INFLUENCE OF CONSIDERING MALAYSIA NATIONAL ANNEX FOR SEISMIC DESIGN OF REINFORCED CONCRETE BUILDING

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DEDICATION

This project report is dedicated to my parents who continuously provide a great support and encouragement for me to complete this project.

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ABSTRACT

The current practice for reinforced concrete building design in Malaysia using BS 8110 does not include seismic design provision since Malaysia is not located in active fault zones. The urgency of seismic design in Malaysia started when several tremors from neighbouring countries were felt and slightly damaged some structures especially after a recent earthquake in Sabah which hit Ranau in 2015 with 5.9-magnitude. In 2017, Malaysia has recently published its own National Annex (NA) for seismic design according to Eurocode 8 (EC 8) to include seismic provision into account. This study focuses on the estimation of the required reinforcement for conventional design (BS 8110) and seismic design (Malaysia NA to EC 8); and the seismic performance of the buildings when such codes are used for design. In this study, buildings have been designed based on different parameters such as number of storey (3 and 6 storey), ductility class (low and medium ductility) and soil type (stiff and soft soil). One Peak Ground Acceleration (PGA) has been selected which is 0.1g based on condition in Peninsular Malaysia. The results show low ductility class with soft soil buildings have 95% to 173% higher reinforcement percentage difference when compared to the with conventional design This indicates higher additional reinforcement is needed for low ductility class with soft soil buildings to withstand the seismic load in such condition. Furthermore, the seismic capacity curves of the buildings are established by using non-linear static pushover analysis. The maximum displacements are obtained for all load cases of 3-storey and 6-storey buildings and have been compared to the conventional design. The results indicate the maximum displacement for conventional design is less than buildings that are designed with seismic provision. This shows under the earthquake event, building with conventional design will form plastic hinges and proceed to failure stage earlier than seismic designed buildings. In addition, the seismic performance points are obtained for all types of buildings. The results showed for all load cases conventional designed 3-storey building and 6 storey building considered safe under 0.1g ground motion if they were designed under stiff soil ground condition (type A) as plastic hinges formed only reached to IO state. However, if they were designed under soft soil (type D), the buildings were not safe as the hinges formed beyond CP state at the target displacement. For seismic designed of 3-storey buildings, only buildings with soft soil regardless of ductility class were not safe even though the seismic provisions were included in the design. Meanwhile, for seismic designed of 6-storey buildings, all types of buildings were safe under 0.1g ground motion as plastic hinges formed only reached to IO to LS states. The results obtained for 6-storey seismic designed buildings were different with 3-storey seismic designed buildings due to additional structure element that were added in the 6-storey buildings which was shear walls that been designed from bottom to the top of building. The shear wall made the structure become stiffer thus can cater the earthquake load applied to the building.

ABSTRAK

Praktis semasa untuk rekaan bangunan konkrit bertetulang di Malaysia menggunakan BS8110 tidak termasuk rekaan keadaan seismik kerana Malaysia tidak berada di aktif zone seismik. Kepentingan rekaan seismic di Malaysia bermula apabila beberapa gegaran daripada negara jiran telah dirasai dan merosakkan beberapa bangunan terutama selepas gepa bumi terbaru di Sabah telah terjadi kepada Ranau pada 2015 dengan 5.9 magnitude. Pada 2017, Malaysia telah mengeluarkan National Annex (NA) tersendiri untuk rekaan seismik mengikut Eurocode 8 (EC8) untuk memasukan rekaan keadaan seismik. Kajian ini bertumpu kepada anggaran kuantiti besi diperlukan unutk rekaan tradisi (BS8110) dan rekaan seismik (Malaysia NA kepada EC8); dan prestasi seismik untuk bangunan apabila koda digunakan untuk rekaan. Dalam kajian ini, bangunan telah direka bergantung kepada kelainan situasi seperti bilangan tingkat (3 dan 6 tingkat), kelas duktiliti (rendah dan sederhana) dan jenis tanah (tanah keras dan tanah lembut). Satu kelajuan tinggi tanah telah dipilih adalah 0.1g bergantung kepada keadaan di Semenanjung Malaysia. Keputusan telah menunjukan bangunan kelas duktiliti rendah dengan tanah lembut mempunyai 95% hingga 173% ketinggian kelainan peratusan besi berbanding kepada reaan tradisi. Ini menunjukan jumlah lebih tinggi besi diperlukan untuk bangunan kelas duktiliti rendah dengan tanah lembut untuk bertahan dengan berat seismik. Tambahan pula, lengkokan kapasiti seismik telah diperolehi dengan menggunakan analisis statik tidak sekata. Keputusan telah menunujukan kadar tertinggi perbezaaan kedudukan untuk rekaan tradisi adalah kurang daripada bangunan direka seismik. Ini menunjukan apabila berlaku gempa bumi, rekaan tradisi akan mengalami kegagalan lebih pantas berbanding bangunan direka seismik. Selain itu, titik prestasi seismik telah diperolehi untuk semua bangunan. Keputusan menunjukan untuk semua jenis berat, bangunan direka dengan rekaan tradisi untuk 3 tingkat and 6 tingkat dikira selamat untuk keadaan tanah 0.1g jikalau ia direka dengan tanah keras (jenis A) kerana hinge plastik telah terjadi dalam keadaan IO sahaja. Untuk bangunan 3 tingkat direka dengan rekaan seismik dengan tanah lembut sahaja tidak dikira kelas duktiliti dikira tidak selamat walaupun keadaan seismik telah diambil kira. Manakala keputusan untuk bangunan 6 tingkat direka dengan rekaan seismik dikira selamat untuk semua jenis bangunan kerana hinge plastik telah terjadi pada tahap IO hingga LS sahaja. Keputusan berlainan untuk 6 tingkat and 3 tingkat untuk bangunan direka dengan rekaan seismik adalah kerana pertambahan elemen struktur diperkenalkan unutk bangunan 6 tingkat yang telah direka dari tingkat bawah sehingga tingkat atas bangunan. Elemen struktur ini menjadikan bangunan lebih kukuh dan membuatkan bangunan boleh menerima beban gempa bumi.

