EFFECT OF CONSIDERATION OF SEISMIC DESIGN ON COST INCREASE OF REGULAR LAYOUT REINFORCED CONCRETE HIGH RISE BUILDINGS IN PENANG ISLAND

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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

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2021/2022

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Effect of Consideration of Seismic Design on Cost Increase of Regular Layout Reinforced Concrete High Rise Buildings in Penang Island

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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Date : 9/8/2022.

ACKNOWLEDGEMENT

First of all, I would like to acknowledge and give my warmest thanks to my supervisor Professor Ir. Dr. Choong Kok Keong who giving me the opportunity to conduct my final year project under his supervision at Universiti Sains Malaysia Engineering Campus. I have been extremely lucky to have a supervisor who cared so much about my work and who responded to my questions and queries so promptly.

I am really fortunate that I had the kind association with my coursemate, Tiew Ming Jie and Tan Hong Yang who have share their knowledge and assist me in my research study. I also mentored by Ir Chua from IEM Penang Section during my work on using software modelling. They have all provided a huge amount of their precious time and effort to shared their experience with me when I felt puzzled in all those unresolved issues.

Lastly, I would like to extend my grateful thanks to my family for the financial support and encouragement. The accomplishment would not be achieved without their blessings and unwavering support.

ABSTRAK

Memandangkan Malaysia tidak terletak di kawasan yang mempunyai sesar seismik aktif, sebahagian besar strukturnya telah dibina mengikut Eurocode 2 dan MS 1553:2002 yang tidak termasuk sebarang peruntukan seismik. Walau bagaimanapun, pembangunan Lampiran Kebangsaan Malaysia (NA) kepada Eurocode 8 mengatasi kemungkinan bahaya gempa bumi disebabkan oleh integriti bangunan sedia ada yang direka bentuk tanpa mengambil kira beban seismik. Kajian ini bertujuan untuk menentukan variasi dalam kos bahan dengan mengambil kira kesan beban seismik dalam reka bentuk. Pengaruh tiga jenis tanah dan bilangan tingkat bangunan terhadap kos bahan telah dipertimbangkan. Sebanyak 12 analisis model telah dijalankan oleh EtabsV18 dengan ketinggian tingkat 35 tingkat, 40 tingkat dan 45 tingkat dengan dan tanpa pertimbangan kesan seismik pada jenis tanah A, D, dan E. Kenaikan kos bahan antara reka bentuk bukan seismik dan reka bentuk seismik telah ditentukan. Tambahan pula, kenaikan kos bahan reka bentuk seismik dalam jenis tanah yang berbeza juga ditentukan. Bangunan konkrit bertetulang direka bentuk berdasarkan EC 2 dan direka bentuk semula mengikut EC 8 dengan pecutan tanah puncak, αgR 0.06g mencerminkan zon seismik rendah untuk kelas kemuluran rendah (DCL) termasuk jenis tanah biasa A, D dan E di Pulau Pinang. Berbanding dengan EC8, penyediaan bar tetulang mengikut EC2 adalah lebih tinggi untuk setiap ketinggian tingkat yang disiasat. Peratusan kenaikan kos didapati -8.47%, -7.19% dan -1.05% untuk bangunan 35 tingkat, 40 tingkat dan 45 tingkat, masing-masing untuk jenis tanah D. Selain itu, apabila dibandingkan dengan jenis tanah D, kos bahan untuk jenis tanah A ialah -1.344%, -1.229% dan -1.365% masing-masing untuk bangunan 35 tingkat, 40 tingkat dan 45 tingkat. Berbanding dengan jenis tanah D, kos bahan untuk jenis tanah E tidak menunjukkan perbezaan ketara untuk bangunan 35 tingkat, 40 tingkat dan 45 tingkat, masing-masing.

ABSTRACT

Since Malaysia is not situated in an area with active seismic faults, the majority of its structures were designed in accordance with Eurocode 2 and MS 1553:2002, which does not include any seismic provisions. However, the development of Malaysian National Annex (NA) to Eurocode 8 has provided a design guideline to check the ability of the existing buildings that were designed without considering seismic load to satisfy the design requirements. This study is aimed at determining the variation in material cost considering the effect of seismic load in the design. The influence of three ground type and three different number of storeys building on material cost was considered. A total of 12 analysis models was carried out by EtabsV18 with storey height of 35 storey, 40 storey and 45 storey with and without the consideration of seismic effect on ground types A, D, and E. The material cost increment between seismic design and non-seismic design was determined. Furthermore, the material cost increment of models considering seismic design on different ground types was also determined. The models of reinforced concrete building were designed based on EC 2 and redesigned according to EC 8 with peak ground acceleration, α_{gR} 0.06g reflecting the low seismic zone for ductility class low (DCL) including the common ground type A, D and E in Penang. In comparison with EC8, the provision of reinforcement bar according to EC2 is higher for every storey height investigated. The percentage of cost increment for seismic design models are found as negative percentage values for 35 storey, 40 storey and 45 storey buildings. Besides, when comparing with ground type D, the material cost for ground type A are -1.344%, -1.229% and -1.365% for 35 storey, 40 storey and 45 storey buildings, respectively. In comparison with ground

type D, the material cost for ground type E does not show significant differences for 35 storey, 40 storey and 45 storey buildings, respectively.

