

SEISMIC FRAGILITY OF TALL CONCRETE WALL STRUCTURES IN  
MALAYSIA UNDER FAR-FIELD EARTHQUAKES

SITI AISYAH BINTI FATHOL KARIB

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 thesis is dedicated to my beloved parent, Fathol Karib b. Hj Mohd Kassim and Hendon bt. Mohd. I love you to the moon and back. My siblings, and friends whose always supporting me through thick and thin. In addition special thanks to my supervisors, Dr. Mohamadreza Vafaei and Dr. Sophia C.Alih whose guiding me thoroughly for this research study.

## **ACKNOWLEDGEMENT**

First of foremost, all praise is to Allah and Almighty for His power and blessing, I can complete my project of Master of Engineering (Structure).

Firstly, I wish to express my appreciation to Universiti Teknologi Malaysia for giving me the excellent study environment and all the facilities to complete this study. I am gratefully and would like to express my sincere gratitude to my respected supervisors Dr. Mohammadreza Vafaei and Dr. Sophia C.Alih because of their invaluable guidance, continuous encouragement and constant support for me in completing my master project. Their guidance have helped me a lot in my thesis writing and further understanding about the earthquake field. Very special thanks to them for teaching me valuable knowledge and still supporting me during my up and down.

Finally, I must express my very profound gratitude to my parents and to my friends for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

## ABSTRACT

Over the years, Malaysia has encountered far-field and near-field earthquakes. Peninsular Malaysia, were affected the most by far-field earthquakes due to Sumatra fault line. On the other hand, high-rise structures are more vulnerable to far-field earthquakes compared to low-rise. Damage to the tall buildings will give a huge impact on countries financial and endangers numbers of human life. This study addresses the seismic fragility of high-rise buildings under far-field earthquake using Etabs 2017 software. The main aim of this study is to develop a seismic fragility curve of tall concrete wall structures in Malaysia. This study employs Incremental Dynamic Analysis (IDA) in order to determine the failure mechanism, inter-story drift demand, and capacity. There were two tall concrete wall structures with similar building plan and number of stories, with different number of parking level have been selected for seismic evaluation. In building 1 three stories were allocated to the parking while in building 2 it was 5 stories. The exterior and interior shear wall frame system (SWFS) at grid A and B for each building were selected. The results of the inter-story drift demand under 15 ground motions at each increment of peak ground acceleration (PGA) were used for derivation of fragility curves. Based on FEMA 356, three performance levels namely immediate occupancy (IO), life safety (LS) and collapse prevention (CP) levels were adopted. It was observed in both buildings the drift demand values increased with the increase in PGAs. The exterior SWFS have higher range of median drift demand value compared to interior SWFS. In addition, in both frame the median drift demand and PGA correlated well with each other. On the other hand, building 1 provided lower drift capacities compared to building 2. There were four fragility curves of four 2D SWFS developed from this study. Result shows that the probability of exceeding IO and CP limit state in exterior SWFS is higher than interior SWFS for both buildings. For a design PGA of 0.13g, the probability of exceeding CP limit state in building 1 was 5.6%. Although this value is considered to be small, at 0.5g the probability of significant damage rose up to 84%.

