MITIGATION OF PROGRESSIVE COLLAPSE
IN CONCRETE STRUCTURE INCORPORATING
THE GSA LINEAR STATIC PROCEDURE

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A Project Report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
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JUNE 2013

I would like to dedicate this Project Report to
my beloved father and mother
and my beloved wife

ACKNOWLEDGEMENT

Foremost, I wish to express my sincere appreciation to my supervisor. Ir. Azhar bin Ahmad for his encouragement, support, guidance and advices from time to time throughout the duration of this dissertation. Without his continued support and interest, this report would not have been the same as presented here.

In this opportunity, I would like to convey a million thanks and appreciation to my family who have strong faith in me and providing me with countless support in term to complete this study. In addition, I would like to express my gratitude to my beloved wife whom supported me nonstop during the entire project.

Last but not least, my sincere appreciation also extend to all my colleagues and other who have provided assistance at various occasions. Their views and tips are useful indeed unfortunately; it is no possible to list all of them in this limited space.

ABSTRACT

A progressive collapse involves a series of failures that lead to partial or total collapse of a structure(Kim & Kim, 2009). The first aim of this study is to understanding the most critical condition of column removal to create progressive collapse. The second one, is to understanding the effects of increasing beam capacity in various condition throughout the structure levels to mitigate of progressive collapse. The case study is a 12-story concrete structure and the analysis and design is according to Euro Cod and the General Services Administration (GSA) standard. For objective one, three condition of column removal center, corner and side column removal are chosen to understanding the most critical of column removal. For the second objective, three alternative of beam dimension increasing is chosen. The alternatives are, moderate increasing in beam depth in all stories the second and the third one are significant increasing in upper levels and significant increasing in bottom story levels. The results of this study show that, the center condition has the most potential of progressive collapse after column removal. Also, the alternate 1 and 2 are good method however; the third alternative is not an effective way to mitigate the progressive collapse.

ABSTRAK

A keruntuhan progresif melibatkan satu siri kegagalan yang membawa kepada keruntuhan sebahagian atau keseluruhan struktur (Kim & Kim, 2009). Tujuan pertama kajian ini adalah untuk memahami keadaan yang paling kritikal penyingkiran ruang untuk mewujudkan keruntuhan progresif. Yang kedua, adalah untuk memahami kesan-kesan peningkatan kapasiti rasuk dalam pelbagai keadaan seluruh peringkat struktur untuk mengurangkan keruntuhan progresif. Kajian kes adalah satu struktur konkrit 12-cerita dan analisis dan reka bentuk adalah mengikut Cod Euro dan Pentadbiran Perkhidmatan Am (GSA) standard. Untuk tujuan satu, tiga keadaan tiang penyingkiran pusat, sudut dan sisi penyingkiran ruang dipilih untuk memahami yang paling kritikal penyingkiran ruang. Bagi objektif yang kedua, tiga alternatif dimensi rasuk meningkatkan dipilih. Alternatif adalah, sederhana meningkat di kedalaman rasuk dalam semua cerita yang kedua dan yang ketiga adalah semakin meningkat di tahap yang lebih tinggi dan penting dalam meningkatkan tahap cerita bawah ketara. Keputusan kajian ini menunjukkan bahawa, keadaan pusat ini mempunyai potensi yang paling keruntuhan progresif selepas penyingkiran ruang. Juga, 1 alternatif dan 2 adalah kaedah yang baik bagaimanapun; alternatif ketiga yang tidak adalah cara yang berkesan untuk mengurangkan keruntuhan progresif.

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LIST OF SYMBOLS

As	cross sectional area of tension reinforcement
As’	cross sectional area of tension reinforcement
X	Natural axis depth
Z	level arm
Ac	Concrete Cross-sectional
d	effective depth of tension reinforcement
d’	depth of compression reinforcement
QCE	expected ultimate, unfactored capacity,
QUD	acting force (demand) in structural member or joint

CHAPTER 1

INTRODUCTION

1.1 Introduction

In 1986 gas exposing caused to destroying a part of 22-story Ronan Point apartment building. Following the partial collapse this destroying caused progress this collapse to other part of building. The impressive personality of the collapse created a new viewpoint of structural design and resulted in important revisions of structure design codes and named progressive collapse. Recently, progressive collapse of building becomes one of civil engineering noticeable issues after the collapse of the World Trade Center in 2001(Alrudaini, 2011).

A progressive collapse of a building is a terrible partial or total breakdown that began from an initiating event that causes local damage that cannot be prevented by the inherent continuity and ductility the structural system of building. Following the local damage or collapse, a chain reaction of failures Spread vertically or horizontally and develops into an enormous partial or total collapse, where the resulting damage is disproportionate to the local damage because of the initiating event. Progressive collapse is defined in the commentary of the American Society of Civil Engineers Standard 7 Minimum Design Loads for Buildings and Other

Structures (ASCE, 2005) as “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.”

