SEISMIC PERFORMANCE OF LOW DUCTILE RC FRAME DESIGNED IN ACCORDANCE WITH MALAYSIA NATIONAL ANNEX TO EUROCODE 8

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Vafaei for his invaluable advice, guidance and his enormous patience throughout the development of the research.

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ABSTRACT

Eurocode 8, BS EN 1998-1:2004 is specifying Class II ordinary buildings shall be designed to interstory drift limit with displacement reduction factor, v=0.5 at damage limitation. However, Malaysia National Annex, MS EN 1998-1:2017 is specifying a more linear requirement, where no damage limitation limit state check required for Class II ordinary buildings. Historical events and past studies showed that Malaysia is expose to great seismic risk under both long-distance and near fault earthquake. Past researches reported that low ductile RC frame with infilled walls and ground floor soft story has greater tendency to experience brittle failure in vertical elements. This is due to strong column weak beam and excessive story drift. This study investigates seismic performance of residential buildings built with low ductile infilled RC frame with drift uncontrolled in Malaysia. Seismic performance (plastic hinge formation, base shear, displacement, story drift) of structural elements (columns and beams) and non-structural elements (infill wall) were investigated using non-linear static pushover analysis. At performance point, only immediate occupancy, IO plastic hinges founded in column and beams for all buildings cases which implies that seismic performance of buildings are not affected by storey, drift controls and soil types. At performance point, formation of collapse prevention, CP plastic hinges in infill walls are significant in drift uncontrolled building than drift controlled building and on soft ground relative to stiff ground. In short, results indicate that after a design earthquake, vertical and lateral force resisting systems of all buildings studied retain nearly all their pre-earthquake strength. However, infill walls experience extensive damage. According to damage performance evaluation, 4, 7 and 10 story low ductile RC frame with infilled walls and ground floor soft story with drift controlled and drift uncontrolled conditions, Class II ordinary buildings built on stiff soil and soft soil in Malaysia are not achieving intended targeted structural performance level required, life safety under design earthquake.

ABSTRAK

Eurocode 8, BS EN 1998-1: 2004 menetapkan bangunan biasa Kelas II akan dirancang untuk had drift antara tingkat dengan faktor pengurangan anjakan, v = 0.5 pada had kerosakan. MS EN 1998-1: 2015 menetapkan syarat yang lebih linear, tidak perlu pemeriksaan keadaan had kerosakan untuk bangunan biasa Kelas II. Sejarah dan kajian terdahulu menunjukkan bahawa Malaysia terdedah kepada risiko gempa bumi akibat gegaran jauh dan gegeran tempatan. Penyelidikan yang lalu melaporkan bahawa kerangka RC mulur yang dilengkapkan mengalami kerosakan teruk dan rapuh secara tiba-tiba dalam elemen menegak kritikal utama kerana kesan tiang lemah rasuk kuat dan pesongan berlebihan dari tingkat lembut. Kajian ini menyelidiki prestasi bangunan kediaman yang dibina dengan rangka RC diisi dengan mulur rendah tanpa kawalan drift di Malaysia. Prestasi seismik elemen struktur (tiang dan rasuk) dan elemen bukan struktur (dinding pengisi) disiasat menggunakan analisis tolakan statik bukan linier. Hasil kajian menunjukkan bangunan 4, 7 dan 10 tingkat dengan mulur rendah lembut tingkat tanpa kawalan drift dibina di atas tanah kaku dan tanah lembut, setelah gempa bumi, tiang and rasuk mempunyai hampir sama kekuatan pra-gempa. Tetapi, dinding pengisian mengalami kerosakan teruk. Sesuai dengan penilaian prestasi kerosakan daripada ASCE 41-06: 2007 struktur perspektif anggota struktur (tiang dan rasuk) dan anggota bukan struktur (dinding pengisi), 4, 7 dan 10 tingkat dengan mulur rendah lembut tingkat dengan dan tanpa kawalan drift dibina di atas tanah kaku dan tanah lembut tidak mencapai tahap prestasi struktur yang disasarkan, keselamatan nyawa setelah keadaan gempa bumi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADRS	-	Acceleration displacement response spectra
ASCE	-	American Society of Civil Engineers
ATC	-	Applied Technology Council
CP	-	Collapse prevention
CSM	-	Capacity spectrum method
DCM	-	Displacement coefficient method
EC8	-	Eurocode 8
FEMA	-	Federal Emergency Management Agency
IO	-	Immediate occupancy
LS	-	Life safety
Mw	-	Moment magnitude
NDP	-	National determined parameter
NLSP	-	Nonlinear static pushover
PGA	-	Peak ground acceleration
RC	-	Reinforced concrete
SDOF	-	Single degree of freedom
SFZ	-	Sumatran fault zone
SSZ	-	Sumatran subduction zone

