SEISMIC FRAGILITY CURVES FOR TALL WALL CONCRETE BUILDINGS IN MALAYSIA UNDER NEAR-FIELD EARTHQUAKES

KOTAIBA ALJWIM

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structure)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JANUARY 2019

DEDICATION

This work is dedicated to my father, SOLIMAN. Thank you for a lifetime of unfailing love, loyalty and support. I cannot repay you for all that you have done for me, but I can make you proud by the way I live my life every day. To my mother, AMENA. Thank you so much for spending your life loving me and taking such good care of all my needs. You always had your own ways of making me feel so special. You are one great MOM. To my uncle HUSSIN. Your love and support mean the world to me.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Mohammadreza vafaei, for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisor Dr Sophia C.Alih for her guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

The support provided from Universiti Teknologi Malaysia (UTM) is also acknowledged. My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

Tall buildings are widespread in Malaysia and the majority of them are designed to carry only gravity and wind loads. Seismic regulations are not taking into account for such buildings in both design stage and construction stage. This study addresses the seismic behaviour of tall buildings in Malaysia by developing fragility curves for two tall concrete walls. Both buildings are 80m height with two different configurations. The first building with five car park levels and the second one with three car park levels. The structural system of both buildings is moment resisting frame (MRF) at the parking levels and shear wall system at the residential levels. The reference structures were subjected to fifteen near field earthquake records. Fragility curves were obtained by relating the obtained seismic demands from nonlinear time history analysis to the peak ground acceleration using a reliable statistical model. It was found from fragility curves of building (A) the exterior frame is more vulnerable than interior frame for both damage states, while in building (B) the probabilities of both frames to have severe damage were close to each other, but for minor damage, fragility curves illustrate that the exterior frame was more fragile than interior frame. The developed fragility curves demonstrated that the seismic behaviours of both buildings were different under the same ground motion intensities. Results showed that building (A) with five car-park levels has better resistance to seismic load compare to building (B) with three car-park. It can be concluded that design concept of such buildings against wind and gravity is adequate in fulfilling the required performance if the design PGA is less than 0.2g.

.

ABSTRAK

Bangunan-bangunan tinggi yang meluas di Malaysia dan majoriti daripada mereka direka untuk membawa beban yang hanya graviti dan angin. Peraturan-peraturan seismik tidak mengambil kira bangunan tersebut di kedua-dua peringkat rekabentuk dan pembinaan. Kajian ini berucap kelakuan seismik bangunan tinggi di Malaysia dengan membangunkan kerapuhan keluk bagi dua tembok konkrit yang tinggi. Kedua-dua bangunan adalah 80m ketinggian dengan dua tatarajah yang berbeza. Bangunan pertama dengan lima aras tempat letak kereta dan yang kedua dengan tiga aras tempat letak kereta. Sistem struktur kedua-dua bangunan adalah rangka menentang masa di aras tempat letak kereta dan sistem dinding ricih di peringkat kediaman. Struktur tugas adalah tertakluk kepada lima belas berhampiran bidang rekod gempa bumi. Kerapuhan lengkung yang diperolehi oleh berkaitan permintaan seismik yang diperolehi dari analisis sejarah masa tak linear dengan pecutan puncak tanah menggunakan model statistik yang boleh dipercayai. Didapati dari lengkung kerapuhan bangunan (A) rangka luar adalah lebih banyak terdedah daripada kerangka dalaman bagi kedua-dua negeri kerosakan, manakala dalam bangunan (B) kebarangkalian bingkai kedua-dua mempunyai kerosakan teruk adalah berhampiran antara satu sama lain, tetapi bagi kerosakan kecil, kerapuhan lengkung menggambarkan bahawa kerangka luar adalah lebih mudah rosak berbanding kawasan pedalaman bingkai. Lengkung kerapuhan maju menunjukkan tingkah-laku seismik dari kedua-dua bangunan yang berbeza di bawah keamatan aktiviti pergerakan tanah sama. Hasil kajian menunjukkan bahawa bangunan (A) dengan lima aras tempat letak kereta mempunyai ketahanan yang lebih baik untuk seismik beban berbanding bangunan (B) dengan tiga-tempat letak kereta. Maka dapatlah disimpulkan bahawa konsep reka bentuk bangunan tersebut terhadap angin dan graviti adalah mencukupi untuk memenuhi prestasi yang dikehendaki jika Reka bentuk PGA kurang daripada 0.2 g.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASCE	-	American Society of Civil Engineers
FEMA	-	The Federal Emergency Management Agency
ATC	-	Applied Technology Council
BS	-	British Standard
USGS	-	United States Geological Survey
PGA	-	Peak Ground Acceleration
IO	-	Immediate Occupancy
LS	-	Life Safety
CP	-	Collapse Prevention
IDA	-	Incremental Dynamic Analysis
IDR	-	Inter-Story Drift Ratio
ETABS	-	Extended Three-Dimensional Building System

