COST ANALYSIS FOR EARTHQUAKE RESISTANCE DESIGN OF REINFORCED CONCRETE HIGH RISE OFFICE BUILDING IN PENANG

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UNIVERSITI SAINS MALAYSIA
2022

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering
Universiti Sains Malaysia

August 2022

ACKNOWLEDGEMENT

The completion of this dissertation signifies the completion of my Bachelor of Civil Engineering Study. I would want to acknowledge the individuals who have supported and assisted me in achieving the success of this project.

First and foremost, I would like to express the greatest gratitude to my supervisor, Ir. Dr. Shahrudin Shah Zaini, for his time, patience, encouragement, and invaluable advice throughout this project. Without the assistance and dedicated involvement in every uncertainties and obstacles throughout the process, the dissertation would not been possible to complete in time. I appreciated my supervisor had enhanced my seismic design knowledge through his advice. I'm extremely fortunate to have him as my supervisor.

Special thanks to IEM Penang Section Earthquake Sub-committee especially Ir. Chua Beng Seong who shared his invaluable expertise in ETBAS with me to aid in the completion of my analysis work. The analysis work would not be done without the contribution of Ir. Chua. Besides that, I would like to extend my heartiest appreciation to my coursemates, Tan Hong Yang and Daniel Lim Wei Ping, who shared their knowledge and assisted me in this project. I am glad to have them keep me motivated throughout the journey. Thank you to everyone for the valuable advice, support, assistance, and friendship.

ABSTRAK

Pulau Pinang mengalami beberapa siri gegaran daripada Gempa Bumi Sumatera dan Gempa Sumatera Selatan, masing-masing pada November 2002 dan Julai 2004. Disebabkan oleh insiden tersebut terdapat keraguan tentang integriti bangunan sedia ada di Malaysia yang telah direka bentuk tanpa mempertimbangkan beban seismik. Kajian ini dijalankan bertujuan untuk menilai kesan mempertimbangkan beban seismik terhadap keperluan bahan bagi anggota utama kerangka bangunan dan jumlah kos bahan berbanding beban bukan seismik. Model bangunan konkrit bertulang dengan ketinggian 35 tingkat, 40 tingkat dan 45 tingkat telah dianalisis dan direka bentuk dengan menggunakan pakej perisian ETABs V18. Untuk zon seismik yang rendah di Malaysia, kelas kemuluran rendah (DCL) telah digunakan untuk model dengan pecutan tanah puncak 0.05g. Jenis tanah yang telah dipilih ialah jenis tanah A, D Dan E yang menggambarkan keadaan tanah di Malaysia. Secara umumnya, keputusan menunjukan bahawa modal bangunan yang mempertimbangkan reka bentuk seismik menghasilkan jumlah kos bahan yang lebih tinggi berbanding dengan rekaan bukan seismik dan ini adalah benar untuk jenis tanah D dan E sahaja. Perbezaan peratusan kos dalam julat -0.9% hingga 2.0%. Julat perbezaan ini agak rendah dan tidak akan menjejaskan kos pembinaan bangunan tinggi di Pulau Pinang dengan ketara.

ABSTRACT

Penang Island experienced several series of tremors from the Sumatera Earthquake and South Sumatra Earthquake in November 2002 and July 2004, respectively. Due to these incidents, there are doubt about the integrity of the existing buildings in Malaysia that were designed without considering seismic load. This study is carried out with the aim to evaluate the effect of incorporating seismic load towards the material required for the main frame members and the total cost of materials. Reinforced concrete building models with 35-storey, 40-storey and 45-storey were analysed and designed using ETABs V18 software packages. Reflecting the low seismic zone in Malaysia, the ductility class low (DCL) was used for the building models with the peak ground acceleration 0.05g. The selected soil types were soil type A, D and E which reflecting the common ground conditions in Malaysia. In general, the results showed that building models incorporating seismic design resulted in higher total material cost compared to non-seismic design and this is particularly true for soil type D and E only. The percentage difference of cost was in the range of -0.9% to 2.0%. These range of difference is relatively low and will not significantly affecting the construction cost of high-rise buildings in Penang.

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LIST OF ABBREVIATIONS

2-D	Two- Dimensional
3-D	Three-Dimensional
DCH	Ductility Class High
DCL	Ductility Class Low
DCM	Ductility Class Medium
EC	Eurocode
EC 2	Eurocode 2
EC 8	Eurocode 8
IEM	Institute of Engineer Malaysia
MS	Malaysia Standard
NA	National Annex
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
SLS	Serviceability Limit State
USM	University Sains Malaysia

LIST OF SYMBOLS

a_gR	Reference peak ground acceleration on type A ground
a_g	Design ground acceleration on type A ground
EQ_x	Earthquake load in x-direction
EQ_y	Earthquake load in y-direction
F_b	Base Shear Force
f_{ck}	Characteristics compressive cylinder strength of concrete at 28 days
f_y	Yield strength of reinforcement
γ_I	Importance Factor
G_k	Permanent action
h	Average roof height of a structure above ground
h_i	Floor to floor height of the structure
q	Behaviour Factor
Q_k	Variable action
S	Soil Factor
T_1	Fundamental period of vibration of the building
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	Beginning of the constant displacement response range of spectrum
T_S	Site natural period
WL_x	Wind load in x-direction
WL_y	Wind load in y-direction

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquakes were among the most dangerous natural phenomena. A simple definition of an earthquake is the sudden movement of the earth's surface caused by the release of energy in the earth's crust (Awaludin and Adnan, 2016). Malaysia is geographically distant from active earthquake fault zone. Nonetheless, it is evident that the nation is surrounded by regions of high seismicity in the west, south, and east. This phenomenon is due to the occurrence of subduction zones between the Indo-Australian plate and the Eurasian plate in the west and south, and between the Eurasian plate and the Philippines plate in the east (Adiyanto and Majid, 2014). Figure 1.1 shows the location of Malaysia with respect to the surrounding tectonic plates.

