SEISMIC FRAGILITY OF LOW DUCTILE PARTIALLY INFILLED REINFORCED CONCRETE FRAME IN MALAYSIA

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To my beloved mother and father

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ABSTRACT

The purpose of this study is to develop analytical fragility curves for low ductile partially infilled reinforced concrete (RC) frames building under seismic ground motions. Three RC frames with their ground story open and masonry walls infilled in all of the upper stories (pilotis) comprise of three-, six- and nine-stories were selected, modelled, and analysed representing common building type in Malaysia. These frames were designed in accordance with BS 8110-1997 code specification. 45 seismic ground motions were used and subdivided into three groups namely low (L), medium (M) and high (H) records based on peak ground acceleration (PGA) over peak ground velocity (PGV) ratio. ETABS 2015 was used to perform Incremental Dynamic Collapse Analysis (IDA) with increment every 0.1g until 0.5g. The PGA was compared to the maximum inter-story drift demand obtained from nonlinear time history analysis and also to the three levels of performance-based seismic designs, namely, immediate occupancy (IO), life safety (LS), and collapse prevention (CP) to assess structural performance. The results show that as the height of structure increases, the intensity of damage decreases. Therefore, 3 story is the most damaging structure followed by 6-story and 9-story. For all types of structure assessed, the most devastating type of earthquake records is M. For 3 and 9 story, there are no difference observed between IO and LS. This shows that the preserved strength was very small where IO suddenly jumps straight to CP with increasing intensity. As for 6 story there is a clear distance between IO, LS and CP and this shows that the structure is not very fragile.

ABSTRAK

Tujuan kajian ini adalah untuk menghasilkan lengkung kerapuhan bagi rangka konkrit bertetulang (RC) bermulur rendah separa penuh dibawah pengaruh pergerakan tanah seismik. Bingkai RC dengan tingkat bawah terbuka tanpa dinding dan semua tingkat atas dipenuhi dinding yang terdiri daripada tiga-, enam dan sembilan tingkat telah dipilih, peringkat, dan dianalisa mewakili jenis bangunan biasa di Malaysia. Kerangka ini direka mengikut spesifikasi kod BS 8110-1997. 45 rekod pergerakan tanah telah dibahagikan kepada tiga kumpulan iaitu rendah (L), sederhana (M) dan tinggi (H) rekod berdasarkan puncak tanah pecutan (PGA) nisbah halaju (PGV) puncak tanah. ETABS 2015 telah digunakan untuk melakukan analisis kejatuhan dinamik tokokan (IDA) dengan kenaikan setiap 0.1g hingga 0.5g. PGA adalah permintaan maksimum antara tingkat drift yang diperolehi daripada analisis tolakan statik tak linear dan juga kepada tiga peringkat berasaskan prestasi seismik reka bentuk, iaitu serta-merta penghunian (IO), keselamatan hidup (LS), dan pencegahan runtuhan (CP) untuk menilai prestasi struktur. Hasil kajian menunjukkan bahawa apabila ketinggian struktur bertambah, kerosakan struktur berkurangan. Oleh itu, bangunan 3 tingkat adalah yang mengalami kerosakan paling merosakkan struktur diikuti dengan bangunan 6 tingkat dan 9 tingkat. Untuk semua jenis struktur yang dinilai, jenis rekod gempa bumi yg paling menghancurkan adalah jenis M. Bagi bangunan 3 dan 9 tingkat, tiada perbezaan yang diperhatikan antara IO dan LS. Ini menunjukkan bahawa kekuatan dalaman struktur adalah sangat kecil di mana IO tiba-tiba bertukar terus ke CP dengan peningkatan intensiti gempa bumi. Bagi 6 tingkat terdapat jarak yang jelas antara IO, LS dan CP dan ini menunjukkan bahawa struktur itu tidak begitu rapuh.

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LIST OF SYMBOLS

f_{ck}	-	Characteristic cube strength of concrete
f_{yk}	-	Characteristic strength of reinforcement
F_u	-	Ultimate stress of reinforcement
F_y	-	Yield stress of reinforcement
k	-	Stiffness
D	-	Damage
Φ	-	Standard normal cumulative distribution of PGA
μ	-	Mean
σ	-	Standard deviation
Mw	-	Moment magnitude scale
cm	-	centimetre
m	-	metre
km	-	kilometre
MPa	-	MegaPascal
kN	-	kiloNewton
Δ	-	deflection

CHAPTER 1

INTRODUCTION

1.1 Research Background

In this study, the fragility functions developed for low ductile partially infilled Reinforced Concrete (RC) buildings are discussed. The seismic fragility analysis of structure is a requirement for seismic loss estimation and seismic risk management. The vulnerability of structures, seismically, is usually conveyed through functions of fragility, which denote the probability of exceeding or reaching limit state performance damage by seismic ground movements. Fragility curves are tremendously essential to estimate the total risk to the structural buildings from possible tremors and to forecast the effects of loss to the economy from forthcoming tremors. These fragility functions also can be handy in planning for disaster or emergency response by national authority, furthermore an advantage for the insurance companies to execute rough estimation on the total loss of the post-earthquake.

Additionally, fragility curves can also be utilized to outline the design retrofitting for damaged structures or that with inadequate strength to resist earthquake loadings. This is done by performing benefit and cost studies for different sorts of structural material and properties. Moreover, these fragility functions can be used to alleviate risk through the adjustment of seismic codes for the plan of new structures; the potential losses are quantitatively compared with the additional cost in providing seismic resistance.

A large portion of the structures, additionally the buildings constructed without the consideration of seismic code may have adequate and sufficient lateral strength to withstand tremors of moderate size with a small degree of damage but not severe or extreme tremors. Studies on vulnerability are conducted preceding the earthquake events. The significance of the building, its utilization and the owner's necessities will decide whether the damage is acceptable or not.