LIST OF SYMBOLS

ρ	-	Reinforcement Ratio
m	-	Mass
F	-	Force
g	-	Gravitational Acceleration
E	-	Modulus of Elasticity
f_{ck}	-	Characteristic Compressive Strength of Concrete
f_{yk}	-	Characteristic Yielding Tensile Strength of Reinforcements
f_u	-	Ultimate Tensile Strength of Reinforcements
Mpa	-	Mega Pascal
kN	-	Kilo Newton

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Buildings in Malaysia are mostly built of reinforced concrete. Many of them are designed to carry only wind and gravity loads without consideration of seismic forces. Assessment of the vulnerability of these buildings is significant for predicting the potential earthquake losses.

Malaysia seismicity falls between low to moderate. The seismic hazard of Malaysia is characterized by far-field events from Sumatra and near-field events due to local seismic faults (Balendra and Li, 2008). The recent earthquake in Ranau drew attention to predicting and mitigating earthquake losses.

Fragility curves are one of the essential tools in the risk assessment field and effective approach to evaluate the performance of different structures under various level of seismic events intensities(Calvi et al., 2006). This tool describes the probability of structures to exceed certain limit states under various ground motion scenarios(Mwafy, 2012).

Derivation of fragility curves for tall wall concrete building in Malaysia through non-linear time history analysis is discussed in this study. One reference building is designed according to the building codes adopted in Malaysia. The building behaviour is evaluated under 15 input near-field ground motions. The seismic response is measured for two concrete walls.

1.2 Problem Statement

Building codes and construction practice adopted in Malaysia do not take into account the anti-seismic regulations (Abas, 2001). Although Malaysia is considered as a stable region, but in 2015, Ranau, East Malaysia had been stricken by an earthquake with 5.9 magnitude. Several buildings were damaged due to Ranau earthquake since many of them are designed only based on gravity and wind loads.

Post-event investigations indicated that the primary reason behind the damaged buildings is the poor design and workmanship. Many of buildings were damaged because of the non-engineering construction practice, lack in reinforcement, soft-story phenomenon. These findings promoted the policy makers, engineers and researchers to seriously consider the potential consequences from natural hazard in the future.

Fragility relations are used to evaluate the seismic impact on buildings. These relations are used to predict the potential damage under different earthquake events, and they also effective for mitigating seismic risk in future. The latter objective can be achieved through reinforcement jacketing, steel jacketing and FRP installation for existing structures as well as calibration of the seismic design provisions of new structures (Mwafy, 2012).

Few studies have been conducted to evaluate the seismic performance of different structures in Malaysia(Hamid and Mohamad, 2013).These studies are limited for low to medium rise concrete buildings in Malaysia (Saruddin and Nazri, 2015). However, high-rise building stock is the most significant since it represents the majority of building inventories in Malaysia.

The focus of this study is on the physical damage of tall wall concrete building in Malaysia since it has not been addressed yet. The seismic behaviour of tall wall concrete building will be discussed through fragility relations.

1.3 Research Goal

This study aims to increase the awareness of the policy makers and the planners toward seismic vulnerability of existing tall buildings, improve the disasters planning and risk assessment strategies, and dispose anti-seismic regulations and retrofitting schemes.

1.3.1 Research Objectives

The objectives of the research are:

(a) To investigate failure mode of the reference structure when subjected to near-field earthquakes.

(b) To obtain seismic demand of the reference structures through nonlinear time history analysis.

(c) To derive seismic fragility curves for the reference structures under near-field excitations.

1.3.2 Research Scope

The scope of this study can be defined as following:

(a) The employed compressive strength of concrete is 40Mpa.

(b) The employed yield strength of reinforcing bar is 460Mpa

(c) The employed finite element software is ETABS 2017 software.

(d) The foundation will not be modelled in this study.

(e) Two-dimensional idealization models will be modelled.

(f) It is assumed the structures are constructed on stiff soil.

(g) Fifteen near-field earthquake records are selected to perform nonlinear dynamic analysis.

REFERENCES

Abas, M. R. B. C. (2001) 'Earthquake Monitoring in Malaysia', in *the Seismic Risk Seminar, Malaysia.* Selangor: Seismological Division Malaysian Meteorological Service, p. 10.

ASCE/SEI 41 (2006) *Seismic rehabilitation of existing buildings*. Virginia: American Society of Civil Engineers.

ASCE/SEI 7 (2010) *Minimum Design Loads for Buildings and Other Structures*. Virginia: American Society of Civil Engineers.

Balendra, T. and Li, Z. (2008) 'Seismic hazard of Singapore and Malaysia', *Electronic Journal of Structural Engineering*, 8, pp. 57–63.

Barbat, A. H., M.EERI, Moya, F. and Canas, J. A. (1996) 'DamageScenariosUrbanZones', *Earthquake Spectra*, p. 24.

