SEISMIC FRAGILITY ASSESSMENT OF TALL CONCRETE WALL STRUCTURES IN MALAYSIA UNDER FAR-FIELD EARTHQUAKES CONSIDERING MASS IRREGULARITY

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ABSTRACT

Over the past decades, Malaysia had encountered far-field and near-field earthquakes. Peninsular Malaysia was constantly affected by the far-fault excitations that originated from the Sumatra earthquakes besides having the earthquakes of local origin while East Malaysia was affected the most by the earthquakes that are occurred in the Southern Philippines despite being surrounded by the local faults. High-rise buildings were more vulnerable to the far-field earthquakes as compared to low-rise buildings. Damages of infrastructures and public buildings due to seismic excitation will cause a huge financial loss to the affected country while endangering the life of people. Thus, a proper retrofitting scheme and an effective disaster risk mitigation plan are required to address the direct seismic risks and the damage resulted from the occurrence of a seismic event. This study specifically delivers the seismic fragility assessment of tall buildings under far-field earthquakes. The main aim of this study is to develop fragility curves of the 2-D structural models undergoing seismic analyses. This study employs pushover analysis and IDA as the chosen non-linear analysis methods in determining the failure mechanism, inter-story demand and capacity as well as developing fragility curves. Two reference buildings with similar building plan and number of stories but with different number of parking levels were selected for seismic evaluation. Five stories were allocated to the parking level of reference building 1 while for reference building 2, it only consists of a three-story parking level in addition to the residential level. The exterior and interior frames of both buildings were selected from grids A and B. A total of 15 ground motion records and a set of 10 incremental PGAs were adopted in the IDA to obtain the drift demand values at each PGA which leaded to the derivation of fragility curves. According to FEMA 356, three performance limit states, namely IO, LS and CP were used in the ETABS software. It was observed that in both buildings, the drift demand values increase with the increase in PGAs. The exterior frames of reference buildings 1 and 2 have a higher range of median drift demand values as compared to the interior frames of similar buildings. In addition, the median drift demand and PGA have a strong correlation with each other in all the four frames analyzed under IDA. On the other hand, reference building 1 provides lower drift capacity values than reference building 2 for both frames. Four fragility curves were developed towards the end of this study, exhibiting the probability of exceeding IO, LS and CP damage states given the range of seismic intensity as the PGA increases from 0.05 g to 0.5 g. The statistical analysis results show that the probability of exceeding IO, LS and CP damage states for the exterior frames is higher than that for the interior frames of both buildings.