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LIST OF ABBREVIATIONS

NA	-	National Annex
BS	-	British Standard
EC8	-	Eurocode 8
EC2	-	Eurocode 2
RC	-	Reinforced Concrete
IEM	-	Institute of Engineer Malayisa
DCL	-	Ductility Class Low
DCM	-	Ductility Class Medium
DCH	-	Ductility Class High
MS	-	Malaysia Standard
PGA	-	Peak Ground Acceleration
IO	-	Immediate Occupancy
LS	-	Life Safety
CP	-	Collapse Prevention
NCR	-	No-collapse requirement
DLR	-	Damage limitation requirement
CSM	-	Capacity Spectrum Method
ADRS	-	Acceleration Displacement Response Spectra

LIST OF SYMBOLS

$S_e(T)$	-	Elastic acceleration response spectrum
T	-	Vibration period of linear single-degree-of-freedom
a_g	-	Design ground acceleration on type A
T_B	-	Lower limit of period of the constant spectral acceleration branch
T_C	-	Upper limit of period of the constant spectral acceleration branch
T_D	-	Value defining the beginning of the constant displacement response range of the spectrum
S	-	Soil factor
η	-	Damping correction factor
ξ	-	Viscous damping ration
$S_{De}(T)$	-	Elastic displacement response spectrum
q	-	Behaviour factor
q_o	-	Basic value of the behaviour factor
k_w	-	Factor reflecting the prevailing failure mode in the structural systems
β	-	Lower bound factor for the horizontal design spectrum
$S_d(T_1)$	-	Ordinate of the design spectrum at period T_1
T_1	-	Fundamental period of vibration of the building for lateral motion in the direction considered
m	-	Total mass of the building, above the foundation or above the top of a rigid basement
λ	-	Correction factor
C_t	-	Factor for frames
H	-	Height of the building
F_i	-	Horizontal force acting on storey i
F_b	-	Seismic base shear
s_i, s_j	-	Displacements of masses m_i, m_j in the fundamental mode shape

m_i, m_j	-	Storey masses computed
z_i, z_j	-	Heights of the masses m_i, m_j above the level of application of the seismic action (foundation or top of a rigid basement)
S_a	-	Unique spectral acceleration
S_v	-	Spectral velocity
S_d	-	Spectral displacement
V_i	-	Base shear at any point of i
W	-	Building dead weight plus likely live loads
α_i	-	Modal mass coefficient
Δ_{roof}	-	Roof displacement
PF_i	-	Participation factors for the first natural mode of the structure
$\phi_{1,roof}$	-	Roof level amplitude of the first mode

CHAPTER 1

INTRODUCTION

1.1 Introduction

Earthquake is one of the costliest natural phenomena which cause severe damages to the structures and infrastructures. Lots of lives, property and economic losses were reported due to past earthquake incidents. The world strongest earthquake occurred in Valdivia, Chile in 1960 with magnitude of 9.5 killed estimated 1600 people with 2,000,000 people were left homeless and $800 million total cost of damage. In 2017, the strongest earthquake was recorded with 8.2-magnitude hit Chiapas, Mexico. This marked the strongest earthquake Mexico has experienced in 100 years. Following in the same month, another earthquake of 7.1-magnitude struck Puebla, Mexico with 650 km distance of epicenter from the previous one. The total number of 286 people were reported killed in these two earthquakes and estimated $2 billion for the economic loss.