Bilgin, H. (2013) 'Fragility-based assessment of public buildings in Turkey', *Engineering Structures*. Elsevier Ltd, 56, pp. 1283–1294.

BS8110-1 (1997) *Structural use of concrete,Code of practice for design and construction,part 1*. British Standard.

Calabrese, A. and Lai, C. G. (2013) 'Fragility functions of blockwork wharves using artificial neural networks', *Soil Dynamics and Earthquake Engineering*. Elsevier, 52, pp. 88–102.

Calvi, G. M., Pinho, R., Magenes, G., Bommer, J. J. and Crowley, H. (2006) 'Development of Seismic Vulnerability Assessment Methodologies Over the Past 30 Years', 43(472), pp. 75–104.

Charvet, I., Ioannou, I., Rossetto, T., Suppasri, A. and Imamura, F. (2014) 'Empirical fragility assessment of buildings affected by the 2011 Great East Japan tsunami using improved statistical models', *Natural Hazards*, 73(2), pp. 951–973.

Computers and Structures Inc. (2017) 'CSi Analysis Reference Manual CSI Analysis Reference Manual'. Computers and Structures Inc.

Cosenza, E., Di Sarno, L., Maddaloni, G., Magliulo, G., Petrone, C. and Prota, A. (2015) 'Shake table tests for the seismic fragility evaluation of hospital rooms', *Earthquake Engineering and Structural Dynamics*, 44(1), pp. 23–40.

FEMA (2000) *FEMA 356 Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Rehabilitation Requirements*. Virginia: American Society of Civil Engineers.

Günel, M. H. and Ilgin, H. E. (2014) *Tall Buildings : Structural Systems*. New York.

Hamid, N. H. A. and Mohamad, N. M. (2013) 'Seismic assessment of a full-scale double-storey residential house using fragility curve', *Procedia Engineering*. Elsevier B.V., 54, pp. 207–221.

Ji, J., Elnashai, A. S. and Kuchma, D. A. (2007) 'An analytical framework for seismic fragility analysis of RC high-rise buildings', *Engineering Structures*, 29(12), pp. 3197–3209.

Joy, R. and Prasad, C. K. (2016) 'Development of Analytical Fragility Curve – a Review', *International Research Journal of Engineering and Technology (IRJET)*, 3(8), pp. 713–716.

Kappos, A. J., Panagopoulos, G., Panagiotopoulos, C. and Penelis, G. (2006) 'A hybrid method for the vulnerability assessment of R/C and URM buildings', *Bulletin of Earthquake Engineering*, 4(4), pp. 391–413.

Kumitani, S. and Takada, T. (1994) 'Methothods for Regional Damage Estimation', *Earthquake Engineering, Tenth World Conference, Rotterdam*.

Mwafy, A. (2012) 'Analytically derived fragility relationships for the modern high-rise buildings in the UAE', *Structural Design of Tall and Special Buildings*.

Negulescu, C., Ulrich, T., Baills, A. and Seyedi, D. . (2013) 'Fragility curves for masonry structures submitted to permanent ground displacements and earthquakes', *Natural Hazards*.

Negulescu, C., Ulrich, T., Baills, A. and Seyedi, D. M. (2014) 'Fragility curves for masonry structures submitted to permanent ground displacements and earthquakes', *Natural Hazards*, 74(3), pp. 1461–1474.

Rajeev, P. and Tesfamariam, S. (2012) 'Seismic fragilities for reinforced concrete buildings with consideration of irregularities', *Structural Safety*. Elsevier, 39, pp. 1–13.

Saruddin, S. N. A. and Nazri, F. M. (2015) 'Fragility curves for low- and mid-rise buildings in Malaysia', *Procedia Engineering*. Elsevier B.V., 125, pp. 873–878.

Siqueira, G. H., Sanda, A. S., Paultre, P. and Padgett, J. E. (2014) ‘Fragility curves for isolated bridges in eastern Canada using experimental results’, *Engineering Structures*. Elsevier Ltd, 74, pp. 311–324.

Vafaei, M. and Alih, S. C. (2018) ‘Seismic vulnerability of air traffic control towers’, *Natural Hazards*. Springer Netherlands, 90(2), pp. 803–822.

Wen, Y., Ellingwood, B. and Bracci, J. (2004) ‘Vulnerability function framework for consequence-based engineering’, *Mid-America. Earthquake Center Project DS-4 Report. University of Illinois at Urbana- Champaign*, pp. 1–101.

Yamaguchi, N. and Yamazaki, F. (1995) ‘Fragility Curves for Buildings in Japan Based on Damage Surveys After the 1995 Kobe Earthquake’, *City*, pp. 1–8.

Zhou, C., Zeng, X., Pan, Q. and Liu, B. (2014) ‘Seismic fragility assessment of a tall reinforced concrete chimney’, *The Structural Design of Tall and Special Buildings*.