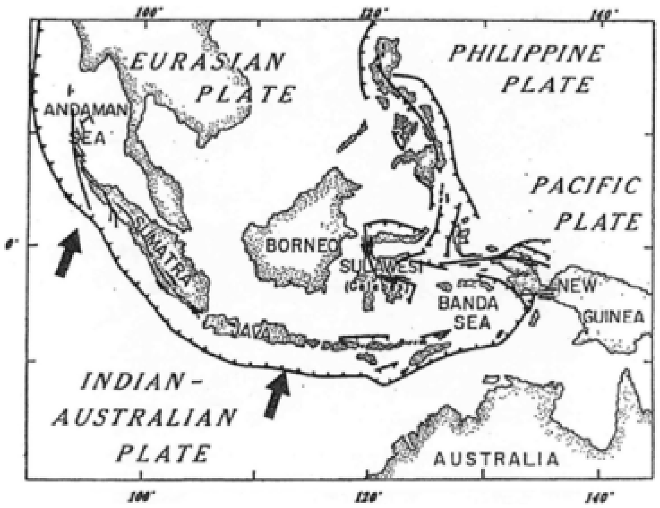
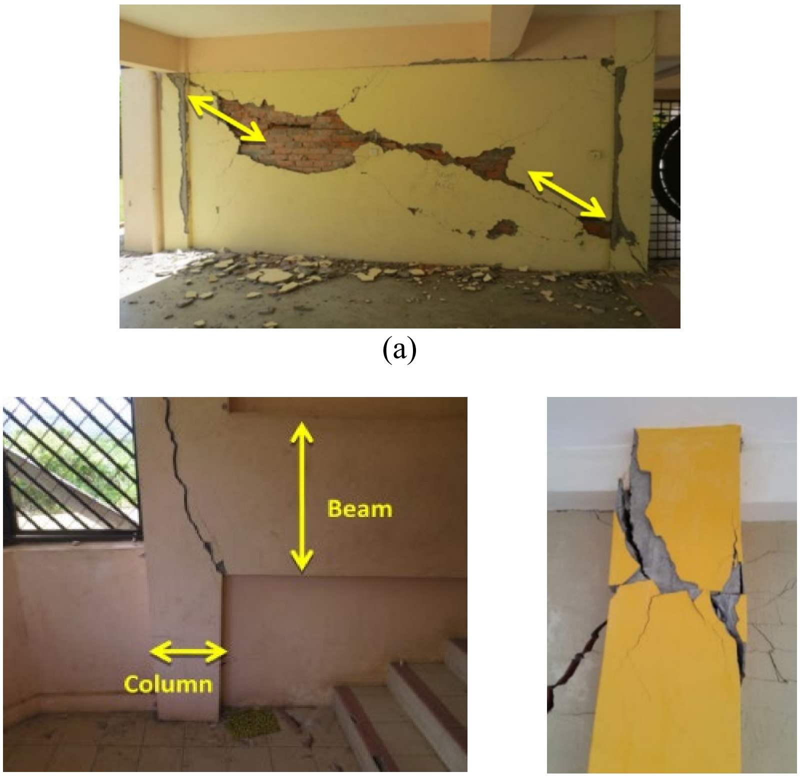


Figure 1.1: Subduction of Indo-Australian Plate into the Eurasian Plate (Tan et al., 2014)

Malaysia is affected by the long-distance earthquakes generated from neighbouring countries such as Indonesia that induced ground shaking and caused the vibration on buildings. Long-period structures such as high-rise buildings, major bridges, and oil and gas storage tanks are affected by the long-distance earthquakes (Avar et al., 2019). Local earthquakes in Peninsular Malaysia are caused by intra-plate fault which is the 80 km long fault line originated from Bukit Tinggi. A series of weak earthquakes recorded in the Bukit Tinggi indicates the possible reactivation of the fault line where more local earthquakes are prone to happen in the future (Tan et al., 2014). In case of East Malaysia, a local earthquake measuring Mw 5.9 struck Ranau, Sabah on 5 June 2015. In the past 45 years, this earthquake event was recorded to be the strongest local earthquake to strike Malaysia (Hong et al., 2020). This seismic incident had caused damage to the buildings in Ranau as shown in Figure 1.2.



(a)

(b) (c)

Figure 1.2: Damage to the building after 2015 Ranau earthquake showing (a) crack on the wall (b) cracks at beam-column joint and (c) shear failure on column (Alih and Vafaei, 2019)

The Malaysia Public Works Department agreed that seismic design consideration is important for new buildings in Malaysia (Adiyanto and Majid, 2014). Due to the fact that almost all buildings in Malaysia were designed according to BS8110 and MS EN-1992 that did not specify any seismic provision, the implication of adopting seismic design has raised a concern about the possible increase in construction cost especially on steel tonnage and concrete volume (Adiyanto et al., 2020; Hong et al., 2020; Roslan et al., 2019). The state of Penang for example, through the Institution of Engineers Malaysia (IEM) Penang Branch (Earthquake Engineering Sub-Committee), has started to venture into the cost evaluation of buildings for the incorporation of seismic design under local conditions. This study is a collaboration with IEM Earthquake Sub-Committee, Penang Branch, and conducted to compare the cost of main structural frame members between non-seismic and seismic design of high-rise buildings.

1.2 Problem Statement

Penang Island experienced several tremors from the Sumatera Earthquake and South Sumatra Earthquake in November 2002 and July 2004, respectively. These earthquakes had caused minor tremors that were felt by the locals. Although Penang is located in a low seismic region, the state is the second highest population density in Malaysia and consists of hundreds of high-rise buildings. The amplification of long-period seismic waves by local soft alluvium deposits, far-field earthquakes may pose a potential risk to high-rise buildings that could be damaged by this event. This is due to the fact that most of the buildings in Malaysia were designed following the requirements stated in BS8110 or MS EN 1992. It is still unclear to what building height that the seismic design will govern the cost due to the fact that buildings need to be designed for wind load (lateral force) as well. As such, a systematic study needs to be conducted to determine the change in the construction cost of high-rise buildings structure in Malaysia in particular, at area where high-rise buildings are a common construction practice, such as Penang. The findings of this study will widen the range of economic implications for adopting seismic design, particularly for local high-rise buildings. The information will aid building professionals in preparing accurate costing and determining the suitable selling/renting price.

