MITIGATION METHODS OF PROGRESSIVE COLLAPSE FOR A 10-STORY REINFORCED CONCRETE STRUCTURE

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Dedicated to all part of my immediate family, specially my father, my mother and my sisters; moreover, my faithful friends

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ABSTRACT

Progressive collapse in a structure occurs when major structural load carrying members are removed suddenly, and the remaining structural elements cannot support the weight of the building and fail. This failure usually occurs in a domino effect and leads to a progressive collapse failure in the structure. A building must have sufficient strength, ductility and redundancy to resist collapse and ensure life safety. Extreme loading events, such as earthquakes and explosions, may cause severe local damage that triggers a chain reaction of large-scale structural failure or progressive collapse such as in the Oklahoma City building and the World Trade Centre. The bombing of the Murray Federal Building in Oklahoma City is a typical example of progressive collapse failure. The initial bomb blast caused only 10% of the structure's damage, and the resulting progressive collapse failure lead to 90% of the structure's damage. This thesis investigates the potential to fail of a 10 story Reinforced Concrete building due to progressive collapse. The modelling and analysis are performed by ETABS 9.5 software. In this study, two approaches will be presented to decrease the potential of progressive collapse in the structures. To gain the best method among all that have been presented for mitigation of progressive collapse, 10 to 15 per cent increase in the size of the structural elements, is the most effective method.

ABSTRAK

Keruntuhan progresif dalam struktur berlaku apabila beban membawa komponen struktur utama dikeluarkan secara tiba-tiba, dan unsur-unsur struktur lain tidak boleh menyokong berat bangunan dan gagal. Kegagalan ini biasanya berlaku dalam kesan domino dan membawa kepada kegagalan keruntuhan progresif dalam struktur. Bangunan A mesti mempunyai kekuatan yang mencukupi, kemuluran dan lebihan untuk menahan keruntuhan dan memastikan keselamatan nyawa. Beban yang melampau, seperti gempa bumi dan letupan, boleh menyebabkan kerosakan teruk tempatan yang mencetuskan tindak balas rantai berskala besar kegagalan struktur atau runtuhan progresif seperti dalam bangunan Oklahoma City dan Pusat Dagangan Dunia. Pengeboman Bangunan Persekutuan Murray di Oklahoma City adalah contoh tipikal kegagalan keruntuhan progresif. Letupan awal bom menyebabkan hanya 10% daripada kerosakan struktur, dan kegagalan keruntuhan progresif yang terhasil membawa kepada 90% daripada kerosakan struktur ini. Tesis ini mengkaji potensi kegagalan sebuah bangunan Reinforced Concrete 10 tingkat kerana keruntuhan progresif. Pemodelan dan analisis dilakukan menggunakan perisian ETABS 9.5. Dalam kajian ini, dua pendekatan akan dibentangkan untuk mengurangkan potensi keruntuhan progresif dalam struktur. Untuk mendapatkan kaedah yang terbaik di kalangan semua yang telah dikemukakan untuk mitigasi keruntuhan progresif, 10 hingga 15 peratus kenaikan dalam saiz elemen struktur, adalah kaedah yang paling berkesan.

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DOD	-	Department of defense
WTC	-	World Trade Centre
APM	-	Alternate Path Method
DCR	-	Demand capacity ratio
RC	-	Reinforced concrete
2D	-	two-dimensional
3D	-	three-dimensional
ASCE	-	American society of civil engineering
ACI	-	American concrete institute
GSA	-	General Service Administration

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, building structures have been designed to resist normal loads such as those due to self-weight, occupancy or seismic effects, etc. Structures are designed to resist all expected loadings without failure. However, structural failures do occasionally occur due to inadequate design and construction, especially for extreme abnormal loads. Since the 1968 chain-reaction failure of the Ronan Point Apartment Block in London, triggered by a gas explosion, abnormal loading and progressive collapse have become increasingly recognized as important phenomena to be accounted for in engineering design practice worldwide. Indeed, the complete structural collapse of the twin towers of the World Trade Center (WTC) in New York City on September 11, 2001, has significantly increased the concern about these phenomena.