Such collapses can be initiated by many causes, such as, design and construction errors and events that are beyond the design basis but usually do not be considered by designers. Such events would include abnormal loads not normally considered in design (e.g., gas explosions, vehicular collisions, and sabotage),(Ellingwood, 2002). In fact, abnormal loads are defined as loading events which have low probability of occurrence to the building also, predicting them is usually impossible. However, there is no certain type of load classified as accidental load or abnormal load (Kwok, 2007). Because of that, usually in progressive collapse usually design the initiate reason of failure is not be considered.

1.2 Examples of progressive collapse

This chapter presents selected examples of building progressive collapses. Although the number of progressive collapses in the history is quite small, the catastrophic consequences in terms of fatalities and other losses, which this phenomenon entails, brings a lot of attention in society, governments and community of civil engineers. Moreover, the growing threat of terrorist attacks makes the problem of progressive collapse should be considered when designing and constructing buildings.

1.2.1 Ronan Point

The Ronan Point Apartment building was erected in London between 1966 and 1968. It was a 23 story, and 64m high building (NIST, 2006). The structural system consisted of precast concrete walls and floors. The floors were supported by the lower stories walls. The floors and walls were fitted by slots and bolted together. The connections were filled with dry packed mortar. Thus, this structural system was characterized by very limited ability to redistribute loads and was prone to progressive collapse when exposing to a local failure.

1.2.2 Alfred P. Murrah Federal Building

On April 19, 1995, the Alfred P. Murrah Federal Building became the target of a terrorist attack. The explosive charge was detonated from a truck situated 4m from one of the columns. The power of the blast was estimated to 1800 kg of TNT equivalent (Kokot, 2009). The direct blast destroyed one column, then the blast wave destroyed floors and beams which in turn was the cause for buckling the other three columns due to lack of lateral supports. Two illustrations of the Alfred P. Murrah Federal Building after the progressive collapse can be seen in Fig. 1.1.

Figure 1.1: Alfred P. Murrah Federal Building

1.2.3 World Trade Centre

On September 11, 2001, a terrorist attack took place in U.S.A. Pentagon and Manhattan was struck in a complex and coordinated terrorist operation involving a series of assaults(Kwok, 2007). After the planes crushed with the towers, upper stories were serious damage and several columns were collapsed by the abnormal load. The initial failure triggered a cascade of failure affecting a major portion of the structure and totally collapse. That was a case of progressive collapse. The progressive collapse was occurred for a short time. (Figure 1.2)

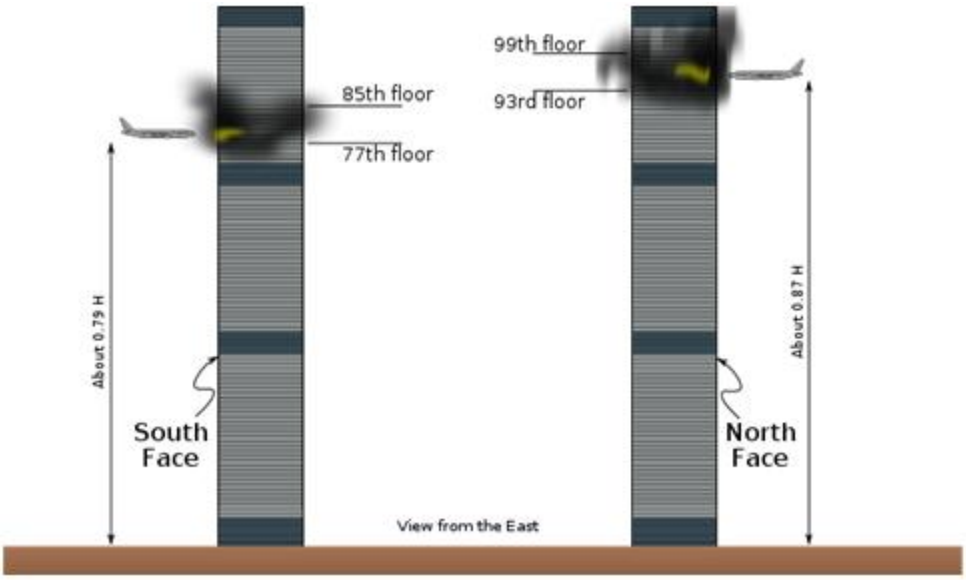

Figure1.2: World Trade Center collapse

1.3 Problem statement

Recently, progressive collapse has become one of the imperative challenges in the structure analysis. So, many design codes and standards mandated considering the progressive collapse of the building in the design process. The General Services Administration has issued general guidelines for evaluating a building's progressive collapse potential. However, little detailed information is available to enable engineers to confidently perform a systematic progressive collapse analysis satisfying these guidelines. In this paper, since some aspects are not explained in depth, it seems that more detailed commentary with calculated examples would be required.