1.3 Objectives

The objectives of this study are listed below:

i) To compare the material required for the main frame members subjected to seismic and non-seismic design with varying soil types.
ii) To evaluate the total material cost for incorporating seismic design.

1.4 Scope of work

In this study, the reinforced concrete office building models are analysed and designed with the aid of ETABs V18 software package. The quantity of the relevant structural materials is extracted with the aid of CSiDetails. The office building's plan dimensions are set to be 27m x 177m, with different heights designated as 35-storey, 40-storey, and 45-storey. All initial parameters such as beams, columns, slabs, and shear walls, peak ground acceleration and wind speed are provided by IEM Penang Branch. In the case of non-seismic design, the lateral force is in the form of wind load in accordance with MS 1553:2002. Since this study is a collaboration with the IEM Penang Branch, it covers the modelling, analysis, design, and taking-off exercise of rectangular office building models with various heights that are subjected to non-seismic and seismic load.

This study only addresses the material demand of the building's major frame: beam, column, and wall in terms of concrete volume and reinforcement weight. The overall material cost of the main frame is calculated by multiplying the relevant unit price with the sum of all materials evaluated.

1.5 Significance of Study

This study compares the costs of the main frame of a building that is subjected to non-seismic and seismic loads. Several building heights with varying PGA values are chosen. The findings of this research expand the range of cost analysis data currently available in the open literature. As a result, the potential benefit of this study contributes a better understanding to the construction players especially for preparing construction budget and setting an accurate selling cost of a property.

1.6 Dissertation Outline

This dissertation comprises of further four chapters and organized as follows:

Chapter 2: Literature Review.

This chapter portrays an overview of the seismic activity in Malaysia as well as the factors that contribute to structural damage during earthquake events. Furthermore, the seismic design approach for reinforced concrete buildings using Eurocode 8 and Malaysia National Annex is presented, and previous research-based studies on cost considerations for non-seismic and seismic design are reviewed accordingly.

Chapter 3: Methodology.

This chapter demonstrates the processes for modelling, analysis, and design of rectangular reinforced concrete buildings subjected to non-seismic and seismic loads, and the method to estimate the material cost by using ETABs V18 and CSiDetails. Furthermore, it also describes about the models, building data, load intensity, load combination and other relevant parameters required for the analysis and design of the office building models adopted in this study.

Chapter 4: Results and Discussions

The findings of all building models incorporating non-seismic or seismic design are presented in this chapter. This chapter calculates and presents the % difference in concrete volume and reinforcement tonnage for beam, column, and wall between non-seismic and seismic designs. Furthermore, the total material cost of the structural frame is calculated and compared.

Chapter 5: Conclusions and Recommendations.

This chapter summarizes the important findings of this research based on the objectives of the study before the conclusion can be made. Recommendations for further work are presented to further appreciate the study on MS EN:1998 of the buildings.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter starts with brief presentation pertaining to the seismic activities around Malaysia and the factors that affecting the level of structural damage during earthquakes. In addition, the overview on the design approach for reinforced concrete building using Eurocode 8 and Malaysia National Annex is highlighted. This chapter also reviews the past research works on the cost comparison between non-seismic and seismic design of RC buildings under the influence of various seismic design considerations.

2.2 Seismicity of Malaysia

Malaysia is geographically rested on a stable Sunda platform on the Eurasian plate, bordered by two seismically active plate boundaries, namely, the Indo-Australian Plate and Pacific-Philippine Plate (refer to Figure 2.1). In addition, as shown in Figure 2.1, Malaysia is located outside of the Ring of Fire and can be considered as relatively far away from the active volcanoes that are formed along the tectonic plat boundaries. However, the high rise building in several cities of Malaysia experienced tremors due to Sumatra earthquakes (Awaludin and Adnan, 2016).

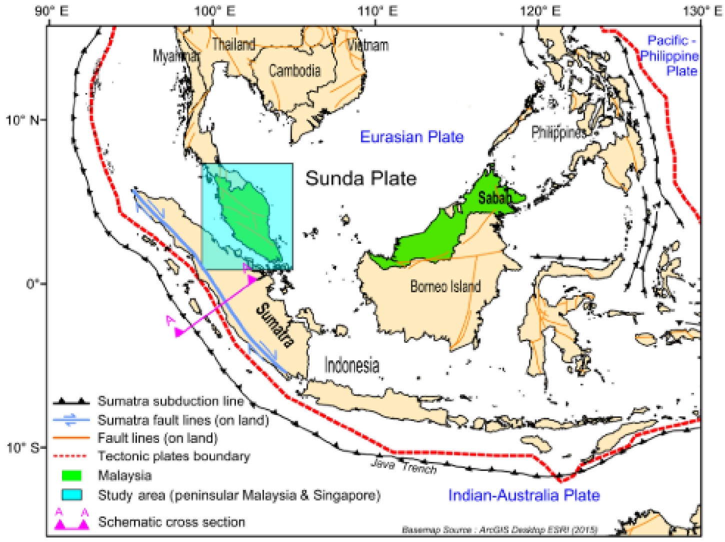


Figure 2.1: Location of Malaysia on Sunda plate and its nearby seismic sources (Loi et al., 2018)

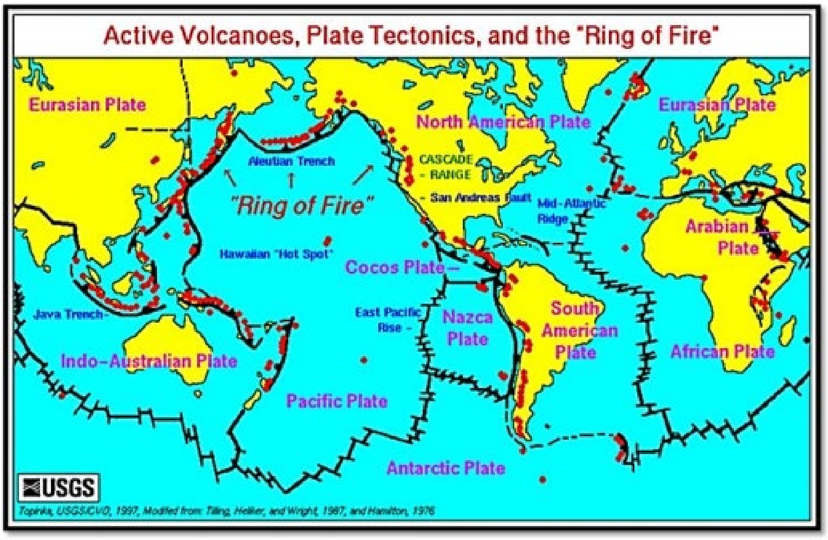


Figure 2.2: Active Volcanoes, Plate Tectonics, and the Ring of Fire around Malaysia (Azmi et al., 2021)