LIST OF SYMBOLS

v	-	Reduction factor
fy	-	Yield strength of reinforcement
Tn / T_1	-	Natural period
Vs	-	Basic wind speed
K_s	-	Post-elastic stiffness
K_e	-	Effective elastic stiffness
V_y	-	Intersection point of post-elastic stiffness and effective stiffness
T_e	-	Effective fundamental period
β	-	Lower bound factor
H	-	Building height
d_r	-	Design interstory drift
X-Dir	-	Push uniform x direction in nonlinear static pushover load cases
X-M Dir	-	Push uniform mode shape x direction in nonlinear static pushover load cases

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Before the incident of 2004 Indian Ocean Tsunami and 2015 Ranau Earthquake Malaysia is believed to be a country free from natural disaster. However, in 2001, Malaysian Seismological Division reported that West Malaysia (Peninsular) and East Malaysia (Sabah & Sarawak) are susceptible to earthquake tremor from neighbouring tectonic plate and local fault respectively.

Peninsular Malaysia is situated on a tectonically stable Sunda Plate. However, it is located nears to 2 seismically active plate which is Indian-Australian Plate on the West and close to Eurasian & Philippine Plate on the East. Peninsular Malaysia is located 300-600 kilometers from the very seismic active Sumatran Subduction Zone as shown in Figure 1.1 and Figure 1.2. Figure 1.2 shows that multiple earthquakes with magnitude Ritcher Scale up to 9.0 Mw has been happened up to year 2000 was originated from Sumatran Subduction Zone and Sumatran Fault (Rosaidi, 2001). Building in Penang, Ipoh, Johor Bahru, Port Klang and Kuala Lumpur and Selangor been shocked by these far-field earthquake. Evident to former, The Star newspaper reported that at least 800 residents of 2 blocks of condominiums in Johor Bahru were evacuated after tremors were felt in March 2016. Over 5500 residents at multiple high-rise apartments in Kuala Lumpur, Malacca and Johor Bahru were evacuated after tremors from massive earthquake happened to Western coast of Indonesia’s Sumatra island on September 2017 (The Star, 2017).