Progressive collapse results from abnormal loads. These abnormal loads may be grouped as pressure loads (e.g., explosions, detonations, tornado wind pressures), impact (e.g., vehicular collision, aircraft or missile impact, debris, swinging objects during construction or demolition), deformation-related (e.g., softening of steel in fire, foundation subsidence).

In progressive collapse, an initial localized damage or local failure spreads through neighboring elements, possibly resulting in the failure of the entire

structural system. The most viable approach to limiting this propagation of localized damage is to maintain the integrity and ductility of the structural system. The commentary in ASCE 7-05 suggests general design guidance for improving the progressive collapse resistance of structures, but does not provide any specific implementation rules. Recent design procedures to mitigate the potential for progressive collapse in structures can be found in the design guidelines issued by the U.S. General Services Administration (GSA 2003) and the Department of Defense (DOD 2005).

The direct approach, or the Alternate Path Method (APM), is preferred in these design guidelines. In this method, a single column is typically assumed to be suddenly missing, and an analysis is conducted to determine the ability of the structure to bridge across the missing column. The APM is mainly concerned with the vertical deflection phase or the chord rotation of the beams of the building after the sudden removal of a column. The chord rotation is equal to the vertical deflection divided by beam span. As such, it is a threat independent, design-oriented method for introducing further redundancy into the structure to resist propagation of collapse.

Mostly Failure in building occurs due to insufficient strength in the beams to bridge the load from the removed column to the adjacent columns, which leads to the failure of those beams and consequently the whole building. This means that upgrading the beam and increasing its strength and stiffness will prevent a building from failing. On the other hand, in case of high hazard events where more than one column is lost, upgrading both beams and columns is needed.

The first prominent progressive collapse of building that encouraged attentions of engineers and researchers was the partial progressive of the Ronan point apartment tower in England. The Ronan point building was a high rise 22-story residential building constructed in England between July, 1966 and March, 1968. The Ronan point building have a structure that consisted of load bearing precast concrete walls supporting precast flat plate floor systems. The Ronan apartment building which was partially collapsed in May, 1968 as a result of gas

explosion on the corner flat on the 18th floor is shown in figure 1.1. This gas explosion pushed forward the exterior bearing wall which caused the collapse of the floors above the 18th floor. The collapse of floors 19-22 over the 18th floor triggered chain collapse of below floors down to ground.

Figure 1.1 Partial collapse of Ronan Point apartment building

Later investigations on the structure showed that inadequate provisions of lateral support for the precast panel led to demolishing of that precast bearing walls under the effect of gas explosions. In addition, the investigations showed that the lack of continuity of the structure system was the main factor of propagating the collapse.

Another milestone in the history of progressive collapse was the complete structural collapse of the world trade center. The (WTC) towers were constructed in New York and were the world tallest building in 1972. In 2001 two planes attacked the world trade center (WTC) towers which the first plane hit the north

tower between the 94th and 98th floors at an estimated speed equal to 760 km/h, while the second plane hit the south tower between the 78th and 84th floors at an estimated speed equal to 950 km/h. Therefore, the planes crushing into the top part of the towers caused in rigorous damages in the towers and caused a complete destruction. In addition, fuel explosion could be caused a massive fire that was expanded to a wider area, which caused failure of components of the structures on those levels and a complete collapse of the towers as shown in the figure 1.2.