ABSTRAK

Sepanjang dekad yang lalu, Malaysia telah menemui gempa bumi yang jauh dan padang. Semenanjung Malaysia sentiasa terjejas oleh kegelisahan yang berasal dari gempa bumi Sumatera selain mempunyai gempa bumi tempatan manakala Malaysia Timur terpengaruh oleh gempa bumi yang berlaku di Filipina Selatan walaupun dikelilingi oleh kesalahan tempatan. Bangunan bertingkat tinggi lebih terdedah kepada gempa bumi jauh berbanding dengan bangunan rendah. Kerosakan infrastruktur dan bangunan awam akibat pengujaan seismik akan menyebabkan kerugian kewangan yang besar kepada negara yang terjejas ketika membahayakan nyawa orang. Oleh itu, skim pengubahsuaian yang betul dan pelan mitigasi risiko bencana yang berkesan dikehendaki menangani risiko seismik langsung dan kerosakan yang disebabkan oleh kejadian seismik. Kajian ini secara khusus menyampaikan penilaian kerapuhan seismik bangunan tinggi di bawah gempa bumi yang jauh. Tujuan utama kajian ini adalah untuk membangunkan lengkung kerapuhan model-model struktur 2-D yang menjalani analisis seismik. Kajian ini menggunakan analisa pushover dan IDA sebagai kaedah analisis bukan linear yang dipilih dalam menentukan mekanisme kegagalan, permintaan dan kemampuan antara cerita dan juga keluk kerapuhan. Dua bangunan rujukan dengan pelan bangunan dan bilangan cerita yang sama tetapi dengan bilangan tempat letak kereta yang berbeza dipilih untuk penilaian seismik. Lima cerita telah diperuntukkan ke tingkat tempat letak bangunan bangunan rujukan 1 manakala bagi bangunan rujukan 2, ia hanya terdiri daripada tingkat tempat letak kereta tiga tingkat di samping tahap kediaman. Bingkai luar dan dalaman kedua-dua bangunan dipilih dari grid A dan B. Sebanyak 15 rekod pergerakan tanah dan satu set 10 PGA tambahan digunakan di IDA untuk mendapatkan nilai permintaan drift pada setiap PGA yang membawa kepada derivasi keluk kerapuhan. Menurut FEMA 356, tiga had prestasi negara, iaitu IO, LS dan CP digunakan dalam perisian ETABS. Telah diperhatikan bahawa di kedua-dua bangunan, nilai permintaan drift meningkat dengan peningkatan PGAs. Bingkai luaran bangunan rujukan 1 dan 2 mempunyai nilai permintaan drift median yang lebih tinggi berbanding dengan bingkai dalaman bangunan yang serupa. Di samping itu, permintaan drift median dan PGA mempunyai korelasi yang kuat antara satu sama lain dalam semua empat bingkai yang dianalisis di bawah IDA. Sebaliknya, bangunan rujukan 1 memberikan nilai kapasiti drift yang lebih rendah daripada bangunan rujukan 2 untuk kedua-dua bingkai. Empat keluk kerapuhan telah dibangunkan menjelang akhir kajian ini, menunjukkan kebarangkalian melebihi IO, LS dan keadaan kerosakan CP memandangkan pelbagai intensiti seismik apabila PGA meningkat dari 0.05 g kepada 0.5 g. Keputusan analisis statistik menunjukkan bahawa kebarangkalian melebihi kerosakan IO, LS dan CP menyatakan untuk bingkai luar lebih tinggi daripada itu untuk bingkai dalaman kedua-dua bangunan.

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LIST OF ABBREVIATIONS

GDP	Gross domestic product
$CTBUH$	Council on Tall Buildings and Urban Habitat
PA	Pushover analysis
IDA	Incremental dynamic analysis
$NLTHA$	Non-linear time history analysis
$PGAs$	Peak ground accelerations
IMs	Intensity measures
DS	Damage state
DI	Damage index
SI	Seismic intensity
IO	Immediate occupancy
LS	Life safety
CP	Collapse prevention
SSI	Soil-structure interaction
SRC	Steel-reinforced concrete
$MWFRS$	Main wind-force resisting system
$CMRF$	Concrete moment-resisting frame
$SMRF$	Steel moment-resisting frame
$SWFS$	Shear wall frame system
$UBC\ 97$	Uniform Building Code 97
$IBC\ 2000$	International Building Code 2000
$ASCE$	American Society of Civil Engineers
MMI	Modified Mercalli Intensity
$USGS$	US Geological Survey
MMD	Malaysian Meteorological Department
$DMGM(JMG)$	Department of Mineral and Geoscience Malaysia

LIST OF SYMBOLS

SD	Standard deviation of median drift demand
SE, S	Standard error of median drift demand
$P(DS\|SI)$	Probability of exceeding a certain damage state for a given seismic intensity
ϕ	Standard normal distribution
$\lambda_{D\|SI}$	Natural logarithm of the computed median drift demand given the seismic intensity from the best fit power law equation
λ_C	Natural logarithm of the median drift capacity for a particular damage state
$\beta_{D\|SI}$	Demand uncertainty
β_C	Uncertainty associated with capacity
β_M	Uncertainty associated with modelling
Cov	Coefficient of variation of the computed limit state capacities
M_w	Moment magnitude