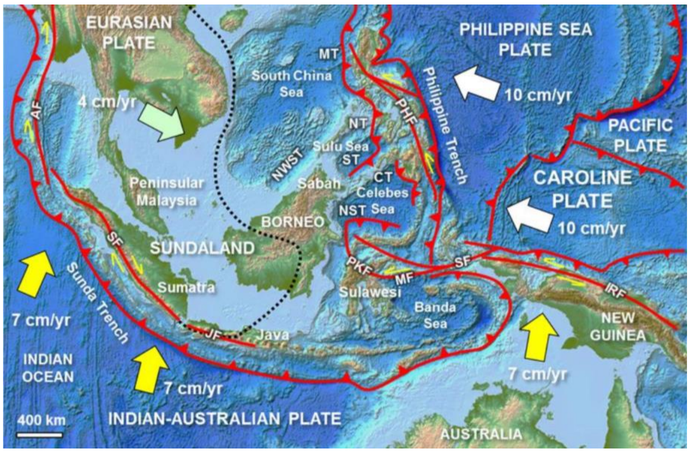
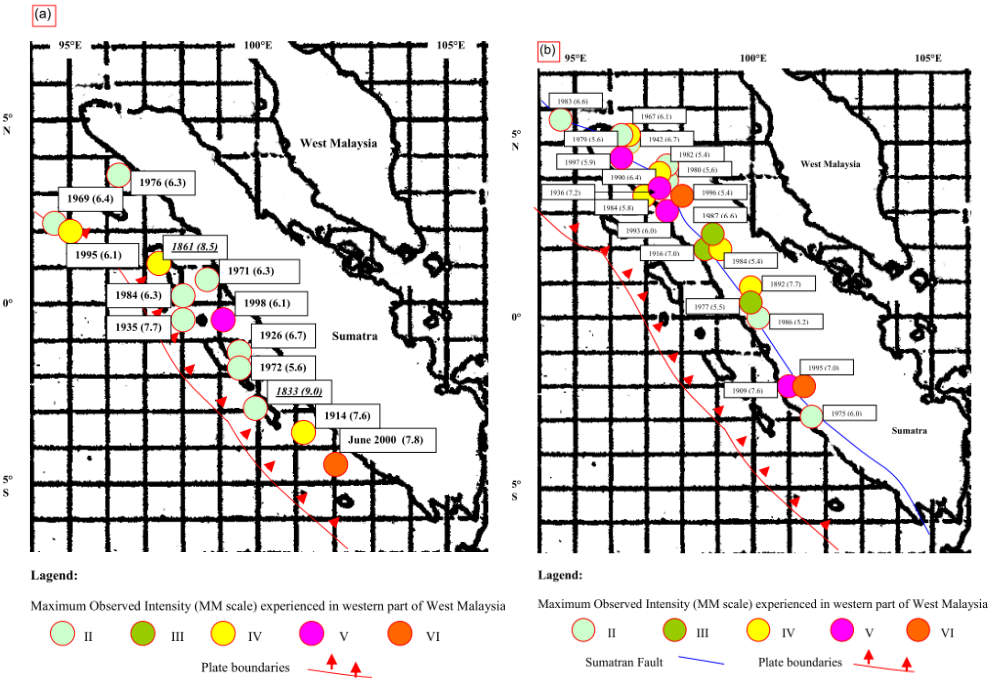


Figure 1.1 Tectonic Plate of Southeast Asia (Tongkul, 2018)



(a) (b)

Figure 1.2 Maximum observed intensity (Mw scale) experienced in Western part of Peninsular Malaysia due to (a) From Sumatran subduction zone (b) From Sumatran fault (Rosaidi, 2001)

In 2015, a research was conducted by Sun and Pan reported that far-field earthquake wave from Sumatra is expected to be amplified by soft surface materials and posts serious damage to buildings in Peninsular Malaysia. The similar phenomena of distant earthquake wave amplified by soft soil basin was happened to Mexico City on year 1985 which caused 4000 people lost their lives, 100,000 people were left homeless, 400 buildings were destroyed, and 3200 buildings were damaged (Mayoral et al., 2019).

In year 2013, Aminaton et al. reported that Peninsular Malaysia was experiencing local earthquakes since year 2007 as depicted in Table 1.1. These local earthquakes were believed from reactivations of ancient inactive fault resulted of intraplate stress built up after 2004 Indian Ocean Earthquake with magnitude Mw 9.1. Therefore, Peninsular Malaysia is regarded expose to far field earthquake as it is occasionally affected by earthquake tremors from Sumatran fault and Sumatran Subduction Zone and also local fault earthquake.