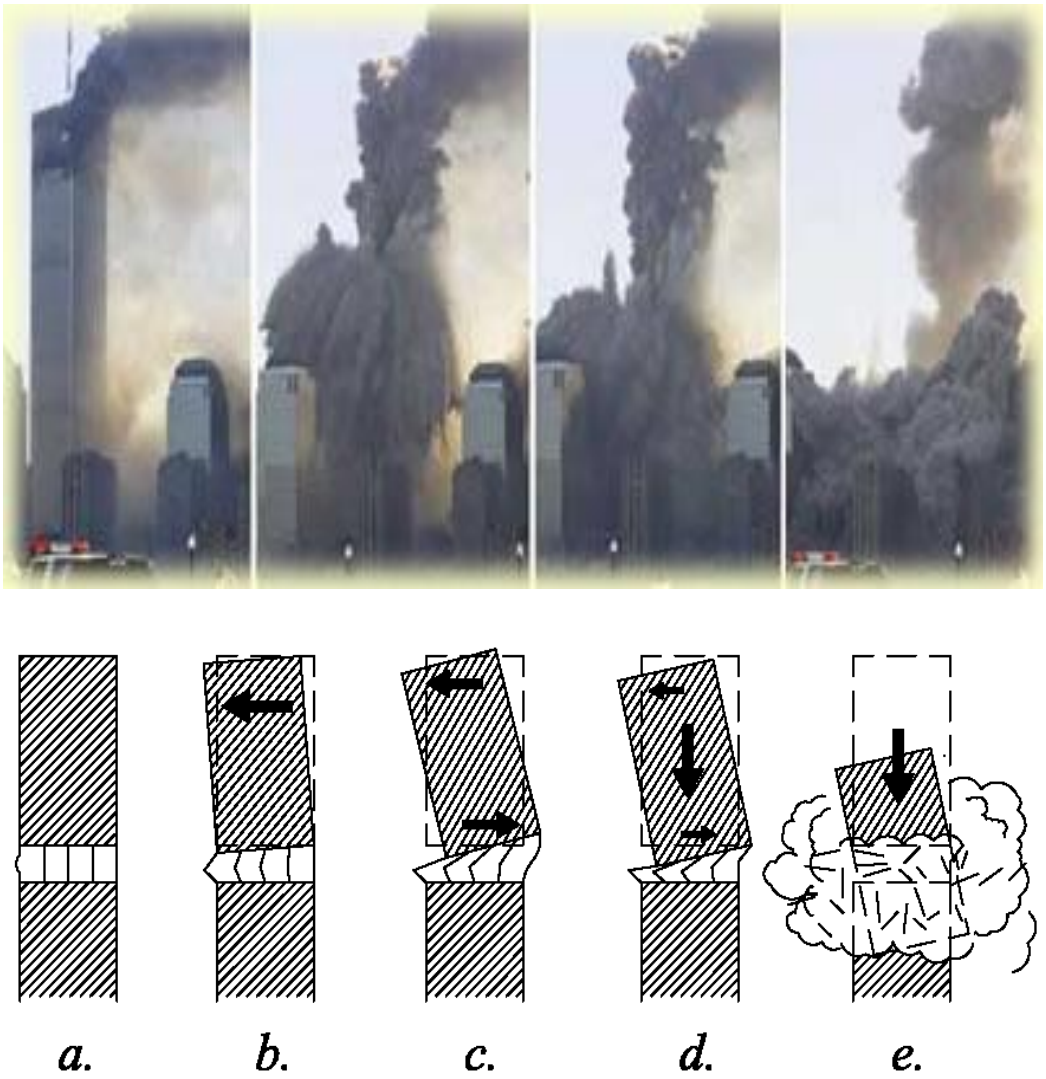

Figure 1.2 Collapse of World Trade Center towers

As far as designing of the structures against some events relevant to progressive collapse were not important for the designers before, it has become

most important and has been become a field in the engineering since the event of collapsing World Trade Center towers.

This thesis will present the influence of different mitigation methods of the progressive collapse for a 10 story symmetrical Reinforced concrete building.

1.2 Problem statements

Structures are usually designed to resist against normal loads such as gravity loads and lateral loads such as earthquake and wind load. However the phenomenon of abnormal loads came to centre of attention after the disastrous progressive collapse of Roman Point apartment building in London in 1968. Another accident which was a mile-stone in the history of progressive collapse was the complete collapse of World Trade Centre in United State in 2001. Since that time, the issue of progressive collapse became a controversial topic among structural engineers.