Malaysia still experiences ground movement due to the earthquakes from the neighbouring country especially Indonesia. Particularly, residents within the West Coast of Peninsular Malaysia felt the tremors due to the seismic activities from active Sumatran sources (Loi et al., 2018). Sumatran subduction and fault zones are the two active tectonic features of far-field earthquakes that are near to Malaysia. The mechanism of the major seismic activities due to the tectonic plate movement near Sumatra Island is shown in

Figure 2.3. The seismic waves produced by the Sumatera earthquake travel a long distance before reaching the Malaysia bedrock. The high frequency earthquake waves were quickly dampened out during propagation, while the low-frequency earthquake waves were more resistant to energy dissipation, hence, travelled a greater distance. As a result, seismic waves hitting the bedrock of Malaysia are rich in low-frequency wave, and when they spread upward through soft soil sites with a period similar to the prevailing period of seismic waves, they are intensified due to resonance (Balendra and Li, 2008).

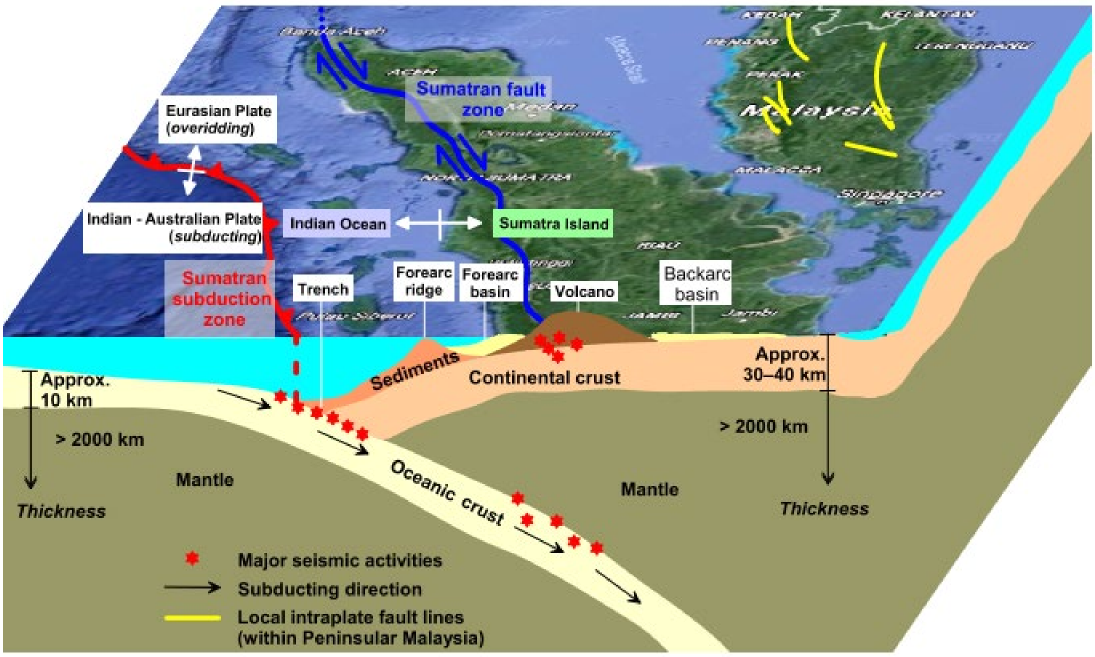


Figure 2.3: The mechanism of the major seismic activities due to the tectonic plate movement near Sumatra Island (Loi et al., 2018).

Past earthquakes events demonstrated that Malaysia is becoming more vulnerable to the seismic hazards due to the far-field earthquakes. For example, on 26 December 2004, the Indian Ocean earthquake with the magnitude Mw 9.0 struck Aceh, Indonesia (Balendra and Li, 2008). The earthquake also generated the disastrous India Ocean Tsunami which has destroyed part of the northwest coastal area of Malaysia. Moreover, Malaysia also felt the tremors of far-field earthquake due to the Nias earthquake with magnitude Mw 8.6 on 28 March 2005 as well as 11 April 2012 in Acheh and Sumatera, Indonesia (Adiyanto and Majid, 2014).

The near filed earthquakes of Malaysia are normally triggered along the local intra plate fault lines (Loi et al., 2018). The Bentong Fault Zone for example, that consists of the Bukit Tinggi Fault and the Kuala Lumpur Fault, is the most active seismic feature in Peninsular Malaysia. At least 24 cases of weak earthquakes around Bukit Tinggi were triggered between the period of 2007 to 2009 (Marto et al., 2013). Table 2.1 summarises part of the local earthquakes that were recorded up to 2012.

Table 2.1: Local Earthquakes Occurrences in Peninsular Malaysia (Marto et al., 2013)

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

On 5 June 2015, an earthquake of magnitude Mw 6.0 occurred near Ranau, Sabah in the early morning (Hong et al., 2020). This earthquake was considered as near-field earthquakes since the epicentre was located 16 km only from Ranau and the depth is 54 km beneath the earth. The tremors of the event were felt at Kundasang, Tambun, Pedalaman, Tuaran, Kota Kinabalu and Kota Belud (Adiyanto et al., 2017). This event had caused damage to the buildings and infrastructure. The economic loss due to this earthquake in Sabah was estimated to be approximately RM100 million (Lee, n.d.). The

past earthquake events in Malaysia have raised a concern on the need and importance of considering seismic design for the buildings in Malaysia.

2.3 Factors Affecting the Structural Damages due to Earthquake Events

Earthquakes can impose significant structural damage to the structure when inappropriate structural configurations are adopted. There are various factors affecting the damage of a building during earthquake. These factors are discussed in the following sub-sections.