Table 1.1 Local earthquake occurrences in Peninsular Malaysia (Aminaton et al., 2013)

Date	**Case**	**Location**	**Number of Earthquake**
2007-2009	24	Bukit Tinggi, Kuala Lumpur	24
2009	4	Kuala Pilah, Perak	4
2009	1	Jerantut, Pahang	1
2009	1	Manjung, Perak	1
2010	1	Kenyir Dam, Terengganu	1
2012	1	Mersing, Johor	1

East Malaysia, Sabah & Sarawak were reported to experienced far-field earthquake from Southern Philippines, Straits of Macassar, Sulu Sea, Celebes Sea and earthquake from active local fault. Figure 1.3 shows that Sabah was structed by multiple earthquakes induced from local active fault with magnitude of Ritcher scale 3.0 Mw to 6.5 Mw between year 1995 to 2015. A highlight from Sabah earthquake history, a severe earthquake with 6.0 Mw was happened on June 2015 at Ranau. This caused RM100 million damage and 18 people were killed due to rock fall (The Star, 2015).

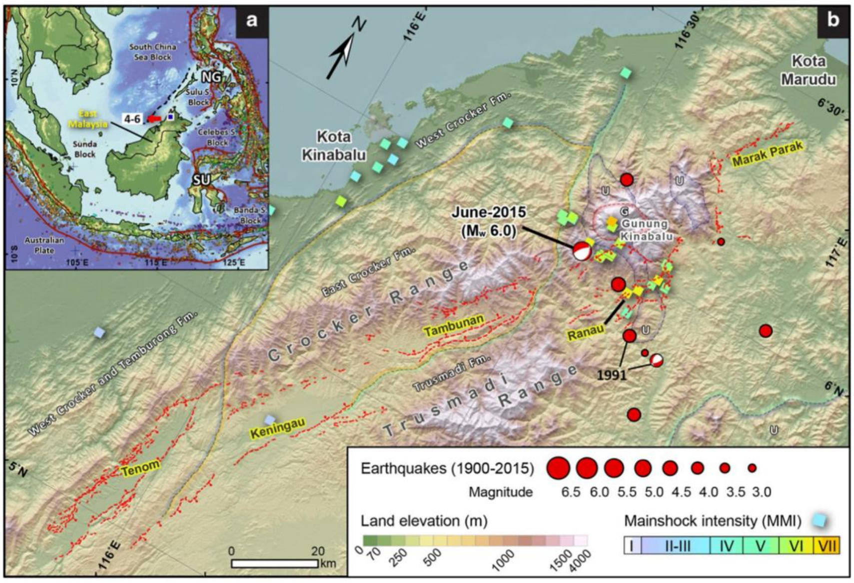


Figure 1.3 (a) Regional tectonic map of Southeast Asia (b) Topography of Sabah of recorded earthquake and geomorphologically evident active fault in the region (C.Alih and Vafaei, 2019)

East of Sabah is exposed to risk of tremors originated from Southern Philippines and Celebes sea. This is evident by a recent report from The Star newspaper, where on October 2018 about 24 earthquakes with magnitude of 4.4 Mw to 4.9 Mw have struck Mindanao, Sulawesi and Mihahass which these area is nears to Sabah. At the same period, a 1.2 Mw local earthquake struck Northeast of Ranau as marked as depicted in Figure 1.4.

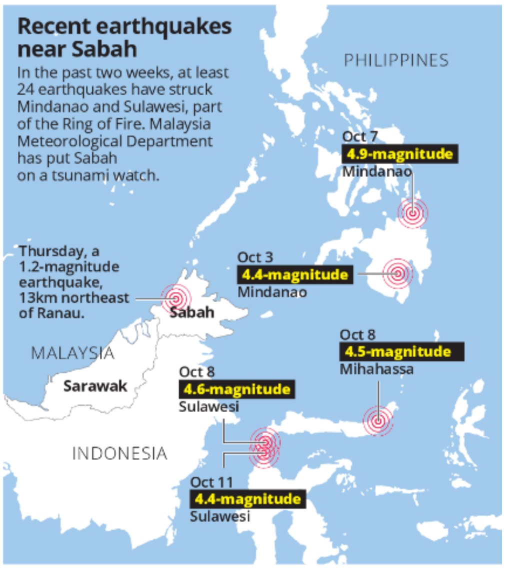


Figure 1.4 Earthquakes near Sabah (The Star, 2018)