## ABSTRAK

Dalam beberapa tahun ini, Malaysia telah mengalami gempa bumi yang berpunca dari jarak-jauh dan lokal. Semenanjung Malaysia paling terkesan kepada gempa bumi jarak jauh yang berpusat di Sumatra. Bangunan/struktur tinggi menunjukkan reaksi yang aktif kepada gempabumi jarak jauh berbanding bangunan/struktur yang rendah. Kerosakan ke atas bangunan/struktur tinggi akan memberi impak yang buruk kepada kewangan negara dan juga boleh membahayakan banyak nyawa manusia. Kajian ini membincangkan kerapuhan seismik ke atas bangunan tinggi yang diuji dengan rekod gempa bumi jarak jauh menggunakan perisian Etabs 2017. Tujuan utama kajian ini adalah untuk menghasilkan graf kerapuhan seismik struktur dinding konkrit tinggi di Malaysia. Kajian ini menggunakan Analisis Dinamik Peningkatan (IDA) untuk menentukan mekanisme kegagalan, permintaan dan kapasiti gerakan pengantara tingkat. Terdapat dua struktur dinding konkrit yang tinggi dengan pelan bangunan dan bilangan tingkat yang sama, tetapi bilangan tingkat yang berbeza untuk tempat letak kereta telah dipilih untuk penilaian seismik. Dalam bangunan 1, tiga tingkat telah diperuntukkan untuk tempat letak kereta dan bangunan 2 adalah 5 tingkat. Sistem bingkai dinding geseran luaran dan dalaman (SWFS) di grid A dan B untuk setiap bangunan telah dipilih. Keputusan permintaan gerakan antara tingkat, di bawah 15 gerakan tanah pada setiap kenaikan pecutan puncak (PGA) digunakan untuk pembentukan graf keluk kerapuhan. Berdasarkan FEMA 356, tiga tahap prestasi iaitu penghunian segera (IO), tahap keselamatan hidup (LS) dan tahap pencegahan keruntuhan (CP) telah diterima pakai. Ia diperhatikan di kedua-dua bangunan nilai permintaan gerakan meningkat dengan peningkatan PGA. SWFS luaran mempunyai nilai median gerakan yang lebih tinggi berbanding dengan SWFS dalaman. Di samping itu, dalam kedua-dua bingkai permintaan drift median dan PGA mempunyai hubungan yang baik antara satu sama lain. Sebaliknya, bangunan 1 mempunyai kapasiti drift yang lebih rendah berbanding dengan bangunan 2. Terdapat empat lengkung kerapuhan dari empat SWFS 2D yang dibangunkan dari kajian ini. Keputusan menunjukkan bahawa kebarangkalian melebihi had IO dan CP untuk SWFS luaran adalah lebih tinggi daripada SWFS dalaman untuk kedua-dua bangunan. Untuk PGA reka bentuk 0.13g, kebarangkalian melebihi had had CP dalam bangunan 1 ialah 5.6%. Walaupun nilai ini dianggap kecil, pada 0.5g kebarangkalian kerosakan ketara meningkat sehingga 84%.

## TABLE OF CONTENTS

	<b>TITLE</b>	<b>PAGE</b>
	<b>DECLARATION</b>	<b>i</b>
	<b>DEDICATION</b>	<b>ii</b>
	<b>ACKNOWLEDGEMENT</b>	<b>iii</b>
	<b>ABSTRACT</b>	<b>iv</b>
	<b>ABSTRAK</b>	<b>v</b>
	<b>TABLE OF CONTENTS</b>	<b>vi</b>
	<b>LIST OF TABLES</b>	<b>ix</b>
	<b>LIST OF FIGURES</b>	<b>x</b>
	<b>LIST OF SYMBOLS</b>	<b>xiv</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Research Objectives	3
	1.4 Scope of Study	3
	1.5 Significance of Research	4
	1.6 Organization of Thesis	4
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>7</b>
	2.1 Introduction	7
	2.2 Earthquakes	7
	2.3 Malaysia Earthquakes History	11
	2.3.1 Peninsular Malaysia	13
	2.3.2 East Malaysia	17
	2.4 Near and Far-Field Earthquakes	19
	2.5 Tall Building System	20
	2.5.1 Rigid Frame System/ Moment-Resisting Frame	20

2.5.2	Flat Plate/ Slab System	21
2.5.3	Core System	22
2.5.4	Shear Wall System	24
2.5.5	Shear Frame System	25
2.6	Incremental Dynamic Analysis (IDA)	25
2.7	Fragility Curve	26
2.8	Summary	29
<b>CHAPTER 3</b>	<b>RESEARCH METHODOLOGY</b>	<b>31</b>
3.1	Introduction	31
3.2	Research Framework	31
3.3	Data Collection	33
3.3.1	Model Properties	33
3.3.2	Ground Motions	40
3.4	Generating Finite Element (FE) Models	42
3.4.1	Define Material Properties	46
3.4.1.1	Concrete Material Properties	46
3.4.1.2	Steel Material Properties	46
3.4.2	Define Section Properties	47
3.4.2.1	Beam and Column	47
3.4.2.2	Wall and Slab	50
3.4.3	Draw Beams, Columns, Slabs & Walls	51
3.4.4	Assign Base Constraint	53
3.4.5	Assign a Diaphragm to Floors	55
3.4.6	Meshing of Elements	56
3.4.7	Loading of Structure	57
3.4.7.1	Load Calculation	57
3.4.7.2	Define Load Pattern	64
3.4.7.3	Define Load Cases	65
3.4.7.4	Assign Load	66
3.5	Analysis and Design for gravity and wind load	68
3.6	Incremental Dynamic Analysis	69