2.3.1 Weak Stories Mechanism

Reinforced concrete buildings with weak storey mechanism tend to damage during the seismic activities. The typical building categorised as weak first storey mechanism configuration is shown in Figure 2.4. This structural configuration is largely applied in existing buildings as it allows optimum distribution of space at the ground floor serves as parking and upper floor as residential house. The weak first storey indicates that the stiffness and strength of the first floor are significantly lower than the upper floors, leading to the large inter-storey first between the first floor and upper floors (Alih and Vafaei, 2019). Figure 2.5 shows the damage of a building in Mexico City in the 2017 earthquakes due to presence of vertically irregular weak storey buildings. Most of the buildings that collapse during the earthquake event posed a common characteristic where first floor had open spaces and other floor used masonry walls to support the slabs. During the ground movement event, the rigid upper floor frame had experienced relatively small movement than the flexible first floor frame (Jara et al., 2020).

Figure 2.4: Typical weak first floor configuration for the RC buildings (Alih and Vafaei, 2019)

Figure 2.5: Collapse of the buildings in Mexico City (Jara et al., 2020)

2.3.2 Strong-beam Weak-column Effect

When a deep and rigid beam is used with flexible column, a strong-beam weak-column failure mechanism during the seismic event is developed. In this case, plastic hinge developed in columns rather than beam when it has smaller resistance of moment. On 2015 Sabah earthquake, a large crack appeared at the joint and transferred to the upper part of the column when deep beam is intact (Alih and Vafaei, 2019). Figure 2.6 shows the damage of structure during earthquake due to strong-beam weak-column effect.

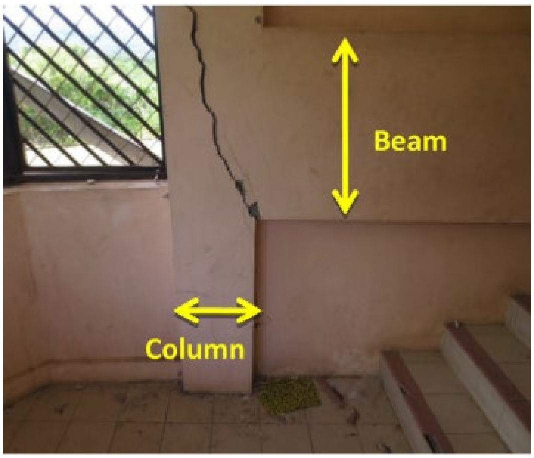


Figure 2.6: Damage of structure due to strong-beam weak-column effect (Alih and Vafaei, 2019)

In Malaysia, strong-beam weak-column construction is quite popular in RC frame building, and deep beams are frequently supported by flexible columns. However, this strong-beam to weak-column can be eliminated by allowing a proportional size of beam against size of column. Otherwise, it can be prevented using concrete with higher compressive strength for column than that of beams and slabs. Figure 2.7 shows the proportional size of beam against size of column.

Figure 2.7: Proportional size of beam against size of columns (Alih and Vafaei, 2019)

2.3.3 Amount of transverse reinforcement

The inadequate amount of transverse reinforcement in column and beam especially in the plastic hinge locations is also one of the factors causing damage to the structure during earthquakes event (Alih and Vafaei, 2019). Moreover, the wide spacing of stirrups as reported by Yon et al. (2018) was found to be one of the main reasons for the damage of building during earthquakes. During the seismic event, structural element usually failed due to the shear force that exceeds the allowable limits. The presence of high shear forces during an earthquake, especially at column and beam-column joints can lead to failure, as shown in Figure 2.8 and Figure 2.9. This type of damage can be arrested by providing sufficient transverse reinforcement and stirrups.

Figure 2.8: Damaged Structure Due to Inadequate Shear Reinforcement Spacing (Yon et al., 2018)

Figure 2.9: Damaged of columns due to large spacing between stirrups (Alih and Vafaei, 2019)

2.3.4 Short Column Effect

Short column mechanism can be developed due to the lateral displacement of a column that is partially restricted by infill walls. Other than that, short column phenomena are common for the structure built on sloping ground where columns supporting the first storey have varying height. The lateral forces induced by the earthquake are carried by columns and shear walls. When the length of column decreases, it becomes stiffer and more rigid in bending. Thus, the short column attracts higher shear forces and bending moment than other column (Alih and Vafaei, 2019; Yon, 2018). At times, the presence of short column in a structure is unavoidable. In order to prevent the issue of short column effect, closely spaced transverse reinforcement is provided along the height of columns. Figure 2.10 shows the failure of column on slope due to short column effect.

Figure 2.10: Failure of column on slope due to short column effect (Alih and Vafaei, 2019)

2.3.5 Ductility

Ductility can be defined as the ability of building to sway and deform without collapse. Brittle materials such as bricks and concrete blocks tend to be crack compared to ductile materials during the earthquake. Anusha (2014) stated that most of the building damage came from brittle materials. Furthermore, the ductility class of steel reinforcement is also one of the important factors. Generally, there are three ductility classes used in Malaysia seismic design condition (Awaludin and Adnan, 2016), namely:

i. Ductility Class Low (DCL). Lightly supplemented by a few additional detailing rules for the enhancement of ductility.
ii. Ductility Class Medium (DCM). Enable the structure to enter within the inelastic range without any failure in term of brittle.
iii. Ductility Class High (DCH). Ensure the whole structure have a stable mechanism associated with large hysteretic energy dissipation.

The ductility class of the building is affected by the Peak Ground Acceleration. Commonly Ductility Class Low is used for the Peninsular Malaysia while Ductility Class Medium and High is used for East Malaysia.

2.4 Eurocode 8 and Malaysia National Annex

MS EN 1998-1, "Design of Structure for Earthquake Resistance: General rules, seismic actions and rules for buildings" specifies the design requirements for buildings and other structures in the seismic region with respect to Malaysia local conditions. EC 8 is aimed at securing the human lives, minimised damage, and ensure civil protection remain operational after the earthquakes event. As a result, the avoidance of structural damage and collapse of structures are the most important design criteria in the code.