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LIST OF ABBREVIATION

CQC	Complete Quadratic Combination
DCH	Ductility Class High
DCL	Ductility Class Low
DCM	Ductility Class Medium
EC2	Eurocode 2
EC8	Eurocode 8
IEM	Institute of Engineer Malaysia
MS	Malaysian Standard
NA	National Annex
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
SLS	Serviceability Limit State
SRSS	Square Root of The Sum of Squares
ULS	Ultimate Limit State
2-D	Two-Dimensional
3-D	Three-Dimensional

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake is a sudden release of energy in the earth crust that creates seismic waves in a surrounding area. Penang Island is located on stable Sunda Plate but the seismically active Sumatran Subduction Zone and the Sumatran Fault cause certain degree of effect in the events of earthquakes, as shown in Figure 1.1. The distance of the closest potential earthquake epicentre may be located at a distance. However, a very low peak ground acceleration from a distant earthquake might lead to disastrous events due to the occurrence of large displacement properties (Balendra et al., 2002). One evidence shows that one of the most significant regional earthquakes which brought serious effects is the 2004 Indian-Ocean earthquake with the magnitude of Mw 9.1. It caused devastating tsunami and killed 68 lives in Malaysia and thousand others in Indonesia, Sri Lanka and Thailand (Marto et al., 2013).

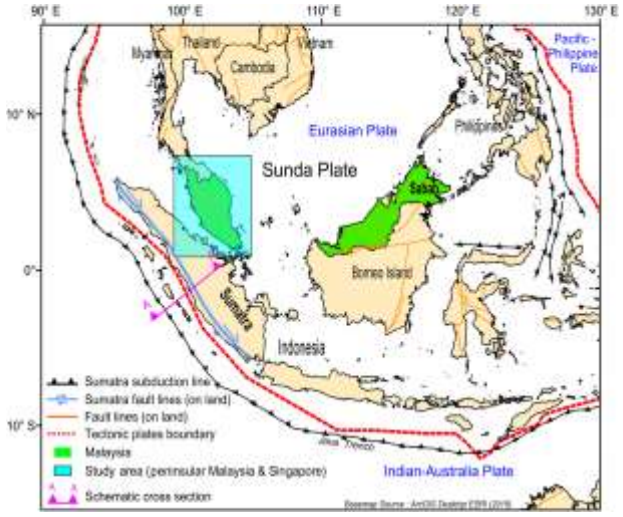


Figure 1.1: Location of Malaysia on the Sunda Plate and Tectonic Plates Surrounded Malaysia (Loi et al., 2018)

In Malaysia, there are several cases of minor to moderate earthquakes experienced in the country. On the 5th of June 2015, a small earthquake struck Ranau, Sabah, killing 18 people and caused major damage to engineered infrastructure and buildings. As contrasted to the beam, in-situ observation revealed that the column experienced severe damage. Thus, the earthquake incidences that hit Ranau and Kundasang with a magnitude of 6.0 had triggered the Malaysian Government to emphasize on seismic design of buildings (Yuen, 2017). Penang island has recently been struck by a series of earthquakes, including the Great Sumatran-Andaman earthquake of 2004, which resulted in tsunami and extreme shaking on high ground (Azmi et al., 2013).

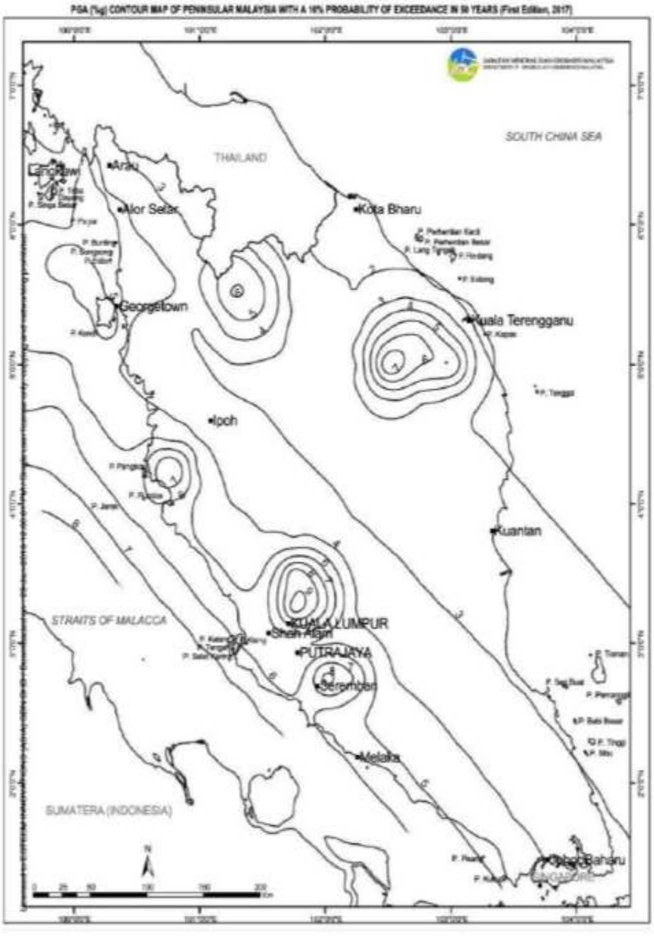


Figure 1.2: Seismic hazard Map of Peninsular Malaysia (MS EN 1998-1:2015)