In addition, few method s are presented to mitigate progressive collapse for using in real performance condition. Therefore, in this thesis some methods to mitigate progressive collapse in concrete structure will be present. After that, they will be compared to finding the most effective and economic one.

1.4 Research objective

The main objectives of this research are:

1. Finding the most critical column removal condition potential of progressive collapse using GSA criteria.
2. Recommend and perform solutions to reduce DCR and mitigate progressive collapse.

1.5 Scope of Study

This investigation is based on the design methods recommended in EUROCODE and GSA (General Service Administration). The present study is focused on the DCR (Demand capacity ratio) in concrete structure after column removal.

Therefore the scope of this study is:

i. EUROCODE
ii. GSA(General Service Administration)
iii. Linear Static Procedure
iv. Concrete Structures

REFERENCES

Alrudaini, T. M. S. (2011). A new mitigation scheme to resist the progressive collapse of reinforced concrete buildings.

Bilow, D. N., & Kamara, M. (2004). *US General Services Administration Progressive Collapse Design Guidelines Applied to Concrete Moment-Resisting Frame Buildings.* Paper presented at the ASCE Structures Congress.

Choi, H., & Kim, J. (2011). Progressive collapse-resisting capacity of RC beam–column sub-assemblage. *Magazine of Concrete Research, 63*(4), 297-310.

Ellingwood, B. R. (2002). *Load and resistance factor criteria for progressive collapse design.* Paper presented at the Multihazard Mitigation Council National Workshop on Prevention of Progressive Collapse, Chicago. IL.

Kaewkulchai, G., & Williamson, E. (2003). *Dynamic behavior of planar frames during progressive collapse.* Paper presented at the 16th ASCE engineering mechanics conference.

Kim, J., & Yu, J. (2012). Analysis of reinforced concrete frames subjected to column loss. *Magazine of Concrete Research, 64*(1), 21-33.

Kokot, S. (2009). Literature survey on current methodologies of assessment of building robustness and avoidance of progressive collapse. *JRC Scientific and Technical Reports: JRC, 5598*.

Kwok, K. W. (2007). Understanding progressive collapse and its effect to structural design.

Marjanishvili, S. (2004). Progressive analysis procedure for progressive collapse. *Journal of Performance of Constructed Facilities, 18*(2), 79-85.

Mohamed, O. A. (2006). Progressive collapse of structures: Annotated bibliography and comparison of codes and standards. *Journal of Performance of Constructed Facilities, 20*(4), 418-425.

Patel, P. V., & Joshi, D. D. (2012). *Various Approaches for Mitigating Progressive Collapse of Asymmetrical RC Building.* Paper presented at the Structures Congress 2012.

Ruth, P., Marchand, K. A., & Williamson, E. B. (2006). Static equivalency in progressive collapse alternate path analysis: reducing conservatism while retaining structural integrity. *Journal of Performance of Constructed Facilities, 20*(4), 349-364.

Tsai, M. H., & Lin, B. H. (2009). Dynamic amplification factor for progressive collapse resistance analysis of an RC building. *The Structural Design of Tall and Special Buildings, 18*(5), 539-557.

Yu, J., & Tan, K. H. (2011). Progressive collapse resistance of RC beam-column sub-assemblages.

ASCE (American Society of Civil Engineers) (2005) Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, Reston, Virginia, USA, ASCE 7-05.

NIST (National Institute of Standards and Technology) (2007) Best Practices for Reducing the Potential for Progressive Collapse in Buildings. NIST, Washington, D.C.

GSA (US General Services Administration) (2003) Progressive Collapse Analysis and Design

Guidelines for New Federal Office Buildings and Major Modernization Projects. The US General Services Administration, Washington, DC.

British Standards Institute,(1997), BS 8110: Structural use of concrete: Part Code of practice for design and construction, London.

British Standards Institute,(1985), BS 8110: Structural use of concrete: Part Code of practice for design and construction, London.

British Standards Institute,(1996), BS 6399: Structural use of concrete: Part Code of practice for dead and imposed loads, London.

UFC (Unified Facilities Criteria) (2005) Design of Buildings to Resist Progressive Collapse. Department of Defense, USA, UFC4-023-03.

Yi, W.J., He, Q.F., Xiao, Y., and Kunnath, S.K. (2008). "Experimental Study on Progressive Collapse-Resistant Behavior of Reinforced Concrete Frame Structures." *ACI Structural Journal*, V.105, No. 4, July-August 2008, pp. 433-439.