3.7	Data Extraction	71
3.8	Fragility Curve	71
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSION</b>	<b>73</b>
4.1	Introduction	73
4.2	Failure Mechanism	73
4.2.1	Building 1 (Three-stories Car-park)	74
4.2.1.1	Plastic Hinge Formation at Exterior Shear Wall Frame System (SWFS)	74
4.2.1.2	Plastic Hinge Formation at Interior Shear Wall Frame System (SWFS)	79
4.2.2	Building 2 (Five-stories Car-park)	84
4.2.2.1	Plastic Hinge Formation at Exterior Shear Wall Frame System (SWFS)	84
4.2.2.2	Plastic Hinge Formation at Interior Shear Wall Frame System (SWFS)	89
4.3	Inter-story Drift Demand	94
4.3.1	Building 1 (Three-stories Car-park)	94
4.3.2	Building 2 (Five-stories Car-park)	97
4.4	Inter-story Drift Capacity	100
4.5	Fragility Curve	102
4.5.1	Building 1 (Three-stories Car-park)	102
4.5.2	Building 2 (Five-stories Car-park)	104
4.6	Comparison between Building 1 and Building 2	106
4.7	Case Study in Peninsular Malaysia	107
<b>CHAPTER 5</b>	<b>CONCLUSIONS</b>	<b>109</b>
	<b>REFERENCES</b>	<b>111</b>



## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
Table 2.1	Statistic of Far-field Earthquake at Peninsular Malaysia (Marto et al., 2013)	14
Table 2.2	Data of Near-field Earthquake in Peninsular Malaysia (Marto et al., 2013)	16
Table 3.1	15 ground motions characteristics used in this study	42
Table 3.2	Sizes and rebar ratios in the transverse direction of concrete shear walls in building 1.	50
Table 3.3	Sizes and rebar ratios in the transverse direction of concrete shear walls in building 2.	50
Table 3.4	Residential floor load calculation	57
Table 3.5	Parking floor load calculation	58
Table 3.6	Wall load calculation	58
Table 3.7	Summary of dead load	59
Table 3.8	Live load on each floor	60
Table 3.9	Values of exposure coefficient $K_z$	61
Table 3.10	Design wind pressure, $P$	62
Table 3.11	Wind forces at each story	62
Table 4.1	Inter-story drift demand for building 1 exterior SWFS	95
Table 4.2	Inter-story drift demand for building 1 interior SWFS	96
Table 4.3	Inter-story drift demand for building 2 exterior SWFS	98
Table 4.4	Inter-story drift demand for building 2 interior SWFS	99
Table 4.5	Summary of the inter-story drift capacity for building 1 and 2	101

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
Figure 2.1	Global Tectonic Plate Boundaries (Chen & Lui, 2006)	9
Figure 2.2	Various Fault Types (Chen & Lui, 2006)	9
Figure 2.3	San Andreas Fault Line (Chen & Lui, 2006)	10
Figure 2.4	Himalaya Mountain (Chen & Lui, 2006)	10
Figure 2.5	Illustration of Epicenter, Hypocenter and Fault Line (Chen & Lui, 2006)	11
Figure 2.6	South East Trench Line (Shoushtari et al., 2016)	12
Figure 2.7	Map of 2015 Sabah Earthquake (Wang et al., 2017)	19
Figure 2.8	Lateral drift in rigid frame system (a) Deformation due to cantilever bending, (b) Deformation due to the bending of the columns and beams (Günel & Ilgin 2014)	21
Figure 2.9	Flat plate/slab system with drop panel (Günel & Ilgin 2014)	22
Figure 2.10	Core system (Günel & Ilgin 2014)	23
Figure 2.11	Shear wall system (Günel & Ilgin 2014)	24
Figure 3.1	Research Methodology Flowchart	32
Figure 3.2	Data Collection Process	33
Figure 3.3	Car-park floor plan view (37.6m x 34m)	35
Figure 3.4	Residential floor plan view (37.6m x 20m)	36
Figure 3.5	Elevation view of building 1	37
Figure 3.6	Elevation view of building 2	38
Figure 3.7	Elevation view of building 1 (three-stories parking level) at grid A & B	39
Figure 3.8	Elevation view of building 2 (five-stories parking level) at grid A & B	40
Figure 3.9	Step by step procedure to FE model in ETABS 2017	43
Figure 3.10	3D view of building 1 in Etabs 2017	44
Figure 3.11	3D view of building 2 in Etabs 2017	45