Earthquakes occur along the plate tectonic edges and along faults. Malaysia is located at the inactive Sunda plate in the plate tectonic. The west of Malaysia (Peninsular) is located in between two major boundaries of tectonic plates; Australia plate and Eurasian plate meanwhile east of Malaysia (Sabah & Sarawak) is placed between Philippine Sea plate and Eurasian plate. Figure 1.1 shows the location of Malaysia in the plate tectonic boundaries. Even though Malaysia is not located along plate tectonic edges and considered in the low seismicity zones, the tremor of earthquakes from neighbouring countries such as Indonesia and Philippine sometimes can be felt (Abdul Rahman, 2015). In 2004, an earthquake with magnitude of 9.0 struck Acheh, Indonesia killed 76 people in Peninsular Malaysia with many properties were destroyed when tsunami hit along the northwest coastal areas of Perlis, Kedah, Penang and some part of Perak (Adiyanto and Majid, 2014). Furthermore, according to Che Abas (2001), east Malaysia also affected by large earthquakes located over Southern

Philippines and in the Straits of Macassar, Sulu Sea and Celebs Sea. Based on Modified Mercalli (MM) scale, the maximum observed intensity was VII. Figure 1.2 shows major earthquake events that have been occurred around Malaysia region since 1972.

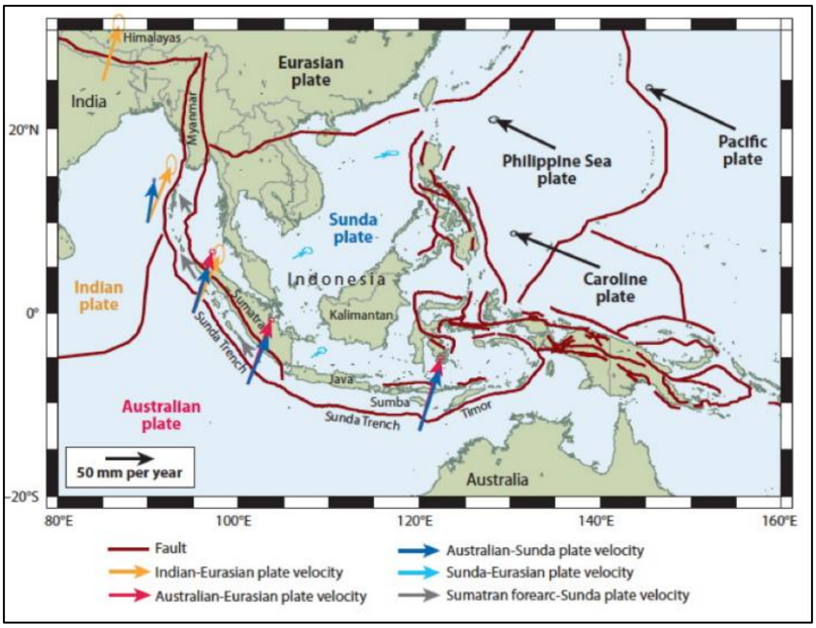

Figure 1.1 Location of Malaysia in plate tectonic (MacCaffrey, 2008)