The Standard Malaysia Department recommended a new design requirement to make the structure more earthquake-resistant, which would result in a 5 percent to 10 percent increase in construction costs over standard design (Yuen, 2017). The Malaysia National Annex to MS EN 1998-1:2015 (National Annex: 2017) was published with a seismic hazard map of Peninsular Malaysia shown in Figure 1.2. It is a set of guidelines for designing earthquake-resistant structures. Peninsular Malaysia has PGA, which is 5%g at Penang and 9% g at Kuala Lumpur (MS EN 1998-1:2015).

Foundation soils are one of the key components in carrying out an accurate seismic design for structures with the soil types having an impact on a building's seismic performance. The earthquake from Sumatera affects cities of Malaysia which the peak ground accelerations at bedrock increases around 2 to 5 times at the surface due to the action of local soil (Hong et al., 2020). From the hazard mapping in landslides and earthquakes in Malaysia by the Department of Minerals and Geoscience Malaysia the PGA for Malaysia is between the range of 0.001g-0.165g.

1.2 Problem Statement

Malaysia is gradually adopting seismic design for new building structures. However, there is still lack of sufficient knowledge about effects of seismic loads on reinforced concrete structures in Malaysia which are designed for wind load but not for seismic load. Specifically for the case of Penang Island where the PGA is low at 5% g, how well buildings of different heights and plan sized designed for wind load are able to satisfy design requirements considering seismic effect are questions that many stakeholders in construction industry would like to know. For cases where buildings designed for wind load not able to satisfy design requirements under seismic load consideration, what will be the increase in member sizes and amount of reinforcements.

Availability of such information will assist stakeholders in construction industry to prepare for cost increase in buildings designed to resist seismic loads.

Past studies on the increase in material cost of main building frames shows scattered results in terms of concrete volume and steel reinforcement tonnage (Chan, 2021). Also, the percentage of increment in the material demand varied with the type of structural frame elements (Lim, 2021). The design of high-rise building is governed by wind load and seismic design. Buildings located at soft soil was found to be more dominant in cost evaluation than hard rock by generating stronger amplification of the ground motion towards the buildings (Toh, 2021).

The cost of the construction of high-rise building to comply with seismic design under different soil type is still uncertain due to low to medium seismic region. It These problems should be solved by conducting a project on cost considerations of seismic design in terms of total concrete volumes and the quantity of steel reinforcement needed. It is not clear for a specific building type to what building height the seismic design or wind load design will govern the cost. Further analysis for higher number of storey and different soil type factor is needed to be determined for the preparation of budget for a construction project in Penang. Past studies explained above covered buildings with height of 10 to 30 storey. In order to understand better effect of consideration of seismic loading on possible increase in cost of buildings, analysis and design has to be extended to buildings beyond 30-storey height.

1.3 Objectives

The objectives of this research are:

1. To determine the effect of consideration of seismic loading on volume of concrete and steel reinforcement in the design of 35, 40 and 45 storey buildings in Penang Island.
2. To determine the cost increment of total materials between design considering seismic effect in comparison with design not considering seismic effect for 35, 40 and 45 storeys on ground type A, D and E.

1.4 Scope of Work

In this research study, modelling of rectangular office building with a plan view of 15 x 3 bays is carried out by using ETABS V18 software according to Eurocode 2 under wind loading and Malaysian National Annex (NA) to Eurocode 8 under seismic loading, respectively. Buildings are modelled with height of 35, 40 and 45 storeys under ground types A, D and E. Wind load is the form of lateral force which considered in non-seismic design in accordance with MS 1553:2002. The seismic design is carried out in accordance with EC8/ NA-2017 based on modal spectrum analysis.

Overall, a total of 15 models are generated with three numbers of storeys and soil types. Analysis and design considering wind loading and seismic loading are carried out. The building and model properties with the description, design data and its code reference are provided by Instituition of Engineers Penang Branch Earthquake Sub Committee.

Total cost of concrete and steel reinforcement is calculated by using CSiDetail software. The cost comparison between seismic and non-seismic design are mainly on members of the main frame of the structures such as beams, columns and RC walls.

1.5 Significance of Study

This research investigates cost increment of three level of office buildings under three soil types with and without the consideration of seismic effect. Systematic study is carried out to recognize the effects of earthquake on high-rise structure in Penang. The information is valuable for the construction sector for budget planning and costing purpose.

