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

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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.

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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%.

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S_E^2	Standard error of demand drift
DS	Standard error of demand drift
SI	Seismic intensity
ϕ	Standard normal distribution
$\lambda_{D/SI}$	Natural logarithm of the median demand drift given the seismic intensity from the best fit power law
λc	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.

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