2.4.1 Ground Types

Eurocode 8 consists of seven ground types, namely, A, B, C, D, E, S1 and S2 for soil sediments with depth less than or equal to 30m. On the other hand, Malaysia National Annex only considers five ground types of namely A, B, C, D and E for soil deposit less or exceeding 30 m in depth. Ground type S1 and S2 are irrelevant to the ground condition of Malaysia. Table 2.2 show the ground type classification scheme based on Table 3.1 of Eurocode.

Table 2.2: Ground Type Classification (Eurocode 8, 2004)

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT} (blows/30 cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800m/s	-	-	-
S_1	Deposits consisting, or containing a layer at least 10m thick, of soft clays/slits with a high plasticity index (PI > 40) and high water content	<100 (indicative)	-	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1	-	-	-

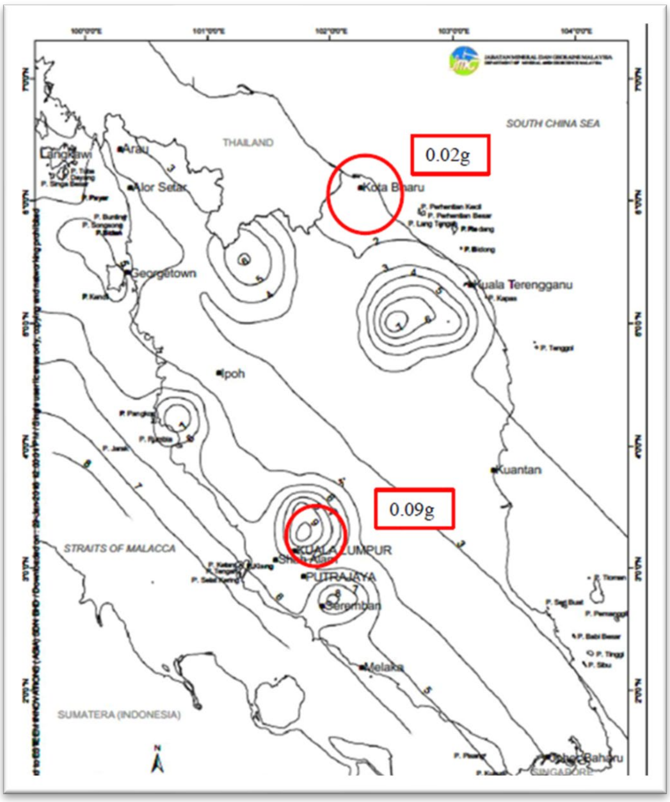
The site natural period parameter, *Ts*, which is proportional to the total depth of the soil sediment and inversely proportional to the average value of shear wave velocity of the soil material, *Vs*, determines the site classes in National Annex 2017. Table 2.3 shows the ground type classification according to the Table NA-1 Malaysia National Annex. The weak and soft ground type for the seismic building tend to experience greater amplification for the seismic load and the improvisation on design requirements will lead to the increase in the construction cost (Hong et al., 2020). Roslan et al. (2019) also commented that if the site condition having soft soil as the ground type, the construction cost of a building will be higher than a building constructed on hard soil.

Table 2.3: Ground Type Classification (Malaysia NA, 2017)

Ground type	Description and range of Site Natural Period, T_S (S)
A	Rock site, or site with very thin sediments and $T_S < 0.15$ s
B	A site not classified as Ground Type A, C, D or E
C	A site with sediments of more than 30 m deep to bedrock and $T_S = 0.5$ s to 0.7 s
D	A site with sediments of more than 30 m deep to bedrock and $T_S = 0.7$ s to 1.0 s
E	A site with sediments of more than 30 m deep to bedrock and $T_S = > 1.0$ s, or deposits consisting of at least 10 m thick of clays/silts with a high plasticity index (PI > 50)

2.4.2 References Peak Ground Acceleration (PGA)

The peak ground acceleration is the most direct measurement of ground motion. Peak ground acceleration can be defined as the maximum ground acceleration that occurred during earthquake event. Seismic design can be overlooked if the bedrock peak ground acceleration has a 10% chance of being exceeded in next 50 years is less than 0.04g. For higher seismic ground motion, simpler rules that eliminates ductile detailing can be used if the bedrock peak ground acceleration has a 10% chance of being surpassed in the next 50 years is less than 0.08g (Eurocode 8, 2004). Figure 2.11 (a) to (c) shows the seismic hazard map of Peninsular Malaysia, Sabah and Sarawak as extracted from the Malaysia National Annex (2017).


0.02g
0.09g
SOUTH CHINA SEA
THAILAND
STRAITS OF MALACCA
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Arau
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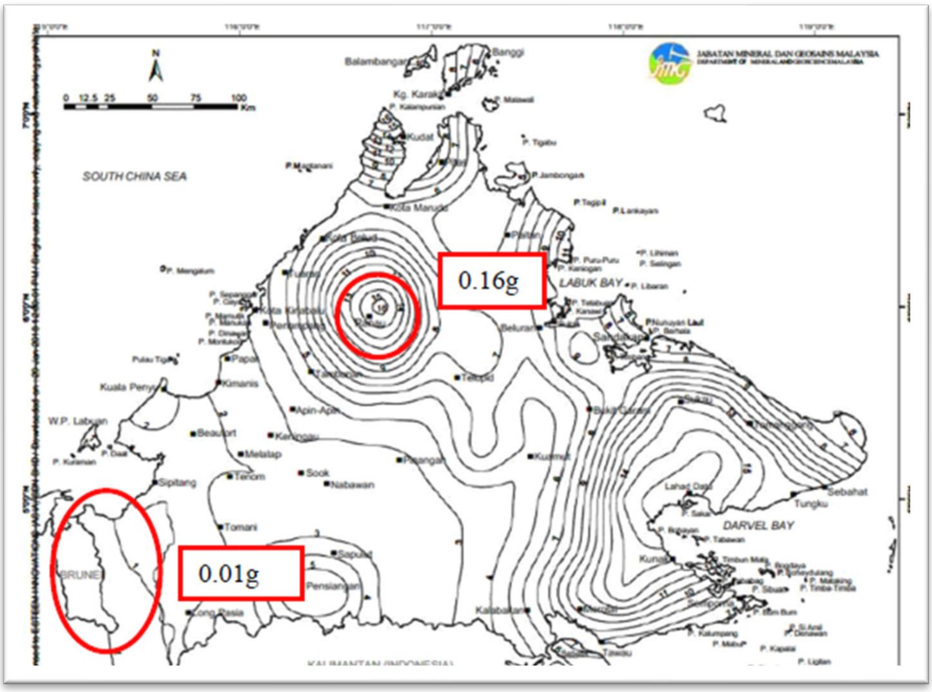
Kuantan
KUALA LUMPUR
PUTRAJAYA
Seremban
Melaka