Furthermore, the Eurasian Plate includes Sundaland and South China Sea Basin is moving south-east at a rate of about 4 cm/yr. The Indian-Australian Plate is moving north a rate of about 7 cm/yr. Philippine Sea-Pacific Plate is moving north at about 10 cm/yr. Movement of tectonic plate on Southeast Asia was shown in Figure 1.5. The relatively parallel plate motion of the tectonic plates is largely accommodated by lateral strike-slip faulting across the Sumatran fault and with recent geomorphic analyses implies that Sabah is likely affected by this contractional tectonic and several local micro faults was generated due to this movement (Felix Tongkul, 2018).

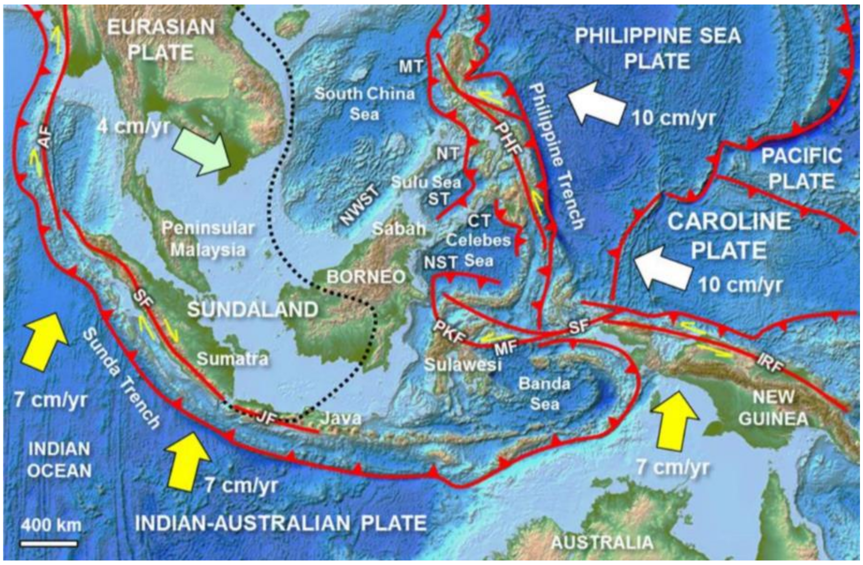


Figure 1.5 Tectonic Plate of Southeast Asia (Felix Tongkul, 2018)

Research findings show that Malaysia is surrounded by seismically active plate, phenomena of distant earthquake wave from Sumatra to West Peninsular Malaysia will be amplified by soft soil, local active fault line founded in Peninsular & East Malaysia. Several earthquake historical events suggest that Malaysia is not forever immune to seismic risk. Earthquake impacts to existing buildings and new buildings in Malaysia should such event occur may also be tremendous due to the countries' in general lack of earthquake preparedness and resilience (Fakhrul et al., 2004). Therefore, Malaysia is exposed to potential severe damages due to earthquake including injury to victim, loss of lives, physical damage to building structures, infrastructures, environmental changes, negative impact to socioeconomic and others.

1.2 Problem Statement

Due to rarity of strong earthquake in Malaysia, lack of building earthquake resistant requirement is emphasized by local authority. Moreover, most buildings in Malaysia is generally designed according to gravity design code (BS 8110, MS EN 1992) and wind design code (BS 6399, MS EN 1991) with low ductile detailing considered in their construction (C.Allih and Vafaei, 2019).

Seismic design code EN 1998 “Design of Structures for Earthquake Resistance”, Eurocode 8 (EC8) is available since year 1994 with National Determined Parameters (NDPs) is left open for local national choices due to differences in geological, geographical conditions, design cultures, and others. However, Malaysia National Annex reference to BS EN 1998 was not established for building design until year 2015.