Failure of some vertical and horizontal components of the structure can be caused to diminish the ability of the structure to stay resistant longer. Consequently, serious casualties can occur for residents. Nowadays many studies are being conducted among engineers to elaborate more, the issue of progressive collapse, in order to mitigate progressive collapse in the structures and prevent further casualties in such accidents.

1.3 Objectives

The objectives of the study are as follow:

1. To determine the position of critical columns in the structure and study the behavior of structure after removing the columns besides.

2. To decrease the possibility of progressive collapse of structure by employing following two methods.
    A. Establishing a bracing system at the top level.
    B. 10 to 15 per cent increase in the size of structural elements throughout the structure.
3. To compare which method is the most effective way to reduce the danger of progressive collapse in the structure.

1.4 Scope

1. A 10-storey symmetrical reinforced concrete structure is being studied.
2. The building will be analyzed and designed by alternate load path (AP) method according to DOD guideline.
3. Linear Dynamic analysis will be applied for this study.
4. ACI318 and UBC97 are used for standard codes in this thesis.
5. The structure will be analyzed and designed by ETABS 9.5.

1.5 Importance of the study

High rise structures have been built to provide more spaces for people in some developed countries, which have problems with restricted urban area; in addition, gathering the most important companies in the same building since many years ago.

REFERENCES

Agarwal, J.; D. Blockley; and N. Woodman. (2003). "Vulnerability of Structural Systems", *Structural Safety,* 25, 263-286

Allen, D.E. and Schriever, W.R. (1973). "Progressive Collapse, Abnormal Loads, and Building Codes", Structural Failures: Modes, Causes, Responsibilities, Proceedings, ASCE.

American Concrete Institute (ACI). (2005). *Building code requirements for structural concrete* (ACI 318-05), Detriot.

ASCE (2002). *Minimum design loads for buildings and other structures*, ASCE-7, Reston, Va.

Bazant, Zdenek P., Verdure, Mathieu. (2007). "Mechanics of progressive collapse: Learning from World Trade Center and building demolitions", *Journal of Engineering Mechanics*, 133(3), 308-319.

Breen, J. E. and C. P. Siess. (1979). "Progressive collapse – Symposium summary", *ACI Journal*, 76(9), 997-1004.

Byfield, M. (2006). "Behavior and Design of Commercial Multistory Buildings Subjected to Blast", *Journal of Performance of Constructed Facilities*, 20(4), 324- 329.

Cagley, J. (2002). "The design professional's concerns regarding progressive collapse design", *Proceedings of the Workshop on Prevention of Progressive Collapse,* Multihazard Mitigation Council of the National Institute of Building Sciences, Rosemont, Il, July 10-12, 2002.

Carino, N., and Lew, H.S. (2001). "Summary of NIST/GSA Workshop on Application of seismic rehabilitation technologies to mitigate blast-induced progressive collapse", *Proc., National Institute of Technology and Standards, Washington, D.C., No. NISTIR 6831*.

Department of Defense (DoD). (2005). *Unified Facilities Criteria (UFC): Design of Structures to Resist Progressive Collapse*, Washington, D.C.

Ellingwood, B. (2002). ”Load and resistance factor criteria for progressive collapse design”, *Proceedings of the Workshop on Prevention of Progressive Collapse,* Multihazard Mitigation Council of the National Institute of Building Sciences, Rosemont, Il, July 10-12, 2002.

Ellingwood, B. (2005). “Strategies for mitigating risk of progressive collapse”, *Proceedings of the ASCE/SEI Structures Congress*, New York, N.Y.

Ellingwood, B. R. and Ang, A. G. S. (1974). “Risk Based Evaluation of Design Criteria”, *Journal of the Structural Division, ASCE,* 100(ST9), Proc. Paper 10778, 1771-1788.

Ellingwood, B. R. and E. E. Leyendecker. (1978). “Approaches for design against progressive collapse”, *Journal of the Structural Division, ASCE,* 104(3), pp. 413- 423.