The costs are expected to rise when seismic design is considered in reinforced concrete design buildings. However, available results are scattered where most of the past studies explaining that buildings incorporating seismic design showed an increase in the material cost. Also, previous studies have found that design of 10, 15, 20 and 25 storey of building is governed by seismic load while the wind load governs in storey height in between 25 and 30-storey (Chan, 2021). This research study is to determine the results on material increment for 35-storey, 40 storey and 45 storey. It is to determine whether the trend is still the same as previous study.

1.6 Dissertation Layout

This dissertation consists of five chapters. Chapter 1 presents overviews of the research study, problem statement and objectives. Chapter 2 reviews how the existing code design deals with a building design subjected to earthquake event. In addition, this chapter also presents and reviews the cost comparison of a building between conventional and seismic design based on previous research works. Chapter 3 describes the procedures of this study to achieve the research objectives. The description of the models, building data, loading case, load combination and the steps involved using ETABS V18 software are presented in this chapter. Chapter 4 presents the results from the design of building model subjected to non-seismic and seismic load. The volume of concrete and weight of reinforcement demand were extracted from ETABS V18 software. The discussion pertaining to the percentage difference and the overall cost of the frame and shell building also presented accordingly. Chapter 5 summarizes the findings of this research based on the objectives of the study. Recommendations for future works are listed to improve the study on EC8 which incorporated in high rise buildings.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapters discuss about the earthquake history happens in Malaysia and the predicted increase in construction costs due to the application of seismic loading in Malaysia. Also, the implementation of code of practice such as EC8 and its National Annex are introduced guideline for designing earthquake-resistant structures. This chapters also covers various factors affecting the results in terms of concrete volume and reinforcement tonnage in structure of a high-rise buildings such as ground type, ductility and application of lateral loads.

2.2 Malaysia's Earthquake Activities

Malaysia is tectonically situated on a stable intraplate and experiences relatively little earthquake activities which does not occurs any disastrous earthquake events. Due to the location adjacent to two of the most seismically active plate boarders, Indo-Australian and Eurasian plates, Malaysia has experienced multiple powerful tremors generated by earthquakes in those two seismically active zones recently. The felt tremor grows increasingly often in the recent decade due to the increment of the seismic activity since the massive earthquake in Banda Aceh and the extraordinary Indian Ocean Tsunami in 2004 (Ahmadun et al., 2020). Even though Malaysia is located far from seismic sources, it has a substantial seismic risk from distant earthquakes due to the local geology such as the underlying soft soil tends to enhance ground vibrations. The affected area in Peninsular Malaysia by the Indian Ocean Tsunami is shown in Figure 2.1.

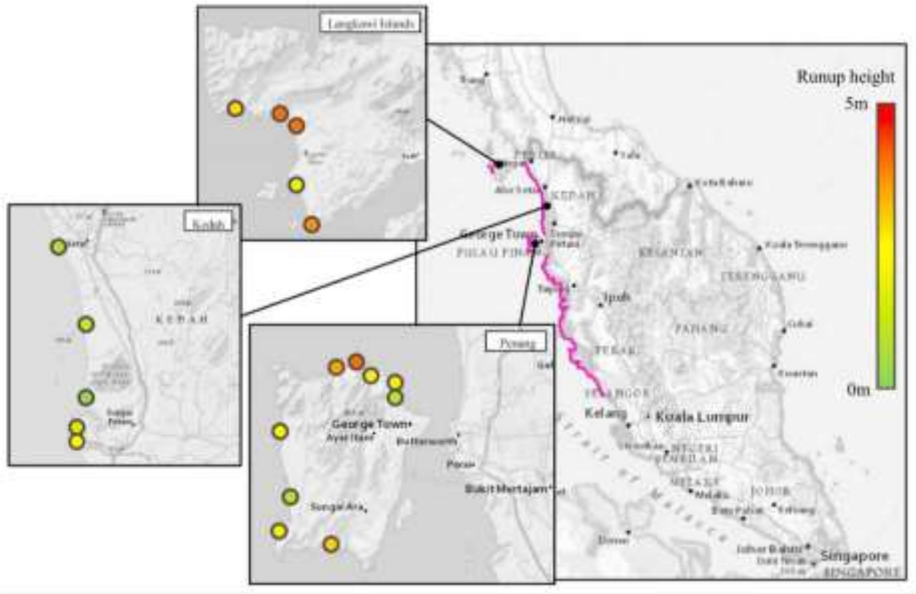


Figure 2.1: Areas in Peninsular Malaysia affected by the Indian Ocean Tsunami in 2004 (Ahmadun et al., 2020)

Numerous large earthquakes near Sumatra and Andaman Islands were connected to fault reactivations in Peninsular Malaysia. The latest earthquake incidence happened near Northern Sumatra cause tremors felt in Malaysia on 2nd November 2022. It has been observed multiple times of tremor that caused cracks on the buildings in Penang and Port Klang. Based on Malaysia Meteorology Department (MMD) and Incorporated Research Institutions for Seismology Earthquake Database (IRIS) Earthquake Databases, the occurrence of earthquake events in Kuala Pilah and Bukit Tinggi will probably leads to reactivation of ancient faults. Figure 2.2 shows the databases of location of earthquake distribution in Peninsular Malaysia.