In year 2015, Malaysia National Annex reference to BS EN 1998-1:2004, Part 1: General rules, seismic actions and rules for buildings is published by Technical Committee of Earthquake under Malaysia Industry Standards Committee to provide appropriate seismic design parameters to Malaysia building engineering industry. Information of 56 NDPs is published in Malaysia National Annex (MS EN 1998-1:, 2015) by Technical Committee to suit Malaysia seismic design condition.

A highlight of finding from comparing design code of BS EN 1998-1: 2004 with Malaysia National Annex is significant difference founded in requirement of damage limitation considering building interstory drift limit as shown in Table 1.2. EC8 is specifying all building class shall be designed complying with interstorey drift limit in clause 4.4.3.2 with displacement reduction factor, v at damage limitation state accordingly. While, Malaysia National Annex is specifying that only class IV buildings, lifeline-built facilities specified in Table 1.3 required to be designed for interstory drift limit at damage limitation limit state based on a return period of 475 years and $v = 0.5$ is to be adopted. Concern of whether building class I, II, III designed accordance to Malaysia National Annex will still achieve intended targeted structural building performance, life safety under design seismic is spurred.

Table 1.2 Reduction factor for building displacement at damage limitation state, Malaysia values for Nationally Determined Parameter (MS EN 1998-1:, 2017)

Clause	Nationally Determined Parameter	Eurocode Recommendation	Malaysia’s Decision
4.4.3.2(2)	Reduction factor, v for displacement at damage limitation limit state	Class I and II: v = 0.5 Class III and IV: v = 0.4	Only Class IV buildings need to be checked for damage limitation limit state based on a return period of 475 years. V = 0.5 is ot be adopted

Table 1.3 Classification of building importance class (MS EN 1998-1, 2017)

Building Importance Class	Recommended Building Categories
I	Minor construction
II	Ordinary buildings (Individual dwellings or shops in low rise buildings)
III	Buildings of large occupancies (condominium, shopping centres, school and public buildings)
IV	Lifeline built facilities (Hospitals, emergency services, power plants and communication facilities)

Most of residential buildings in Malaysia featured with open space ground floor to facilitate driveway and parking. Infill walls above ground floor generally are not adequately separated from reinforced concrete frame which contribute to unintended lateral stiffness to a building. These infill walls are usually considered as non-structural element and are not included in analytical models (Konstantinos K and Asimina A, 2019). Absence of infill wall at ground floor coupled with non-structural infill walls at upper floors leads to differentiate stiffness and strength between the upper floors and the open space ground floor. The aforementioned conditions have caused lateral displacements mostly concentrate on their first floor rather than being distributed along height of the structure (C. Alih and Vafaei, 2019). Subsequently, building inter-storey drift at first floor is expected to be detriment great as shown in Figure 1.6 due to building vertical irregularity, namely soft storey effect.