(a)


0.16g
0.01g
SOUTH CHINA SEA
LABUK BAY
DARVEL BAY
BRUNEI
Balambangan
Banggi
Kudat
Kota Marudu
Kota Belud
Beluran
Telupid
Papar
Kimanis
W.P. Labuan
Beaufort
Apin-Apin
Keningau
Melalap
Tenom
Sook
Nabawan
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Kunak
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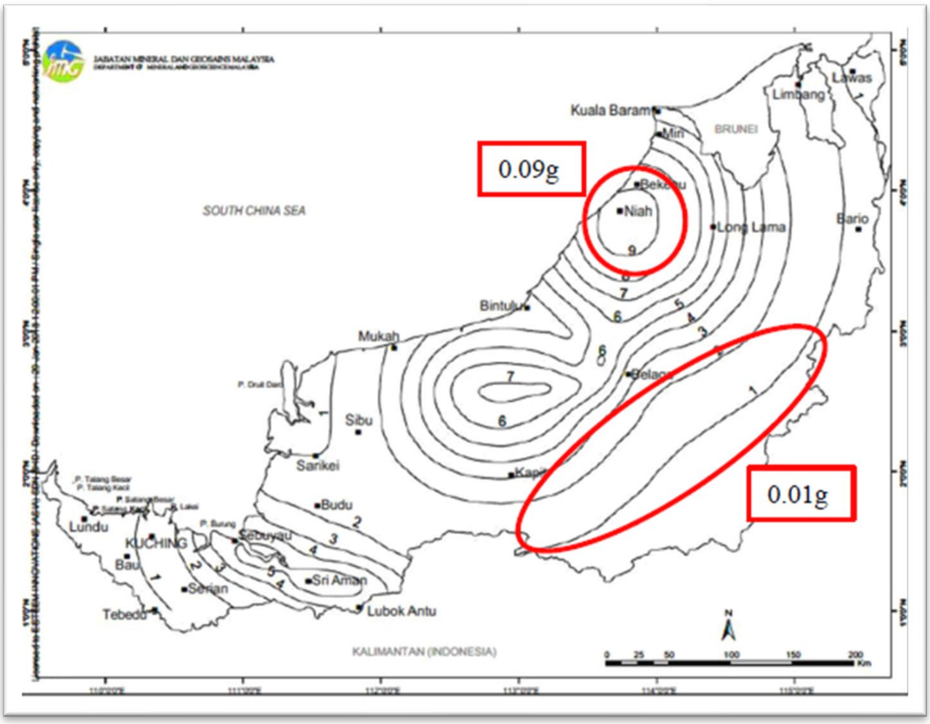
Sebahat

(b)



(c)

Figure 2.11: Seismic Hazard Map of (a) Peninsular Malaysia, (b) Sabah and (c) Sarawak with 10% Probability of Exceedance in 50 years (Malaysia National Annex, 2017)

Based on Figure 2.11 (a), the highest PGA contour in Peninsula Malaysia is located in Kuala Lumpur and lowest contour at Kota Bahru which is 0.09g and 0.02g, respectively. In addition, as shown in the Figure 2.11 (b), the highest contour in Sabah is 0.16g located at Ranau while the lowest PGA is 0.01g located near Brunei. Figure 2.11 (c) shows the highest contour at Sarawak is located at Niah and the lowest contour is located at the inner land of Sarawak. The PGA value for Niah and inner land of Sarawak is 0.09g and 0.01g, respectively.

The reference PGA on ground type A used in Malaysia is derived from contour maps in Malaysia National Annex (2017). The design ground acceleration on ground type A can be obtained by multiplying the importance factor with reference PGA as shown in Equation 2.1. Recommended values of importance factor in Malaysia are shown in Figure 2.12.

$$a_g = \gamma_1 . a_{gR} \tag{2.1}$$

where,

a_g = design ground acceleration on ground type A

γ_1 = importance factor

a_{gR} = reference peak ground acceleration on ground type A

Building importance class	Importance factor 1 (γ_I)	Recommended building categories
I	0.8	Minor construction
II	1.0	Ordinary buildings (individual dwellings or shops in low rise buildings)
III	1.2	Buildings of large occupancies (condominiums, shopping centres, schools and public buildings)
IV	1.5	Lifeline built facilities (hospitals, emergency services, power plants and communication facilities)

Figure 2.12: Importance Factor (γ_1) in Malaysia (Malaysia NA, 2017)

2.4.3 Ductility

Ductility is the capacity of a structure to resist significant deformation beyond the yield point without breaking when subjected to specific loadings. It is stated in terms of demand and availability in the field of earthquake engineering. The available ductility is the maximum ductility that the structure can withstand without damage, while the ductility demand is the highest ductility that the structure can achieve during an earthquake incident (Eurocode 8, 2004).

There are three levels of energy adsorption that is low, medium and high. Clause 3.2.1 (4) of EC 8 (2004), stated an area with a_g smaller or not equal to 0.04g shall be excluded from the seismic provisions. Furthermore, this area is classified as low seismicity area when a_g is not greater than 0.08g. The seismic design consideration for the structure at low seismic area is ductility class low (DCL). Ductility class medium and high are adopted for the seismic design at the medium to high seismicity areas or when the peak ground acceleration, a_g > 0.08 (Looi et al., 2019). Table 2.4 shows the classification of the design category according to Eurocode 8.