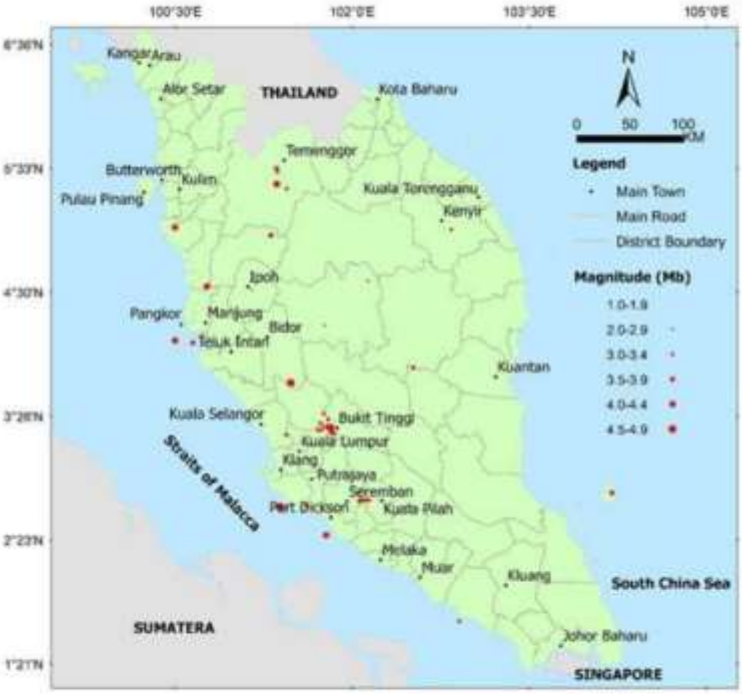


Figure 2.2: Earthquake distribution in Peninsular Malaysia based on MMD and IRIS Earthquake Databases (1970- 2018) (Tongkul, 2021)

A 6.2 magnitude earthquake occurred in west Sumatra at 8.39am local time (9.39am in Malaysia) on Friday (Feb 25, 2022), reports Indonesia's Meteorology, Climatology and Geophysics Agency (BMKG Indonesia). The agency stated the epicentre of the quake is 17km south-east of Palaman in Sumatra. The Malaysian Meteorological Department (MetMalaysia) also issued a notice on the temblor in a tweet at 10.12am (Malaysian time). The epicentre was located 0.2˚N and 100.0˚E with a depth of 10km and the tremors from the quake might be felt throughout the western portion of Peninsular Malaysia, mainly Selangor, Perak, Negri Sembilan, Melaka and Johor. Therefore, it is imperative to notice on this incident to increase the awareness of authority concerned and the profession in reducing losses when catastrophic events has occurred.

Figure 2.3 and Figure 2.4 show the databases of location of earthquake distribution in Sarawak and Sabah respectively. Onshore Sarawak experienced 20 light to moderate earthquakes with magnitudes greater than 3.0 Mw between 1970 and May 2019. These earthquakes appear to be associated to North-South active sinistral strike-slip faults in Niah and North West-South-East dextral faults near Bukit Mersing. However, active faults such as thrust faults, strike-slip faults and normal faults occurs in Sabah. Based on USGS, 2015, three earthquake incidences which occurred in 1976 in the Lahad Datu area and 1991 and 2015 in Ranau area caused considerable damage to buildings (Tongkul, 2021). However, these events may show less significant implications in this study due to Sabah and Sarawak are far from Penang.

Figure 2.3: Distribution of earthquakes in Sarawak based on MMD and IRIS earthquake databases (Tongkul, 2021)

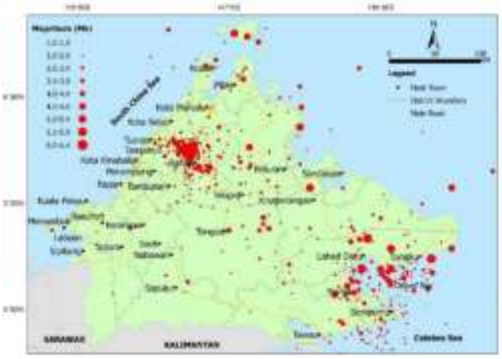


Figure 2.4: Earthquake distribution in Sabah (1966-2019) based on MMD (2019) (Tongkul, 2021)