Figure 3.12	Section properties of beam in Etabs 2017	48
Figure 3.13	Section properties of beam reinforcement in Etabs 2017	48
Figure 3.14	Section properties of column in Etabs 2017	49
Figure 3.15	Section properties of column reinforcement in Etabs 2017	49
Figure 3.16	Draw beam function in Etabs 2017	51
Figure 3.17	Beam and column plan view in Etabs 2017	52
Figure 3.18	Draw slab and wall function in Etabs 2017	52
Figure 3.19	Beams, columns, slabs, and walls plan view in Etabs 2017	53
Figure 3.20	Assign joint restraints function in Etabs 2017	54
Figure 3.21	Joint assignment restraint box in Etabs 2017	54
Figure 3.22	Assign joint diaphragm function in Etabs 2017	55
Figure 3.23	Output of assign diaphragm to floors in Etabs 2017	55
Figure 3.24	Floor auto mesh function in Etabs 2017	56
Figure 3.25	Floor auto mesh options box in Etabs 2017	56
Figure 3.26	Detail of residential floor element	57
Figure 3.27	Detail of parking floor element	58
Figure 3.28	Detail of wall element	59
Figure 3.29	Define load pattern function in Etabs 2017	64
Figure 3.30	Define load pattern box in Etabs 2017	64
Figure 3.31	Define load cases function in Etabs 2017	65
Figure 3.32	Define load cases box in Etabs 2017	65
Figure 3.33	Assign uniform shell loads function in Etabs 2017	66
Figure 3.34	Assign uniform shell load box in Etabs 2017	66
Figure 3.35	Assign distributed frame loads function in Etabs 2017	67
Figure 3.36	Assign frame load instruction box in Etabs 2017	67
Figure 3.37	Analysis and design for gravity and wind load flowchart	68
Figure 3.38	Flowchart of the incremental dynamic analysis (IDA)	70
Figure 4.1	The location of plastic hinge formation at each PGA. a) 0.05g-L12 b) 0.1g-L12	75

Figure 4.2	The location of plastic hinge formation at each PGA. c) 0.15g-L15 d) 0.2g-L2	76
Figure 4.3	The location of plastic hinge formation at each PGA. e) 0.3g-L2 f) 0.4g-L2	77
Figure 4.4	The location of plastic hinge formation at 0.5g-L3	78
Figure 4.5	The location of plastic hinge formation at each PGA. a) 0.05g-L12 b) 0.1g-L12	80
Figure 4.6	The location of plastic hinge formation at each PGA. c) 0.15g-L2 d) 0.2g-L12	81
Figure 4.7	The location of plastic hinge formation at each PGA. e) 0.3g-L15 f) 0.4g-L10	82
Figure 4.8	The location of plastic hinge formation at 0.5g-L1	83
Figure 4.9	The location of plastic hinge formation at each PGA. a) 0.05g-L2 b) 0.1g-L2	85
Figure 4.10	The location of plastic hinge formation at each PGA. c) 0.15g-L15 d) 0.2g-L15	86
Figure 4.11	The location of plastic hinge formation at each PGA. e) 0.3g-L2 f) 0.4g-L2	87
Figure 4.12	The location of plastic hinge formation at 0.5g-L2	88
Figure 4.13	The location of plastic hinge formation at each PGA. a) 0.05g-L15 b) 0.1g-L15	90
Figure 4.14	The location of plastic hinge formation at each PGA. c) 0.15g-L15 d) 0.2g-L15	91
Figure 4.15	The location of plastic hinge formation at each PGA. e) 0.3g-L15 f) 0.4g-L13	92
Figure 4.16	The location of plastic hinge formation at 0.5g-L13	93
Figure 4.17	The relationship between median drift demand and peak ground acceleration (PGA) of building 1 exterior SWFS	96
Figure 4.18	The relationship between median drift demand and peak ground acceleration (PGA) of building 1 interior SWFS	97
Figure 4.19	The relationship between median drift demand and peak ground acceleration (PGA) of building 2, exterior SWFS	99
Figure 4.20	The relationship between median drift demand and peak ground acceleration (PGA) of building 2, interior SWFS	100
Figure 4.21	Pushover curve from Etabs software	101