The design of the buildings is based on the provisions of British Standard 8110-1997 in this study. The studied buildings are designed to resist wind loads and gravity loads only as most of the buildings in Malaysia did not imply seismic codes on the buildings due to its location outside earthquake prone areas. 45 ground motion records are imposed to estimate the vulnerability of the buildings. The variable considerations are the buildings heights that are the number of storeys and the seismic design level with regard to Peak Ground Acceleration (PGA). Extra consideration for the partially infilled frames is the quantity of infills (brick walls). In this study, three performance levels or limit states, namely immediate occupancy (IO), life safety (LS) and collapse prevention (CP) are considered to assess the structural performance denoting the inter-story demand. The damage scale or measure of interest is corresponded from the median value of the fragility functions.

Hence, in this study, fragility curves are used as the main tool for preparations of seismic risk map. As mentioned before, fragility analysis plays an important role in seismic risk assessment to estimate the vulnerability of a structure reaching or exceeding limit state performance damage by seismic ground movements. This vulnerability assessment method can be categorized into four categories, that are, empirical, hybrid, judgemental and analytical. The classification relies on upon the damage data used in their generation which are established mainly from observed post-tremor study, analytical simulation, expert judgement or combination of both. (Kwon & Elnashai, 2006) The Malaysian Meteorological Department reports that only limited data of strong ground motions have been recorded. In view of that, the curves are developed using analytical simulation.

Moreover, these curves are particularly handy in vulnerability assessment, post tremor assessment and retrofit prioritization from potential seismic tremors. (Jeong & Elnashai, 2007) Additionally, these curves are more critical and vital in the loss estimation of economy, life and occupancy that many happen as an aftereffect of future seismic tremors. (Tan & Abdul Razak, 2010) Therefore, this project report highlights the development of fragility curves to assess the vulnerability of buildings under seismic ground motions.

1.2 Problem Statement

Earthquakes are one of the most disastrous events that could happen in human history and are frequently exciting highly populated cities. Earthquakes impose damages to structures and infrastructures, subsequently cause casualties and fatalities. Malaysia is categorized under low seismicity group as it is located tectonically within the comparatively steady Sunda Shelf. Except for Sabah, where it is categorized under moderate seismicity group. Since Malaysia’s geology is far from earthquake prone area, the buildings have been designed according to BS8110-1997 to resist gravity and wind loads effects only. A large portion of present and existing Malaysian’s structures have not been designed for earthquake thus never designed to take seismic excitation effect. Having experienced with local and distant seismic motions, Malaysia has come to realize that the danger of earthquake is real and has the risk to public safety and welfare.

Therefore, there has been effort to reduce seismic induced damages. One way to decrease seismic induced damages is to retrofit buildings which have not been designed for seismic actions. There are several methods available, namely, reinforcement jacketing, steel jacketing and Fibre-Reinforced Polymer (FRP) installation that have been proposed to mitigate or reduce structural damages under seismic actions. In order to retrofit our structures, we need to allocate enough budgets and the government should have estimation on total cost for retrofitting and rehabilitating the structures. Therefore, one way to estimate seismic induced damages and the cost for retrofit of buildings is by preparing seismic risk map.

Hence, in this study, fragility curves are used as the main tool for preparations of seismic risk map. For Malaysia, there has been no comprehensive study on the preparation of fragility curves. Based on the research carried out by (Saruddin & Mohamed Nazri, 2015), they developed fragility curves for material of moment resisting concrete frame (MRCF) and steel frame (MRSF). It was found that the steel frame has better performance than moment resisting concrete frame. (Tan, et al., 2014) developed fragility curves for three story reinforced concrete frame. From their study, the results indicate that the fragility curves are affected by both the number of stories in the building and soil conditions.

Based on the affirmation studies, there has been no fragility curves developed for low ductile partially infilled RC frame in Malaysia. There is also no fragility curves developed for partially infilled RC frame that takes into consideration near- and far-field effects of earthquakes in Malaysia. Therefore, in this study fragility curves for low ductile partially infilled RC frame considering near-field and far-field seismic ground motions are developed in contributing to the shortcomings of previous studies.

1.3 Objectives of Research

Therefore, this study embarks on the following objectives:

1. To study failure mechanism of low ductile partially infilled RC frames subjected to ground motions.

2. To investigate inter-storey drift demand of low ductile partially infilled RC frames subjected to ground motions.

3. To develop seismic fragility curves for low ductile partially infilled RC frames subjected to ground motions.

1.4 Scopes of Research

This project focuses on the following scopes:

1. Seismic fragility of low ductile partially reinforced concrete frames in Malaysia subjected to seismic ground motions.

2. Seismic risk analysis using fragility curves for three-, six- and nine storeys of RC frame buildings are selected as studied buildings

3. All of the buildings are regular in both plan and elevation configuration.

4. Each frame of three-, six- and nine-story has four 6m bays and typical story height of 3m except for the ground story having height of 4m. The total height of building is 10m, 19m and 28m respectively.

5. Compressive strength of concrete: 20 MPa

6. Yield stress of reinforcement, F_y : 300 MPa

7. Ultimate stress of reinforcement, F_u : 420 MPa

8. Live load applied is 6 kN/m^2

9. Dead load applied is 25.5kN/m except for the top floor (without walls) i.e. 15.54kN/m

10. 45 earthquake records will be used to perform Incremental Dynamic Collapse Analysis (IDA)

11. The structures are designed in compliance with the BS 8110-1997 code specification

12. Preliminary design of these 3 models is performed by using ETABS 2015 software. This finite element simulation and design of buildings are according to common practice in Malaysia.

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