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia's strategic geographical location protects the country from most of the major natural disasters. Being situated on a seismically stable Sunda Plate with little modern history of volcanic activity, the tectonically slow or nearly inactive movement of the plate reduces the direct seismic risks resulted from enormous earthquakes and the devastating effects of active volcanoes. Earthquakes are constantly regarded as one of the natural disaster phenomena affecting Malaysia, but still with a much smaller magnitude as compared to the earthquakes with their epicentres occur along the most vibrant tectonic plate boundaries and especially those occurred at the Pacific Ring of Fire. Although Malaysia is a country with low seismicity, it is surrounded by the world's most active tectonic plates that will cause a strong relative motion of the plates in between their boundaries and subsequently induce a vigorous fault rupture at the Earth's surface which may trigger a large earthquake. Despite from being affected by the near-field earthquakes of local origin, Peninsular Malaysia also experiences far-fault excitations originated from the Sumatra earthquakes while East Malaysia is also affected by the far-field earthquakes take place in the Southern Philippines. By referring to the statistics of far-field earthquakes occurrence in Peninsular Malaysia and East Malaysia, it is proven that the Peninsular Malaysia is struck the most by the distant earthquakes from the Sumatra while East Malaysia is subjected to the distant earthquakes from the Southern Philippines. As a result, this exposes the entire continent of Malaysia to both near-field and far-field earthquakes.

The number of high-rises or tall buildings have been increased tremendously in Malaysia because of the rapid urbanization and substantial development of infrastructures in this country for the last two decades. This is to fulfill the needs of the progressively increasing populations due to the continuous gross domestic product (GDP) growth of the country in terms of the rising economic demands as an important initiative of the Malaysian government to serve the nation in upgrading the standard of living of vast communities while eliminating the poverty to the minimum extent from all aspects of a developing country for the overall betterment of its society. However, most of the slender buildings in Malaysia are designed to carry gravity (combination of dead and live) and wind loads only. The absence in the formulation of the earthquake-resistant design related regulations and guidelines which are later to be implemented on buildings as prescribed by building codes makes them to become more vulnerable to the seismic excitation (for non-earthquake-resistant buildings) especially in possessing an adequate strength and stiffness to resist earthquake-induced load, another crtitical lateral load to tall buildings in addition to wind load. This will eventually cause a great extent of damage to those buildings which will further affect their structural performances such as the degree of vulnerability (fragility) in response to a seismic event, leading to an incapability of predicting the potential risks and consequences of future earthquakes for ensuring an effective earthquake loss estimation system.

According to the Council on Tall Buildings and Urban Habitat (CTBUH), it is common that any tall building constructed in the major cities of Malaysia with a total number of stories exceeding 20 stories and some even reach up to 50 stories. Most of the tall buildings are developed for residential and commercial uses, which the latter includes the establishments for office use consisting of administration blocks. For these kinds of tall buildings covering numerous purposes of usage, one of the common building materials used to construct the buildings is reinforced concrete due to its monolithic behavior, high compressive strength, recognition as a widely available material adopting locally available resources and concrete technologies, and highly economical in terms of its cost-effectiveness in ensuring a high cost benefit in return in addition to steel component and its related products. Due to the widely use of reinforced concrete in the construction industry as the most common construction material for civil engineering structures, the damages caused to the buildings will impose a significant impact on the country especially in causing a huge financial loss to the government and public for their affected property assets including the damaged infrastructures, public buildings and buildings constructed for industrial, commercial and residential uses as well as endangering the important lives of all the occupants reside in the buildings located in seismic zones.