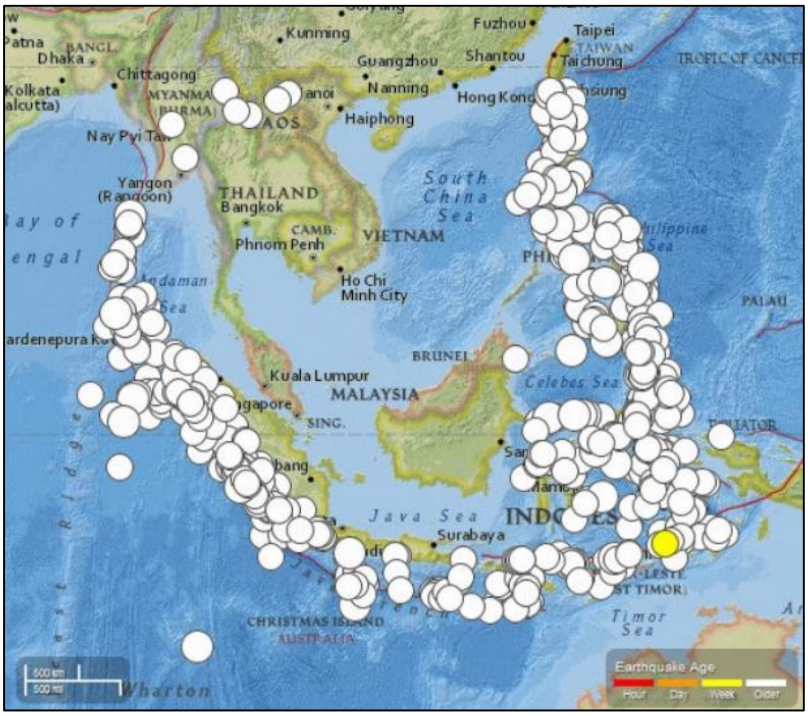

Figure 1.2 Major earthquake events since 1972 (Adiyanto and Majid, 2014)

In 2015, Malaysia itself has experienced an earthquake of 5.9 magnitude in Ranau which had killed 18 people and caused RM94.8 million cost damages to the structures including mosques, schools, hospitals, Ranau police headquarters and infrastructures (The Malaymail Online, 2015). Even though Ranau earthquake was not considered as a high-level earthquake, however, the damages were quite severe on the structures. This is mainly due to the structural design implemented in Malaysia does not incorporate with seismic criteria. Figure 1.3 shows the effect of Ranau earthquake on the structures.

Figure 1.3 Effect of Ranau earthquake in 2015 (Majid et al., 2017)

In the past design practices, Malaysia has been using British Standard (BS) codes which does not specify any seismic provision. In 2006, Malaysia has taken the steps to adopt Eurocodes following United Kingdom (UK). Even though, the awareness of implementing Eurocodes has been spread around consultant firms and educational institutions, the common design practices that being use nowadays are still BS codes (Chiang, 2015). For seismic design purposes, since earthquake in Acheh has affected Malaysia as well, Institute of Engineers Malaysia (IEM) started to develop the draft of National Annex for EC8 in 2007 and in 2017 the Malaysia National Annex (NA) to EC8 has been published. It is important for engineers and researchers to study the effectiveness of newly developed annex.

Therefore, the aim of this study to analyse the seismic performance of reinforced concrete building when it is designed according to Malaysia NA to EC8 in terms of cost and safety. The non-linear static pushover analysis will be carried out to produce the capacity curve of the structure and demand response spectrum curve to obtain the performance point of the structure. This performance point act as an indicator to engineers to predict the target displacement the structure likely to have in the event of earthquake. (Freeman, 2004).

1.2 Problem Statement

The current design of concrete building in Malaysia does not include the provision of the seismic because Malaysia's location is located at inactive seismic fault zones. The recent earthquakes in Sabah and several tremors from neighboring countries such as Indonesia and Philippines intrigued a major concern towards the building design to withstand such load. In 2017, Malaysia has produced its own NA to EC8 to suit Malaysia's condition for the seismic design. However, the question arises regarding the economic effect in term of construction cost if seismic design to be implemented in the Malaysia construction industry.

According to Chiang and Arshad (2015), the former Senior Director of the Civil and Structural Engineering Branch of the Public Works Department, Dato' Ir. Dr. Abdul Aziz b. Haji Arshad stated the main concern of the seismic design is the expected increase in cost to incorporate earthquake resistance elements in building and structural designs. The clients mainly ministries and government agencies are well aware that Malaysia is located in low seismic region and with additional cost will be imposed in the new design makes it hard to convince them that it is significant to include earthquake requirements (Chiang and Arshad, 2015). Hence, it is important to carry out comparative studies to justify the cost increase in the seismic design due to the National Annex and to know to what extent the design based on the newly developed annex can enhance the safety of new construction in Malaysia.