Figure 4.22	Building 1 fragility curve a) Exterior SWFS b) Interior SWFS	103
Figure 4.23	Building 2 fragility curve a) Exterior SWFS b) Interior SWFS	105
Figure 4.24	PGA (%g) contour map of peninsular Malaysia (MS EN 1998-1:2015)	107

## LIST OF SYMBOLS

$S_E^2$	Standard error of demand drift
DS	Standard error of demand drift
SI	Seismic intensity
$\phi$	Standard normal distribution
$\lambda_{D/SI}$	Natural logarithm of the median demand drift given the seismic intensity from the best fit power law
$\lambda_c$	Natural logarithm of the median of drift capacities for particular damage state
$\beta_c\beta_m$	Uncertainties related to capacity and modelling

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Earthquakes are one of the natural hazards in Malaysia. Although Malaysia is considered as a low seismic country, Malaysia is surrounded by world most active fault that lay in Indonesia and Philippine. Eventually, this will cause Malaysia to be exposed to earthquake risk from both distant and local earthquakes. Based on the statistic, Peninsular Malaysia is hit the most by the distant-earthquake from Sumatra subduction zone while Eastern Malaysia subjected to large earthquake from the Southern Philippines.

Over the years, the number of tall-buildings in Malaysia has increased rapidly in line with the urbanization and development of the country. According to the Council on Tall Buildings and Urban Habitat (CTBUH), a common building constructed in a major city in Malaysia ranges from 20 to 50 stories with function as office and residential use. In addition, a common material used in tall buildings is reinforced concrete due to its high strength and cost-effectiveness. Damage to the tall buildings will give a huge impact on countries financial and endangers numbers of human life.

There are many solutions to retrofit vulnerable buildings, for instance, jacketing, damping devices, and base isolation. Since most of the building in Malaysia has not been designed for seismic loads, during an earthquake the degree of damages are unidentifiable. It is important to predict the damage in order to get an optimum cost of retrofitting and risk mitigation plan. Fragility curves are one of the tools to predict potential damage during earthquakes. Fragility curves are defined as the probability of reaching or exceeding a specific damage state under earthquake excitation (Sadraddin et al. 2014). These curves represent the seismic risk assessment

and are used as an indicator to identify the physical damage in the strongest mainshock.

Therefore, the aim of this study is to determine seismic fragility curves of tall concrete wall structures in Malaysia under far-field earthquake. This study will use Incremental Dynamic Analysis (IDA) in order to determine inter-story drift demands.

## **1.2 Problem Statement**

During past few years, Malaysia has been struck many times by near-field and far-field earthquakes. Based on the statistic, Peninsular Malaysia is hit the most by the distant-earthquake from Sumatra earthquake. On the other hand, Eastern Malaysia subjected to large earthquake from the Southern Philippines. Damages to some buildings in Malaysia have been reported due to the far-field earthquake for example in 2002 and 2004 Sumatra earthquakes. This proves that far-field earthquake can affect buildings in Malaysia.

Tall concrete wall buildings are quite common in Malaysia and usually function as a residential apartment. Damage to these buildings can cause huge catastrophic to human and country as it will endanger higher numbers of human life and large monetary losses.

As most buildings in Malaysia are designed based on gravity and wind load only, therefore retrofitting are needed. Prediction of the degree of damage will provide optimum cost and economical design for retrofitting process. The seismic fragility curve is one of the tools that can forecast the damage intensity to buildings.

Previous research on seismic fragility in Malaysia only focuses on low and mid-rise buildings, and industrial structures (Saruddin & Nazri 2015; Ahmadi et al. 2014). It can be concluded that research on a tall building is still lacking. Hence, a study on seismic fragility curves of tall buildings in Malaysia under far-field earthquake is needed. Due to this, the main aim of this study is to determine seismic



fragility curves of tall concrete wall structures in Malaysia under far-field earthquakes.