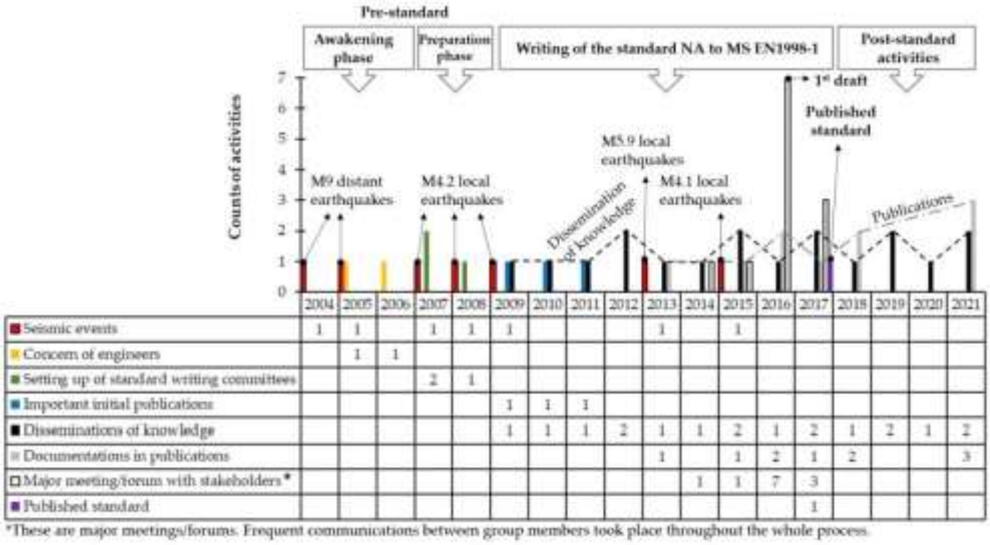
There have been at least 59 earthquake occurrences documented between 1922 and 2020. Near-field earthquakes have been occurring since 2007 as shown in Table 2.1. A slab detachment that broke off from the Sumatran Subduction Zone can be linked to the Street of Malacca's deepest earthquake, which measured 167 km beneath the surface. However, most of the observed earthquakes were classified as shallow earthquakes which occurred at 1-70 km for the vertical (focal depth) distribution. In conclusion, although Peninsular Malaysia is considered as low seismicity region in Malaysia and located in the interior of the plate, it is still having the risks of earthquakes from regional tectonics and local tectonics (Nazaruddin & Duerrast, 2021).

Table 2.1: Local earthquake occurrences in Peninsular Malaysia (After Alexander, 2011)

Date	**Case**	**Location**	**Magnitude**
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

2.3 Development of Malaysia National Annex to Eurocode 8

Malaysia has enacted its first national code of practice for the seismic design of buildings following the release of the Malaysian National Annex (NA) of Eurocode 8 (EC8) in late 2017. A historical review of the relevant important activities since 2004 is shown in Figure 2.5. It summarized the relevant critical activities in chronological sequence since 2004. The goals of EC 8 are to safeguard lives, reduce damage, and make sure that civil defence systems continue to function after an earthquake event. Therefore, the most important design and implementation criteria are no-collapse and damage-limitation. However, the early earthquake events in the area of Ranau and Lahad Datu had not shown much attention due to the small population in the impacted areas and the scarcity of significant designed building structures. So, the Institution of Engineers Malaysia (IEM) and Structural Engineering Technical Division took the initiative to prepare a position paper that was released in 2008 in response to the public's concerns. It expressed the concerned on the lack of consideration of seismic design on building structures in Malaysia in order to cater the potential risks in long term and short-term measures. The purpose of developing earthquake-resistant structural design standard for Malaysia based on Eurocode 8 is to train engineers and advise them on how to properly implement the recently released standard in an area with low to moderate seismic activity. According to Looi et al., (2021), the four specific difficulties and suggestions for how to deal with the issues are covered under several subheadings.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
🟥 Seismic events	1	1		1	1	1				1		1						
🟨 Concern of engineers		1	1															
🟩 Setting up of standard writing committees				2	1													
🟦 Important initial publications						1	1	1										
■ Disseminations of knowledge						1	1	1	2	1	1	2	1	2	1	2	1	2
▨ Documentations in publications										1		1	2	1	2			3
☐ Major meeting/forum with stakeholders*											1	1	7	3				
🟪 Published standard														1				