Few studies have been carried out related to the construction cost when seismic provision is incorporated in the design. Elawady (2017) has evaluated the seismic performance of the building in Portugal for different ductility classes meanwhile Drivas (2014) conducted a research for cost evaluation of seismic design structure based on ductility class for building in Sweden. Furthermore, two more researches have been conducted for buildings in Malaysia in order to see the cost difference for seismic design. Ramli et al (2017) conducted a similar research to estimate construction cost for building with non-seismic design and seismic design with different ductility classes meanwhile Adiyanto and Majid (2014) focused on the cost impact on low ductility class building when they were subjected to different peak ground acceleration and behaviour factor. The results obtained were quite different even though similar basis of design was used which using EC8. Therefore, these studies require further investigation and comprehensive research and for building in Malaysia, Malaysia NA to EC8 shall be used as the basis of design

Hence, this study will focus on the seismic performance of the reinforced concrete building in Malaysia when it is designed based on BS8110 and Malaysia NA to EC8. The typical structural building layout is selected and several parameters will be considered in this study such as the peak ground acceleration, number of building storey, ductility class and type of soil. The main outcome of this research is the cost comparison between conventional design (BS8110) and seismic design (Malaysia NA to EC8). Furthermore, the performance of the building designed based on Malaysia National Annex will be determined by non-linear static pushover analysis in order to produce the capacity curve of the structure and demand response spectrum curve to obtain the performance point of the structure.

1.3 Objective of the study

The main purpose of this study is to evaluate the seismic behavior of the building when subjected to the gravity load and earthquake load with regards to the new national annex developed by Malaysia. This study will focus on the following objectives:

(a) To design short and mid-rise RC buildings based on the Malaysian National Annex and compare their required reinforcement quantities with conventional design

(b) To obtain seismic capacity curves of the designed RC buildings and compare them with those obtained from conventional design

(c) To determine seismic performance points of the designed RC buildings and compare them with those obtained from conventional design

(d) To evaluate the effect of ductility class, soil type and number of stories on the construction cost and seismic performance of RC buildings in Malaysia

1.4 Scope of Study

This study is limited to following criteria:

i.	Type of building	:	RC Moment Resistance Frame
ii.	Number of storey	:	3-storey and 6-storey buildings
iii.	Code	:	BS8110 (Conventional) EC8 with Malaysia NA (Seismic)
iv.	Peak ground acceleration	:	0.1g
v.	Location	:	Peninsular Malaysia
vi.	Ductility	:	Low ductility class (DCL) and Medium ductility class (DCM)
vii.	Type of soil	:	Stiff soil (type A) and soft soil (type D)
viii.	Type of analysis	:	Nonlinear static pushover analysis
ix.	Compressive strength of concrete	:	30MPa
x.	Yield and Ultimate tensile strength of reinforcement	:	400MPa & 650MPa
xii.	Software	:	ETABs 2016

1.5 Significance of Study

The significance of this study is to determine the cost estimation of reinforced concrete building when it is designed using conventional method and using new developed Malaysia NA based on EC8. In seismic design, few parameters will be evaluated such as ductility class, number of building storey and ground type. The outcome of this study will provide a baseline for engineers and clients to estimate and justify the cost increment when seismic provision is included in the design. Furthermore, this study also will assess the seismic performance of the designed reinforced concrete building by using non-linear static analysis where the capacity of the building and demand from ground motion will be evaluated. The result from the non-linear analysis will provide indication in terms of safety degree of building when it is designed according to Malaysia NA to EC8.

1.6 Thesis Organization

This thesis is presented in 5 chapters. Chapter 1 explained the introduction and motivation of the study. The limited scope of work for this study is listed and the significance of study is explained.

Chapter 2 of this thesis presents the literature review which provides a background information of seismic activities in Malaysia and a brief introduction of Eurocode 8 and the changes in parameters provided by Malaysia NA. Besides, in this chapter, the fundamental of non-linear static pushover analysis is explained. The comprehensive finding regarding the previous researches related to the cost estimation studies for seismic design is also discussed.

Chapter 3 of this thesis shows the case study of three and six storey of reinforced concrete building are designed by using BS8110 and Malaysia National Annex to Eurocode 8. Few parameters are considered for the seismic design; ductility class, number of building storey and ground type. Besides, the procedures of non-linear static pushover analysis to obtain capacity curve and performance point of the structure are stated.

In Chapter 4, the required reinforcement quantities for buildings designed with BS8110 and Malaysia NA to EC8 will be presented. The comparison cost graphs will be established to present the cost difference between conventional designed building and seismic designed buildings. Furthermore, the capacity curves and performance points for all types of buildings will be obtained. All results will be discussed in this chapter in order to achieve all objectives presented in this study.

Chapter 5 of this thesis will present the main conclusion of this study and provide recommendation for future works.

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