High-rise buildings are more vulnerable to the far-field earthquake than low-rise buildings or in other words, tall buildings have higher sensitivity to the seismic activity originated from the far-field seismic source as compared to short buildings. Super-tall buildings are highly vulnerable to the seismic effect if the seismic load is not taken into account in the design of tall concrete structures. The indicators used to measure the importance level of high-rise buildings are the population density that high-rise buildings have and the financial investment in them as well as the expected amount of return in future. From the consideration of these two factors affecting the significance of high-rise buildings, high-rise buildings are important in such a way that they contain high population densities and financial investments. By understanding the importance level of high-rise buildings and then incorporating the expected outcome to a decision-making process, an accurate prediction of seismic risks and structural damages and later followed by a proper implementation of mitigation strategies can be achieved to minimize losses in terms of human life and monetary term. To better predict the earthquake losses such as structural damages so as to obtain an optimum cost of rehabilitating or replacing a damaged building up to its desired capacity, fragility curves have becoming an important tool for predicting and mitigating those damages effectively. It also helps to develop an effective retrofitting scheme and disaster risk mitigation plan for overcoming the seismic hazards in future.

According to Sadraddin et al. (2014), a fragility curve describes the probability of reaching or exceeding a damage limit state of a structure under seismic excitation based on a given range of ground motion intensity. Fragility curves are particularly useful in seismic fragility assessment, which they can be used by future researchers as an indicator to identify the greatest damage in the most powerful main shock zone once an earthquake occurs based on the damage limit states that have been established by previous researchers. Many research studies have used the analytically derived fragility relations to predict the potential damages of the structures and then successfully acquire economic losses by converting the structural damage into a valuable financial term. Fragility curves are developed for different types of reference structures of different categories constructed using different types of materials available, namely concrete, steel and timber as the three main construction materials. There are many factors affecting the process of deriving fragility relations. These factors include plan and elevation irregularities, number of stories, building height and types of construction materials (Polese, 2015).

Therefore, this study discusses the analytical derivation of fragility curves for tall concrete wall structures in Malaysia under far-field earthquake. These curves will be used to predict the potential damages exposed to the buildings when they are subjected to different intensity levels of ground motions at different peak ground accelerations (PGAs). This is to determine whether the buildings in seismic-prone regions are vulnerable to the earthquake or not. As a result, fragility curves can be used as an indicator to monitor the behavioral changes in the buildings under seismic excitation and to decide whether the buildings are permitted to be re-occupied or not through retrofitting of buildings after they are declared to be unsafe for occupancy while reducing the damage cost and loss of life. Last but not least, incremental dynamic analysis (IDA) will be used to perform non-linear dynamic analysis in assessing the failure mechanism and inter-story drift demand and capacity which leaded to the development of fragility curves.

1.2 Problem Statement

Earthquakes have always been one of the deadliest natural disasters and they become even more terrifying when the disastrous earthquakes strike the cities and bring more catastrophic damages by collapsing most of the seismically vulnerable structures and seizing masses of peoples' lives, tossing the victims of the earthquake disaster to death. This significantly paralyzes the economy of the affected country as the whole country will suffer huge economic losses from an economic downturn and loss of life, posing that particular country at a high risk. For instance, the 9.5-magnitude earthquake that struck the coast of Chile in 1960 is regarded as the largest earthquake ever recorded in the earthquake history of the world. Resulting from that seismic event alone, the disaster has brought the death toll to more than six thousands (WSSPC, 2007).

Malaysia's seismic condition is characterized by two seismic sources, namely far-field earthquakes from the Sumatra subduction zone affecting Peninsular Malaysia and far-field earthquakes from the Southern Philippines affecting East Malaysia along with regional earthquakes originated from local causative faults. Although Malaysia is categorized under the group of low seismicity, an earthquake with a moment magnitude of 6.0 has struck Ranau, Sabah in June 2015. In other words, in addition to the far-fault excitations from the Southern Philippines, East Malaysia is also affected by local earthquakes as there are few active fault zones present in some places within East Malaysia. Since the 80s of last century till present, Peninsular Malaysia is hit the most by the distant earthquakes originated from the Northern Sumatra by considering far-field earthquakes. Due to the influence of far-field earthquakes such as the 2002 and 2004 Sumatra earthquakes, structural damages like cracks have been found in some buildings located in Penang and the tremor resulted from the 2004 Sumatra earthquake has also caused a number of deaths in several states within Peninsular Malaysia. This proves that a strong far-field earthquake can cause a severe damage to the building and people in Malaysia.