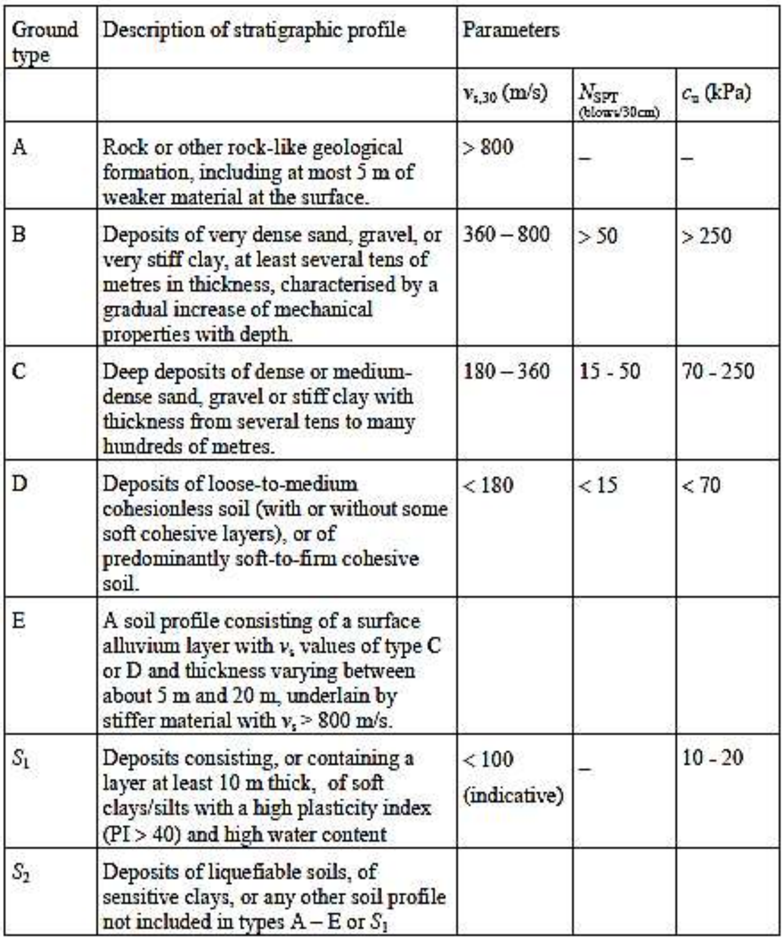
*These are major meetings/forums. Frequent communications between group members took place throughout the whole process.

Figure 2.5: The roadmap of the drafting of the Malaysia NA of EC8 (Looi et al., 2021)

2.4 Ground Types

One of the criteria determining seismic design and structural performance is ground type. There are five common ground types (A, B, C, D, and E) and two special ground types (S1, S2) that can be utilised to account for the impact of local ground conditions on the seismic action according to Eurocode 8 (Sec 3.1.2) shown in Table 2.2. The degree of seismicity in the softer soil state is increased by a greater soil factor, which contributes to a higher seismic intensity when compared to thick or rock situations. In NA-2017, site classes are determined by the site natural period parameter, Ts, which is proportional to the entire depth of the soil sediment and inversely proportional to the average value of the shear wave velocity of the soil material, V_s.

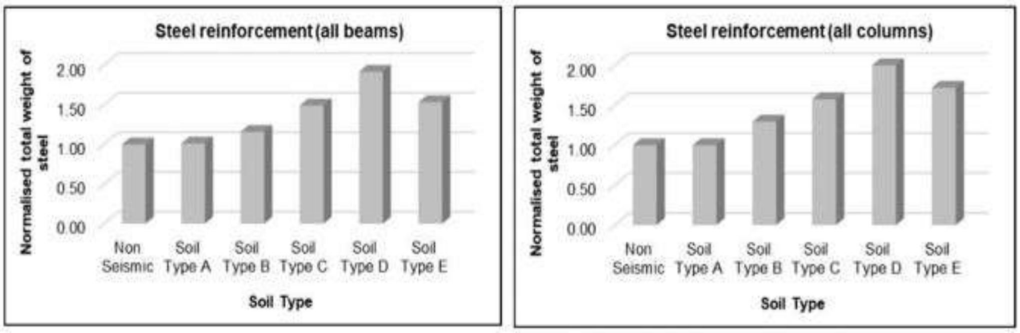
Table 2.2: Ground Types (Eurocode 8, 2004)



Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	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 > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts 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			

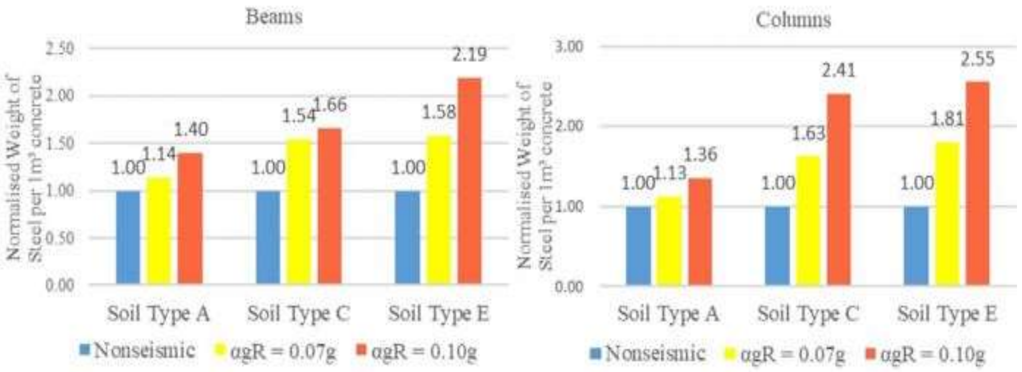
Several research studies have been conducted to investigate the impact of different ground types on seismic load amplification. These studies show how different ground types under seismic design affects the requirement for steel reinforcement in columns and beams.