Table 2.4: Classification of design category (Eurocode 8, 2004; Looi et al., 2019)

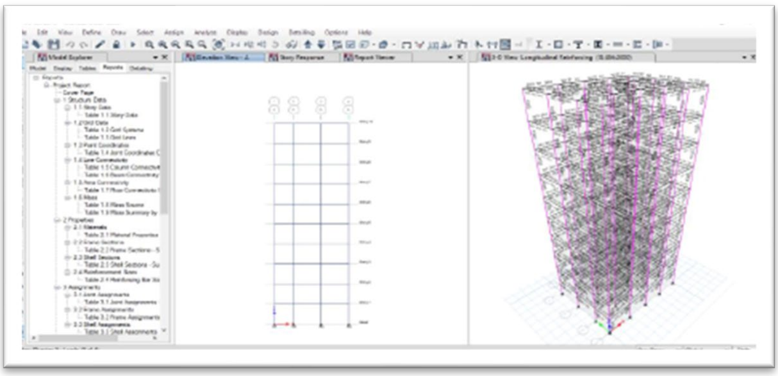
Governing Parameter	Level of Seismicity for Design Consideration	Design Category
$a_g \leq 0.04$g or $a_g.S \leq 0.05$g	Very low seismicity	No need
$0.04g < a_g \leq 0.08$g or $0.05g < a_g.S \leq 0.1$g	Low Seismicity	DCL
$a_g > 0.08$g or $a_g.S > 0.1$g	Medium to high seismicity level	DCM or DCH

DCL or DCM can be used for the seismic design in Malaysia (Luin et al., 2011). On the other hand, DCH is not practical to be used in Malaysia due to its high dissipative structural behaviour that is only suitable for buildings in the earthquake prone countries. In terms of cost implementation on seismic design for the RC building in Malaysia, quantity of concrete and reinforcement tonnage for the structural members are governed by the design category (Ramli et al., 2017).

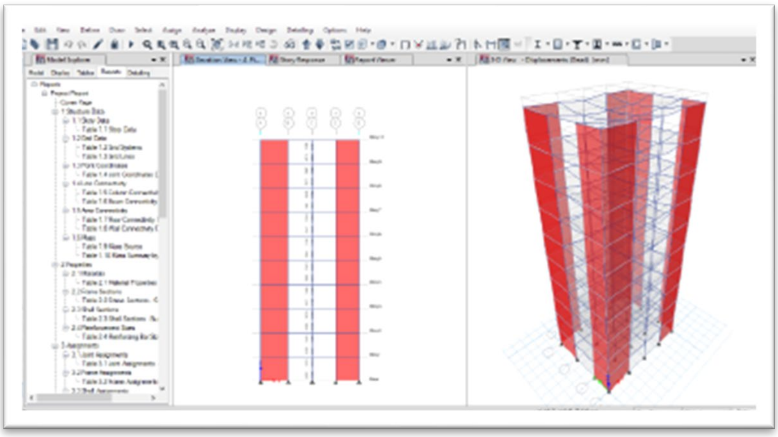
2.5 Modelling

Modelling of the building is conducted before the beginning of full analysis. It can be carried out using a two-dimensional (2D) or three-dimensional (3D) model depending on the computational time and the level of accuracy required. However, 3-D modelling usually provides a more realistic analysis as translational and rotational movement of all directions are considered. There is many commercial software that have the ability to perform seismic analysis and design such as Tekla Structural Designer, SAP200, ETABs and STAADPRO software.

Ranjith and Saibaba (2022) used ETABs software to study about the effectiveness of shear wall in the building subjected to earthquake. In the analysis, both building models with and without shear wall were performed using the response spectrum method. Figure 2.13 shows the building model with and without the shear wall in ETABs. The authors reported that the lateral stiffness of the building enhanced with the presence of shear wall and reduced the reinforcement percentage in the columns. Other studies that utilised ETABs software to perform the seismic analysis for the low to high rise building models can be seen in the work of Sharma (2020); Shakeeb et al. (2015) and Vinoth et al. (2022). Example of the output from ETABs (bending moment of a frame) can be seen in Figure 2.14.



(a)



(b)

Figure 2.13: The building model (a)without and (b) with the shear walls in ETABs (Ranjith and Saibaba, 2022)

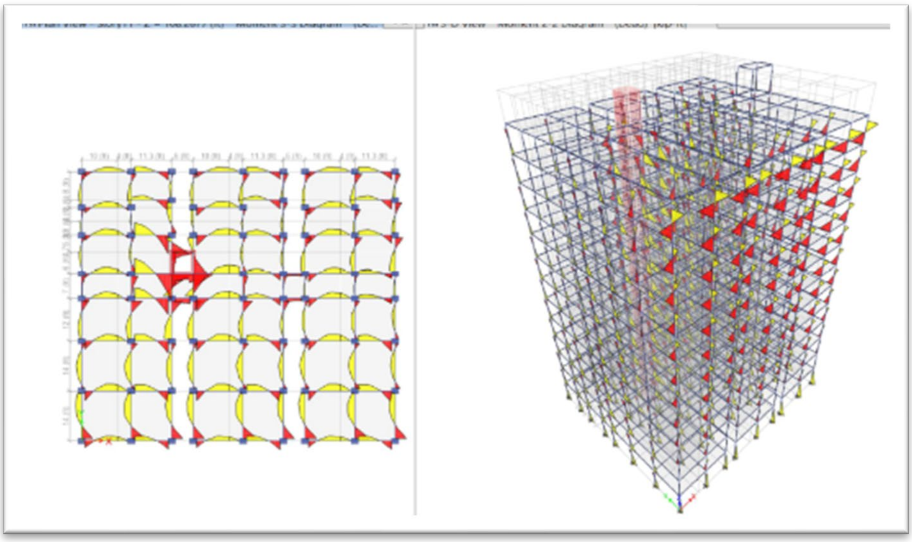


Figure 2.14: Details of bending moment (Vinoth et al., 2022)

Oggu and Gopikrishna (2020) used SAP 2000 software in the analysis and assessment of irregular and non-irregular buildings under repeated earthquake. The side view and result on the hinge pattern of building configuration was shown in Figure 2.15. The outcome of this study indicated the collapse capacity of the RC buildings under repeated earthquakes was significantly lower than a severe single earthquake.