Each building has its own structural system when it is first constructed. In fact, a thorough understanding in the type of structural system of a building is important in vulnerability studies. Different buildings with different types of structural systems will have different structural performances and extents of damages under seismic loading and thus, this produces different vulnerability (fragility) curves correspond to their own buildings. Fragility curves are analytically derived with respect to the structural system of a building for a given range of damage levels under a given range of seismic intensity levels by analyzing the modeled building through IDA or other non-linear dynamic analyses using time history functions. Tall concrete wall structures are becoming more common in the modern construction of new era to meet the rising housing demands. This residential type of building can be an apartment or a condominium, ranging from mid-rise to high-rise.

Several studies have successfully derived fragility curves resulted from the seismic fragility assessment in determining the vulnerability of the buildings in certain areas in which the seismicity is relatively high. For instance, Farsangi et al. (2014) have conducted a seismic risk analysis of steel moment-resisting frames by means of fragility curves exclusively in high seismic zones. Before this, Celik and Ellingwood (2010) have developed fragility curves specially for non-ductile reinforced concrete moment-resisting frames. As most of the tall buildings in Malaysia are designed based on gravity and wind loads only, retrofitting of the old and vulnerable buildings is indeed required because the potential damages caused to those buildings during earthquakes are unpredictable. This is due to the fact that the buildings during old days have not been designed to resist seismic load throughout the design life of the buildings. Majority of those buildings are vulnerable to earthquakes. As a result, it is difficult to mitigate such damages induced by seismic forces. Furthermore, Aiswarya and Mohan (2014) have made a comparison between fragility curves developed for both unretrofitted and retrofitted buildings. The respective study is conducted on a structural model comprises five-story mid-rise reinforced concrete building adopting flat slab system. Another study is essentially about the development of fragility curves for a building adopting shear wall system using analytical method as the chosen methodology to perform time history analyses (Hwang and Jaw, 1990). Moreover, Sadraddin et al. (2014) have conducted a collapse fragility assessment for high-rise reinforced concrete buildings considering the effects from shear wall contributions.

Fragility curves are one of the important tools used to predict potential damages during earthquakes. As the damage resulted from an earthquake is expected to impose great losses on a country, including the damage that caused to the structure which is then translated as monetary loss and loss of life due to downtime and high repair cost, the prediction of the extent of damage can provide an optimum cost for the retrofitting project and an economical design to improve the seismic performance of the structure in a cost-effective way after considering the seismic effect in structural design processes.

In contrast with the drastically expanding trends of high-rise building stock market in Malaysia, existing research studies about the seismic vulnerability assessment of high-rises considering weight (mass) irregularity are still lacking. Mass irregularity shall be considered to exist when the effective mass of a story is more than 150 percent of the effective mass of its adjacent story. A roof that is lighter than the floor below does not need to be considered. The influence of mass irregularity comes in such a way that it will affect the dynamic response of a structure, leading to an unexpected higher mode effects and/or concentrations of seismic demand. To better assess the dynamic response of the structure, a dynamic analysis is needed to be carried out to evaluate the distribution of seismic forces more accurately. By comparing the amount of seismic forces acting on different parts of the structure with the performance control points of the structure, this allows us to check the adequacy of seismic force-resisting elements of the structure based on the depicted damage states of the structure under different seismic intensity levels. Mass irregularity can be detected by the comparison of story weights.