### **1.3 Research Objectives**

The purposes of this study are to develop fragility curve for tall concrete wall structures. This study will embark on the following objectives:

- (a) To study the failure mechanism of tall concrete wall structures through incremental dynamic analysis.
- (b) To determine inter-story drift demand and capacity of tall concrete wall structures under far-field earthquake.
- (c) To develop seismic fragility curve for tall concrete wall structures in Malaysia.

### **1.4 Scope of Study**

This research considers the following scope of works:

- (a) Totally four 2D structures with concrete wall structural system will be analyzed in this study.
- (b) The concrete strength of 40 MPa is used for all structural models.
- (c) Yield and ultimate stress of employed reinforcement steel bar are 400 MPa and 650 MPa respectively.
- (d) Totally 15 far-field ground motions will be used.
- (e) The effect of soil-structure interaction (SSI) will be neglected.

- (f) For numerical analysis, ETABS 2017 software will be used.
- (g) Peak ground acceleration will be selected as the engineering demand parameter.

## **1.5 Significance of Research**

This research is carried out to determine vulnerabilities of tall concrete wall structures in Malaysia under seismic excitation that will give great advantages to the government and non-government organization (NGO). The cause of the failure of tall concrete wall structures during earthquakes excitation also will be investigated. Thus, prediction of building's physical damage during earthquakes can be provided and interpreted in seismic fragility graph. The contribution includes planning to retrofit at-risk structures, seismic damage mitigation framework and create awareness on seismic vulnerability of tall buildings.

## **1.6 Organization of Thesis**

There are five chapters in this thesis and the remaining chapters are as follow:

- (a) **Chapter 2** presents brief explanation about previous studies related to the issues covered in this study. This chapter is presented in the general and concise reviews of earthquakes, Malaysia's earthquakes history, near and far-field earthquakes, tall-building system, incremental dynamic analysis (IDA), and fragility curve on tall buildings. Based on literature review, problem statement, research objectives, the scope of study and research framework were able to determine.
- (b) **Chapter 3** focused on the outline of overall research methodology which gives the details and a brief explanation regarding selection materials (input) and procedure on conducting the analysis in order to determine seismic fragility curve. There are seven main stages which include data collection,

generate models, analysis, and design to gravity and wind load, seismic analysis, data extraction, statistical analysis, and fragility curve.

- (c) **Chapter 4** presents overall discussion finding of the study. The first part of this chapter will discuss the failure mechanism of frame and continue with discussion of interstory drift demand. At the end of this chapter, discussion on seismic fragility curve for all frame will be presented.
- (d) **Chapter 5** concludes the findings of this study.

## REFERENCES

- Abas, M.R.C., 2001. Earthquake Monitoring in Malaysia. *Seismic Risk Seminar, Malaysia*, (September), pp.1–11.
- Adnan, A. et al., 2005. Seismic Hazard Assessment for Peninsular. *Jurnal Teknologi*, 42 (B)(Jun), pp.57–73.
- Adnan, A., Ramli, M.Z. & Sk Abd Razak, S.M., 2015. Disaster Management and Mitigation for Earthquakes : Are We Ready? *9th Asia Pacific Structural Engineering and Construction Conference (APSEC2015)*, (November), University Technology Malaysia, Kuala Lumpur, pp.34-44.
- Ahmadi, R. et al., 2014. Seismic vulnerability assessment of an industrial building in peninsular Malaysia. *5th Brunei International Conference on Engineering and Technology (BICET 2014)*, pp.307–313.
- Bozorgnia, Y. & Bertero, V.V. (Vitelmo V., 2004. Earthquake engineering : from engineering seismology to performance-based engineering, CRC Press, New York.
- Calvi, G.M. & Pinho, R., 2006. Development of seismic vulnerability assessment methodologies over the past 30 years. *ISET Journal of Earthquake Technology*, vol 43, no 3, pp.75–104.
- Chen, G.L. et al., 2013. Study on Far-Field Ground Motion Characteristics. *Applied Mechanics and Materials*, vol 438–439, pp.1471–1473.
- Chen, W.-F. & Lui, E.M., 2006. Earthquake engineering for structural design, CRC/Taylor & Francis, New York.
- Dowrick, D.J., 2003. Earthquake risk reduction, John Wiley, London.
- F. M. Nazri, 2018. Seismic Fragility Assessment for Buildings due to Earthquake Excitation. *Computational Mechanics Journal*, Springer, Singapore
- Farsangi, E.N. et al., 2014. Seismic Risk Analysis of Steel-MRFs by Means of Fragility Curves in High Seismic Zones. *Advances in Structural Engineering*, vol 17, no 9, pp.1227–1240.
- Günel, M.H. & Ilgin, H.E., 2014. Tall Buildings: Structural Systems and Aerodynamic Form, CRC Press, New York.

