numerical simulation. A case study of a RC building with different bracing configurations was analyzed using an alternate load path method. Kai and Li (2012b) experimentally studied the dynamic performance of six beam-column substructures under a loss of a ground corner columns scenario. The dynamic responses of acceleration, velocity, and displacement were determined. Moreover, the dynamic effects of the beam-column substructure caused by sudden removal of a corner column were evaluated. Sasani (2008) and Sasani and Sagiroglu (2008) conducted an in situ test to examine the dynamic response and the possibility of a progressive collapse of a RC frame when one corner column and adjacent exterior columns were simultaneously demolished by explosion. They concluded that the three-dimensional (3D) Vierendeel action of the transverse and longitudinal frames was