Most of the previous reasearch related to the development of fragility curves in Malaysia only focus on low-rise and mid-rise buildings including the industrial building without the consideration of mass irregularity as one of the vertical structural irregularities in the design of the building under gravity load (Ahmadi et al., 2014; Saruddin & Nazri, 2015). To support this statement, a study of the adopted fragility curves to assess the seismic performance of a full-scale double-story residential building in Malaysia carried out by Abdul Hamid and Mohamad (2013) also describe the seismic vulnerability assessment for a landed house instead of evaluating high-rise building for its vulnerability to ground motion. This best explains the plight of the research study pertinent to the development of fragility curves of tall concrete wall structures that is faced by incumbent researchers in Malaysia. Therefore, additional studies on the seismic fragility assessment of tall buildings in Malaysia considering mass irregularity are urgently needed.

The most common feature of the architectural system of high-rises in Malaysia is that a high-rise building composed of parking and typical stories. The parking stories are normally a rigid frame or moment-resisting frame system consisting of a frame with mostly rigidly interconnected beams and columns beneath typical stories while the typical stories are normally a shear wall flat slab system without the use of any beam and column, constructed above the parking stories. The configurations of these two systems produce a discontinuity in shear wall elevation. The doubt lies in to what extent this irregularity can influence the seismic performance of such type of building especially when the building is not designed to carry seismic load. To address the aforementioned problem, this study will provide a framework to analytically derive fragility curves of tall concrete wall structures and to evaluate physical damages of the structures.

1.3 Research Aim and Objectives

The aim of this study is to conduct a seismic fragility assessment for tall concrete wall structures as the reference structures in Malaysia considering mass irregularity as the vertical structural irregularity. This study will work toward achieving the following objectives:

(a) To determine the failure modes of the reference structures under far-field earthquakes.

(b) To evaluate the inter-story drift demand and capacity of the reference structures through pushover and incremental dynamic analyses.

(c) To develop fragility curves for tall concrete wall structures in the evaluation of the seismic performance of the reference structures subjected to far-fault excitations.

1.4 Scope of Study

This research study considers the following scopes of works:

(a) A total of four two-dimensional (2-D) models composed of exterior and interior frames with a shear wall flat slab system as the chosen structural system subjected to different structural configurations of the models will be analyzed in this study.

(b) Concrete with a compressive strength of 40 N/mm^2 is adopted for all the model structures.

(c) Both the yield and ultimate tensile stresses of the adopted rebar in reinforced concrete structures are 460 N/mm^2 and 620 N/mm^2 respectively.

(d) A total of 15 ground motion records that obtained from far-field earthquakes are adopted in the analysis software.

(e) Assume all the reference structures are constructed on a stiff soil.

(f) In the modeling of the reference structures, the foundation system of the real structures will not be simulated to the model structure.

(g) The effect of soil-structure interaction (SSI) is omitted as the modelling of the foundation of the reference structures is excluded from this study.

(h) ETABS 2017 version 17.0.1 software is used to create and design the structural models and also to perform the non-linear static and dynamic analyses.

(i) A set of peak ground accelerations (PGAs) are selected as the engineering demand parameters in seismic analysis.

1.5 Significance of Research

This research is conducted to study the vulnerability of tall concrete wall structures in Malaysia considering mass irregularity under the influence of an earthquake excitation from far-field origin as the seismic source. This research is particularly important as the related study for developing fragility curves of high-rise reinforced concrete buildings in Malaysia considering mass irregularity is not established yet. The outcome of this study can provide a reference to the governmental bodies and non-governmental organizations in decision-making stage especially during the formulation of a series of mitigation strategies to effectively mitigate damages experienced by the seismically vulnerable structures as a result of a seismic event. The attenuation of structural damages through the implementation of earthquake risk mitigation measures can be achieved provided that more research about seismic vulnerability assessment are carried out on vulnerable buildings. Not only that, the findings of this research can also help them to predict the potential risks and consequences of an earthquake through seismic risk analysis and also to develop an effective earthquake loss estimation system in order to minimize the earthquake losses such as a financial loss due to structural damages when the structures are vulnerable to the seismic effect as well as loss of life to a great extent.