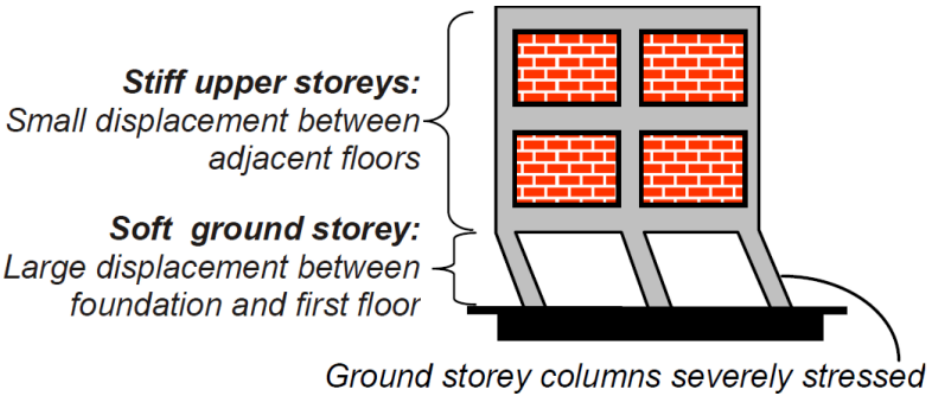


Figure 1.6 Soft storey effect

Soft-story building that caused significant inter-story drift issue often trigger the question of necessity conduct interstory drift check according to limitation requirement for all building class rather than Class IV building, lifeline facilities only as per requirement in Malaysia National Annex. Therefore, the aforementioned condition has initiated the research to investigate seismic response of local common low ductile infilled multi-storey residential building (Class II) with ground soft story feature that built on soft soil and stiff soil that are also susceptible to deep soil effects The drift uncontrolled frames to be investigated are designed to Malaysia National Annex to EC8 in complying with damage limitation requirement and achieve intended targeted structural building performance, life safety.

1.3 Research Objectives

This study is initiated on following objectives:

a) To investigate the failure mode and plastic hinge formation in the ground soft-storey RC framed buildings designed in accordance with the Malaysian National Annex to EC 8 (Drift Uncontrolled) and EC 8 (Drift Controlled) respectively.

b) To calculate the drift demand and capacity of ground soft-storey RC framed buildings designed in accordance with Malaysian National Annex to EC 8 and compare it with EC 8.

c) To establish seismic design recommendation for ground soft-storey RC framed buildings designed in accordance with the Malaysian National Annex to EC 8

1.4 Research Scope

The study is focusing on following scopes:

a) 4, 7, and 10 storeys of RC frame residential buildings (Class II) with regular in plan & elevation configuration and with ground-soft storey.

b) Each building comprises of 5 bays of 2.5m & 6m span (x-axis) and 3 bays of 5m span (y-axis), and typical story height of 3m except for the ground story having height of 4m. The total height of building is 13m, 22m and 31m respectively. Building layout is shown in Figure 3.2.

c) Masonry wall lift shaft is included for 7 and 10 storeys building as it is common to have elevator in building greater than 4 storey.

d) Low ductile ground soft-storey reinforced concrete (RC) infilled framed on soft and stiff soil accounting deep soil effect, designed in accordance Malaysia National Annex to EC8 (Drift Uncontrolled) and EC8 (Drift Controlled) respectively in Peninsular Malaysia.

e) Horizontal elastic response spectrum of ground types B (Stiff soil) and D (Soft soil) for Sabah with 5% damping and peak ground acceleration, PGA of 0.16g in MS EN 1998-1:2017 were considered in building analysis.

f) Low ductile building structures designed and detailed under envelope load combination of following:

   a. Gravity (BS 8110-1997) + Wind (MS 1553:2002) + Seismic (BS EN 1998-1:2004)

   b. Gravity (BS 8110-1997) + Wind (MS 1553:2002) + Seismic (MS EN 1998-1:2005)

g) Compressive cube strength of concrete, fcu (MPa):

   a. Beam and slab = 25

   b. Column = 30, 35, 40, 45, 50

h) Yield strength of reinforcement, fy: 460 MPa.

1.5 Significant of Research

Significant of this study is provided a brief finding whether low-ductile residential building (building Class II) with ground soft storey in Malaysia designed to Malaysia National Annex without considering drift limit can achieve intended targeted “life safety” structural building performance, under design seismic load.

Findings of this study is useful to Department of Standards Malaysia to evaluate whether it is necessary to tighten current requirement in Malaysia National Annex reference to Eurocode 8 from “to conduct interstorey drift limitation check for building Class IV, lifeline-built facilities only” to other building classes.

1.6 Organization of Chapters

This thesis documented the research work into 5 chapters as following:

a) Chapter 1 presented research background, problem statements and research objectives, research scope and significant of research.
b) Chapter 2 presented literature review and findings of past studies by other researchers.
c) Chapter 3 presented the methodology and engineering analysis.
d) Chapter 4 presented result of modal analysis, gravity, wind, and seismic (lateral force method analysis) and non-linear static pushover analysis of buildings studied.
e) Chapter 5 concluded the finding of this research work, technical suggestion and recommendations of future research work.
f) Finally, references and appendices were attached at the end part of this thesis.

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