- Harith, N.S.H., Adnan, A. & Shoushtari, A. V, 2015. Seismic Hazard Assessment of East Malaysia Region. *International Conference on Earthquake Engineering and Seismology, (IZIIS-50), May, Kiel, Denmark*, pp 100-109.
- Kappos, A.J. et al., 2006. A hybrid method for the vulnerability assessment of R/C and URM buildings. *Bulletin of Earthquake Engineering*, vol 4, no 4, pp.391–413.
- Koh, H.L. et al., 2009. Simulation of Andaman 2004 tsunami for assessing impact on Malaysia. *Journal of Asian Earth Sciences*, vol 36, no 1, pp.74–83.
- Luco, N., and C.A.C., 1998. Effects of random connection fractures on the demands and reliability for a 3-story pre-Northridge SMRF structure. *In Proceedings of the 6th US national conference on earthquake engineering*, 244, pp.1–12.
- Malaysian Meteorological Service, 2009. Seismic and Tsunami Hazards and Risks Study in Malaysia. Mosti p.50. Available from: Malaysia Meteorological Department.
- Marto, A. et al., 2013. Seismic impact in Peninsular Malaysia. *The 5th International Geotechnical Symposium - Incheon, Korea*, pp.22–24.
- Muntasir Billah, A.H.M. & Shahria Alam, M., 2015. Seismic fragility assessment of highway bridges: a state-of-the-art review. *Structure and Infrastructure Engineering*, vol 11, no 6, pp.804–832.
- Mustafar, M.A. et al., 2014. Monitoring of Local Deformations in North Borneo. *International Federation of Surveyors (FIG) Congress*, (June), Kuala Lumpur, pp.1–12.
- Mwafy, A., 2010. Analytically derived fragility relationships for the modern high-rise buildings in the UAE. *The Structural Design of Tall and Special Buildings*, vol 21, no 11, pp.824–843.
- Sadraddin, H., Xiaoyun, S. & Yufeng, H., 2014. Fragility assessment of high-rise reinforced concrete buildings considering the effects of shear wall contributions. *The Structural Design of Tall and Special Buildings*, 24(July 2014), pp.421–439.
- Saruddin, S.N.. & Mohamed Nazri, F., 2015. Fragility curves for low- and mid-rise buildings in Malaysia. *Procedia Engineering*, 125, pp.873–878.
- Shoushtari, A.V., Adnan, A. Bin & Zare, M., 2016. On the selection of ground-motion attenuation relations for seismic hazard assessment of the Peninsular

- Malaysia region due to distant Sumatran subduction intraslab earthquakes.  
*Soil Dynamics and Earthquake Engineering*, 82, pp.123–137.
- Simons, W.J.F. et al., 2007. A decade of GPS in Southeast Asia: Resolving Sundaland motion and boundaries. *Journal of Geophysical Research: Solid Earth*, 112(6), pp.1–20.
- Singhal, A. & Kiremidjian, A.S., 1996. Method for Probabilistic Evaluation of Seismic of Seismic Structural Damage. *Journal of structural Engineering, asce*, 122(December), pp.1459–1467.
- Tajammolian, H. et al., 2018. Seismic Fragility Assessment of Asymmetric Structures Supported on TCFP Bearings Subjected to Near-field Earthquakes. *Journal Structures*, 13, pp.66–78.
- Vamvatsikos, D. & Allin Cornell, C., 2002. Incremental dynamic analysis. *Earthquake Engineering and Structural Dynamics*, 31(3), pp.491–514.
- Wang, Y. et al., 2017. The 2015 M w 6.0 Mt. Kinabalu earthquake: an infrequent fault rupture within the Crocker fault system of East Malaysia. *Geoscience Letters*, 4(1), p.6.
- Zonenshain, L.E.V.P. & Savostin, L.A., 1981. Zones : Formation of Marginal Seas and Active. , 74, pp.57–87.