Cairo University

STRENGTHENING OF STEEL BEAM TO COLUMN CONNECTIONS TO RESIST PROGRESSIVE COLLAPSE

By

Ahmed Mohamed Nabil Abdel-Salam

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE in
STRUCTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Key Words:

Progressive collapse; Connections; Steel structures; Finite element modeling; Alternate path method

Summary:

Progressive collapse is currently one of the important research topics in structural engineering. It occurs when a primary structural component of a building fails to resist an accidental overloading. This failure leads to spreading of the forces to other neighboring load bearing components; if this distribution of loads exceeded the component capacity then this will lead to collapse of these components and ultimately to total collapse.

In this research, the progressive collapse of a symmetric steel structure is examined and the effect of different strengthening techniques for the moment resisting frame connections is investigated. The principles presented in this research were examined by developing idealized models and carrying out the alternate path method with the nonlinear static progressive collapse analysis using SAP2000 software according to UFC 2009 guidelines. The strengthening of beam to column moment connections has been carried out for flush end plate connections using five different methods and for extended end plate connections using three different methods, utilizing ANSYS 11.0 software to generate the corresponding moment rotation curves. The study concluded that the most effective way for strengthening the flush end plate connection is welding the end plate entirely with the column and for strengthening the extended end plate connection is adding vertical stiffeners to the beam perpendicular and parallel to the beam web.

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Abstract

For the past 40 years, progressive collapse was extensively researched in structural engineering. It occurs when a primary structural component of a building fails to resist an accidental overloading. This failure leads to spreading of the forces to other neighboring load bearing components; if this distribution of loads exceeded the component capacity then this will lead to collapse of these components and ultimately to total collapse. There are numerous threats which could cause progressive collapse in a structure that may lead to fatality such as: airplane crashes, errors in design or construction process, fire accidents, accidental over load, explosion caused by bombs, vehicular collision and fire accidents. In order to mitigate the effect of progressive collapse; code agencies such as: General Services Administration (GSA/USA) and Department of Defense (DoD/USA) Unified Facilities Criteria (UFC) have established guidelines to resist this phenomenon. Researches on the progressive collapse assessment of steel framed structures are gradually increasing with the improvements in steel material properties, methods of analysis and construction technology.

Nowadays, governmental agencies all over the world are seeking not only to design buildings capable of resisting progressive collapse, but also to retrofit the existing buildings in order to resist this phenomenon. One of the most effective ways used in resisting progressive collapse is strengthening frame connections. Frame connections are critical elements that are responsible for the safe transfer of loads from a member to another. However, the connection may have a paradoxical effect causing the member's failure if it is not strong enough to sustain this load transfer.

In this study the susceptibility of a symmetric steel structure, with different strengthened moment resisting frame connections configurations, to resist progressive collapse has been assessed. To examine the principles presented in the research; idealized building models were analyzed using SAP2000. Alternate path method with the nonlinear static analysis is carried out according to UFC 2009 guidelines. Five methods were implemented to strengthen the flush end plate connections; 1) adding vertical stiffeners in the beam, 2) adding horizontal stiffeners in the column panel zone, 3) adding cover plates in the column panel zone, 4) adding flange and web cover plates at the beam end and 5) complete welding of the end plate to the column. Moreover, three methods were used to strengthen the extended end plate connections; 1) adding vertical stiffeners to the beam, 2) adding horizontal stiffeners in the column panel zone and 3) adding vertical stiffeners to the beam perpendicular and parallel to the beam web. The finite element program ANSYS 11.0 was used to generate the corresponding moment rotation curve for each strengthened connection, and this was used in the idealized building model to represent the retrofitted structure. The study concluded that the most effective way for strengthening the flush end plate connection is welding the end plate entirely with the column and for strengthening the extended end plate connection is adding vertical stiffeners to the beam perpendicular and parallel to the beam web.

