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Toward an economic design of reinforced concrete structures against progressive collapse

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ABSTRACT

A three-dimensional discrete crack model based on the Applied Element Method is used to perform economic design for reinforced concrete structures against progressive collapse. The model adopts fully nonlinear path-dependent constitutive models for concrete and reinforcing bars. The model applies a dynamic solver in which post-failure behavior, element separation, falling and collision are predicted. First, the model is used to study the behavior of multi-story reinforced concrete buildings designed in a traditional manner according to the ACI 318-08 and subjected to accidental removal of one or two central columns at the ground level. In an iterative way, the model is then used to investigate a safe design against progressive collapse for such extreme loading case. Based on the analytical results of the AEM, it can be concluded that the collapse of only one column would not lead to any progressive collapse of the studied reinforced concrete structure. However, the collapse of more than one column may lead to a progressive collapse of a considerable part of it. It is concluded also that the AEM could be successfully used as an analytical tool to suggest economical designs that are safe against progressive collapse of reinforced concrete structures.

1. Introduction

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 has been known as "progressive collapse" [1]. Progressive collapse of a structure takes place when the structure has its loading pattern or boundary conditions changed such that structural elements are loaded beyond their ultimate capacities and fail. When any element fails, the remaining elements of the structure seek alternative load paths to redistribute the load applied to it. As a result, other elements may fail, causing failure mechanism. It first drew the attention of structural engineers after the accidental collapse of the 22-story Ronan Point tower in Canning Town, UK on May 1968. The cause of the collapse was a human-error gas explosion that knocked out the precast concrete panels near the 18th floor causing the floors above to collapse [2].

The Oklahoma City Murrah Fedral Building was not designed to resist progressive collapse. Half the building was collapsed in 1995 due to the destruction of only one column by the blast. Even though the structure met all code provisions, research conducted after the disastrous event showed that alternatives to the building design, such as different reinforcement detailing and addition of some reinforcement, would have prevented the collapse without a significant increase in construction costs [3].

Structural progressive collapse has been the focus of extensive research during the past few years because of the increasing rate of victims resulting from natural disasters (e.g., earthquakes and hurricanes) or human-made disasters (e.g., bomb blasts, fires and vehicular impacts) [4–8]. Structural designers have traditionally focused on optimizing the cost of constructed facilities while meeting code requirements. Unfortunately, most of the structures have been designed to resist gravity loads and lateral loads resulting from wind or moderate earthquakes. The structural behavior of a constructed facility when subjected to loads beyond conventional design is not typically addressed.

1.1. Progressive collapse design in current codes and standards

The cause of the initiating damage to the primary load-bearing element is unimportant; the resulting sudden changes to the structure's geometry and load-path are what matter. This means that the analysis is threat independent. Design codes, therefore, incorporates a threat independent approach to progressive collapse analysis.

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