The cause of failure of tall concrete wall structures subjected to an earthquake excitation can be investigated with more systematic approaches especially in dealing with the failure mechanism of a collapsed structure. It allows a more accurate prediction of the physical damage of the building when the building starts to excite and it ease the interpretation of the damage level in the form of fragility curves. The main contribution includes it provides an established methodology that helps the government to improve the risk management strategies in seismic hazard management and natural disaster planning in Malaysia. Other contributions include providing insight on retrofitting a vulnerable building at an optimum cost through a more reliable retrofitting scheme, providing a suitable seismic damage mitigation framework and providing damage data for other researchers to refer in developing fragility curves associated with fragility analysis. Through the intervention of the government and other supporting private entities and synergism between these parties in community project dealing with the implementation of an earthquake risk mitigation plan as the long-term strategic plan to design a preparedness programme aiming to address the catastrophic impact of the earthquake on societies, this will greatly enhance the safety of the public by identifying more evacuation routes before the earthquake strikes the seismic zone again. This will also help to create awareness on the importance of the seismic vulnerability of tall buildings which in turn facilitates the formulation and implementation of provisions on earthquake-resistant design specifications.

1.6 Organization of Thesis

There are altogether five chapters in this thesis and the outline of each chapter is delineated as follow:

(a) **Chapter 1** provides an overview (a background) of this study, problem statement expressing the difficulties that are faced in the prediction of seismic risks and earthquake losses prior to a seismic event due to the absence of earthquake-resistant design in high-rise buildings located in Malaysia and the lack of research associated with collapse fragility assessment for high-rises, research aim and objectives addressing the main purpose of conducting this study and goals to be achieved at the end of this study, scope of study outlining the research area of this study that restricts a range of tasks to be performed throughout the research by narrowing down the scopes of works in order to ease the implementation of the research work based on the feasibility of study and difficulty level, significance of study explaining the importance level of this study with regard to the decision-making of the government agencies in mitigating potential damages during earthquakes as well as organization of thesis explaining the way the thesis is organized.

(b) **Chapter 2** discusses on the findings of previous studies related to the topics covered in this study. This chapter presents the review on earthquakes including but not limited to factors contributing to the occurrence of earthquakes, relative motions of global plate tectonic boundaries, various types of faults, actual cases of earthquakes happen all over the world, then followed by reviewing Malaysia's earthquake history including seismic hazards in Peninsular Malaysia and East Malaysia, seismic sources such as near-field and far-field earthquakes, tall building systems with different types of structural systems, incremental dynamic analysis (IDA) and lastly, it leads to the discussion on seismic fragility assessment.

(c) **Chapter 3** focuses on the chosen research method employed in this study for the probabilistic damage evaluation of structures due to seismic impact. It gives a general description and detailed explanation regarding the selection of materials as the input of the non-linear static and dynamic analyses and also important procedures in executing a seismic analysis in order to develop fragility curves. This chapter will discuss on the seven main stages in accomplishing a comprehensive vulnerability study. It includes data collection on pertinent information, generating structural models during model simulation process, analysis and design of structural system of the simulated models considering gravity and wind loads, performing non-linear analyses for the models under earthquake excitation, data extraction, and interpretation of data through a statistical analysis as well as performing a fragility analysis for developing fragility curves.

(d) **Chapter 4** discusses on the findings of this study. The first part of this chapter will specifically discuss on the failure mechanism of all the four 2-D structural models composed of (rigid) moment-resisting frame system with typical beam-to-column connections at the parking levels and frame with shear wall flat slab system at the residential levels above the parking levels while the second part of this chapter will continue to discuss on the inter-story drift demand and capacity evaluation. Towards the end of this chapter, a discussion on developing fragility curves for the frame buildings will be presented.

(e) **Chapter 5** concludes the findings of this study in deciding whether all the research aim and objectives are fulfilled or not.

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