Chapter 1: Introduction

1.1 Overview

The term progressive collapse is typically used to refer to the spread of an initial local failure within a structure. The local failure is initiated by the loss of one or more of the primary components of the structure. The sudden removal of a primary component will cause the transmission of gravity loads (Dead Load and Live Load) to the adjoining components in the structure. Thus, an adequate design of these primary elements is required to enable them to resist and redistribute the overloading and to avoid the complete or partial collapse of the structure. A progressive collapse can be triggered by a variety of causes such as vehicle collision, building modifications, explosion, terrorist attacks, earthquake and other natural or artificial hazards including design and construction errors.

The interest in progressive collapse has come in waves, with each wave produced by a catastrophic failure. The landmark event was the Ronan Point Apartment Tower collapse in England in 1968 as shown in figure 1.1. Despite the small number of casualties, the collapse prompted the interest and concern of engineers all over the world and manifested in the generation of many influential papers tackling the phenomena (Levy and Salvadori, 2002). A second wave of interest succeeded the Oklahoma City bombing in 1995, in which a terrorist detonated a bomb outside of the Alfred P. Murrah Federal Building as shown in figure 1.2. This was the first progressive collapse event in recent history of the United States that was not caused by human error or natural disaster. Consequently, as the first wave, this failure had drawn the attention of many researches to eventually producing numerous papers tackling the damage and progression of collapse. A portion of the presented papers included future design recommendations for codes. The last wave, which is still ongoing, was a result of the collapse of the World Trade Centers and the partial collapse of the Pentagon on September 11, 2001. Since 2001, interest in progressive collapse has excessively increased. A major factor in the peak of interest can be attributed to the advancements made in building systems and computational capabilities since the landmark event in 1968.

Figure 1.1: Ronan Point failure

Figure 1.2: Murrah federal building failure

Following the collapse of Ronan Point, a local government minister, Alan Whitehead said, "The lessons of the Ronan Point collapse mean that criteria for building robustness must be constantly reviewed and updated to provide the reliable structures that people expect from modern construction. The proposed amendments to the Building Regulations are intended to make our buildings safer from collapse".

1.2 Significance of progressive collapse

For a rare accident in developed countries, the dangerous effect of the progressive collapse effect on buildings cannot be neglected. This lethal phenomenon can be prevented only with significant consideration of adequate ductility, continuity, and redundancy. In 1995, the Alfred P Murrah building in Oklahoma City was a landmark in the history of progressive collapse resulting in 168 fatalities. In order to prevent such fatalities in the future, new effective preventative/resistant measures to progressive collapse have been introduced taking into consideration all threats that may lead to such an unfortunate event. After the occurrence of these multiple severe accidents, it became inevitable to assess the buildings upon their vulnerability to progressive collapse.

In a natural consequence of the rise in terrorist attacks, especially casualties (nearly 3000 died in the attacks of September 2001) in the World Trade Center case, followed by the many research conducted on progressive collapse led to development of new guidelines, such as General Service Administration (GSA) and Department of Defense, Unified Facilities Criteria (DoD/UFC) publications for resisting and preventing such a phenomena. Unlike reinforced concrete, a limited number of investigations were carried out on steel structures. Researches that are tackling the progressive collapse resistance of steel framed buildings are gradually increasing nowadays as a response to the improvements of steel material properties, technology and methods of analysis.

1.3 Objectives

This research aims to study the effect of strengthening the steel moment frame connections using different techniques in resisting the progressive collapse phenomenon.

1.4 Scope

This research was conducted using two software packages. 1) ANSYS 11.0 was used to generate the moment-rotation curves (M-Theta) of different moment frame structure connections' configurations. For each method different stiffeners' thickness, spacing and length were studied. 2) SAP2000 was used to investigate the vulnerability of different frame connections' configuration to mitigate the progressive collapse phenomenon.

To examine the ideologies presented in this research, an analysis was performed on idealized building models using the alternate path method with the nonlinear static analysis according to UFC 2009 guidelines.