Ellingwood, Bruce R., (2006). “Mitigating risk from abnormal loads and progressive collapse”, *Journal of Performance of Constructed Facilities*, 20(4), 2006, 315-323.

Ettouney, M.; R. Smilowitz; M. Tang; and A. Hapij. (2006). “Global System Considerations for Progressive Collapse with Extensions to Other Natural and Man- Made Hazards”, *Journal of Performance of Constructed Facilities*, 20(4), 403-417.

Gross, J. L., and McGuire, W. (1983). “Progressive Collapse Resistant Design”, *Journal of Structural Engineering*, 109(1), 1-15.

Hamburger, R. and Whittaker, A. (Nov. 15, 2005). “Design of steel structures for blast- related progressive collapse resistance”, *American Society of Civil Engineers, <http:www.aisc.org>*.

Hayes, J., et al. (2005). “Can strengthening for earthquake improve blast and progressive collapse resistance?”, *Journal of Structural Engineering 131(8), 1157- 1177*.

Houghton, D., and Karns, J. (2001). "Effective mitigation of progressive collapse in steel frame buildings using ductile high-capacity girder-to-column moment connections exhibiting discrete structural continuity across a failed column", *Proc., National Symp. on Compreh. Force, Society of Military Engineers, Charleston, S.C.*

Khandelwal, S. M., El-Tawil, Sherif. (2007). "Collapse behavior of steel special moment resisting frame connections," *Journal of Structural Engineering,* 133(5), 646-655.

Krauthammer, T. (2005). "AISC research on structural steel to resist blast and progressive collapse", Nov., 15, 2005, <*http:www.aisc.org*>.

Krauthammer, T.; R. L. Hall; S. C. Woodson; J. T. Baylot; J. R. Hayes; and Y. Sohn. (2002). "Development of Progressive Collapse Analysis Procedure and Condition Assessment for Structures", *Proceedings of the Workshop on Prevention of Progressive Collapse,* Multihazard Mitigation Council of the National Institute of Building Sciences, Rosemont, Il, July 10-12, 2002, http://www.nibs.org/MMC/ mmcactiv9.html.

Liu, R., Davison, B., and Tyas, A. (2005). "A study of progressive collapse in multistory steel frames", *Proc., ASCE/SEI Structure Conference,* New York, NY.

Marchand, K., and Alfawakhiri, F. (2005). *Facts for steel buildings: Blast and progressive collapse, American Institute of Steel Construction,* Chicago, IL.

McGuire, W. (1974). "Prevention of Progressive Collapse", ASCE-International Association for Bridge and Structural Engineering, Proceedings of the Regional Conference on Tall Buildings, Bangkok, 851-865.

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

Nair, R. Shankar. (2006). "Preventing disproportionate collapse", *Journal of Performance of Constructed Facilities,* v 20, n 4, 2006, p 309-314.

Osteraas, J. (2006). "Murrah Building Bombing Revisited: A Qualitative Assessment of Blast Damage and Collapse Patterns", *Journal of Performance of Constructed Facilities,* 20(4), 330-335.

Powell, G. (2005). "Progressive collapse: Case studies using nonlinear analysis" *Proc., ASCE/SEI Structures Conference, New* York, N.Y.

Ruth, P.; K. Marchand; and E. Williamson. (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.

Ruth, P.; K. Marchand; and E. Williamson. (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.

Starossek, Uwe. (2006). “Progressive collapse of structures: Nomenclature and procedures”, *Structural Engineering International: Journal of the International Association for Bridge and Structural Engineering (IABSE)*, v 16, n 2, May, 2006, p 113-117.

Taylor, D.A. (1975). “Progressive Collapse”, *Canadian Journal of Civil Engineering*, 2(4).

United States General Services Administration (GSA). (2003). *Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects*, Washington, D.C.

Zhou, Q, and Yu, T. (2004). “Use of high-efficiency energy absorbing device to arrest progressive collapse of tall building”, *Journal of Engineering Mechanics 130(10), 11771187*.