According to studies by Mustafa *et al.*, (2019), Roslan et al., (2019) and Adiyanto et al., (2020) the amount of steel reinforcement in beams and columns varies when seismic load and various soil types are taken into account as compared to non-seismic design for a fixed number of storeys. Compared with non-seismic design, larger amount of usage of steel reinforcement under seismic design can be seen in Figure 2.6, Figure 2.7 and Figure 2.8. The increases in steel tonnage in columns follow a similar pattern to increases in steel tonnage in beams. The application of soil type D and E shows the highest normalised total weight of steel reinforcement in beam and column under seismic design. This is due to the higher soil factor which contribute higher base shear force and bending moment in those models. However, there is a scarcity of knowledge on the seismic impact on structural members when taking varies soil types and storey number into account. Higher number of storeys with different soil type need to be investigated in order to measure the seismic impact on structural members (Chan, 2021).



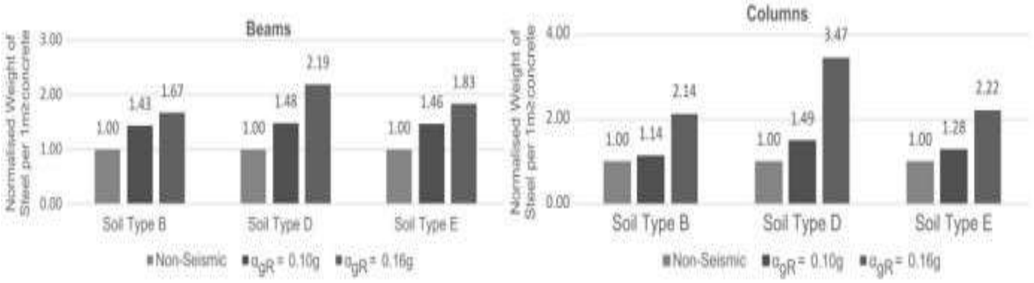
(a) (b)

Figure 2.6: Normalised total weight of steel reinforcement for (a) beam and (b) column (Mustafa *et al.*, 2019)



(a) (b)

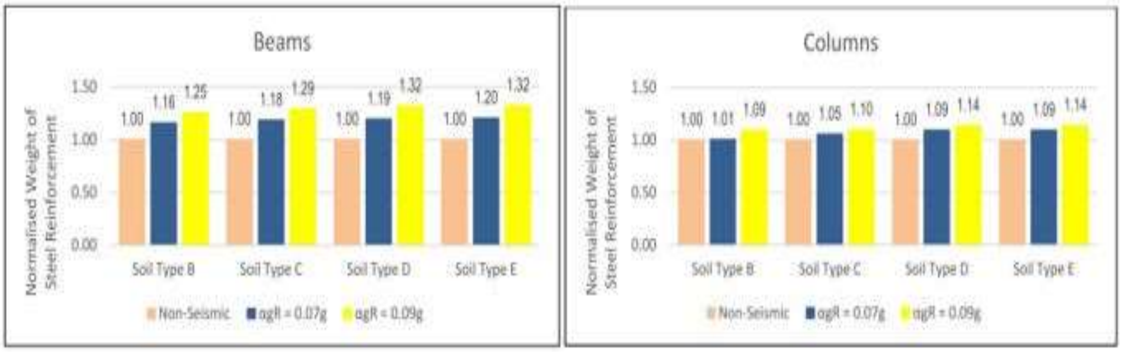
Figure 2.7: Total steel tonnage for (a) all beams and (b) all columns (Roslan et al., 2019)



(a) (b)

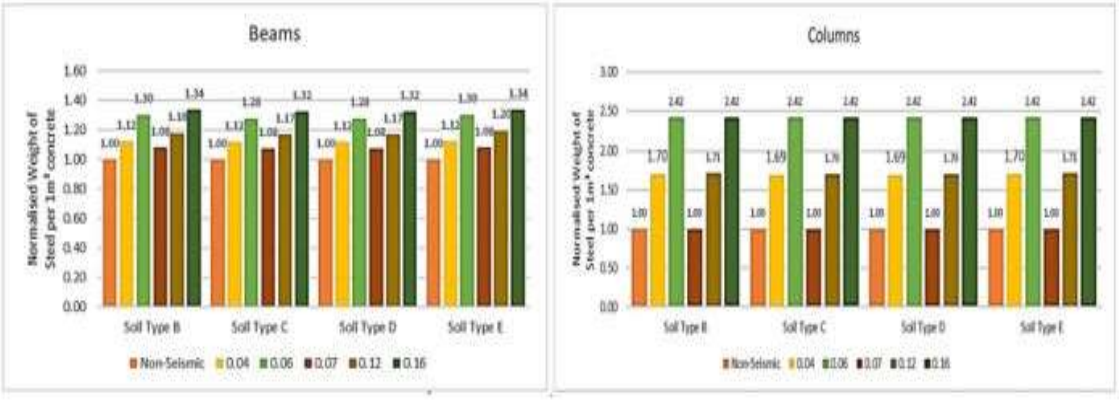
Figure 2.8: Normalized total weight of steel reinforcement per 1 m^3 concrete for (a) beams and (b) columns (Adiyanto et al., 2020)

Recent research studies conducted by Adiyanto et al., (2021) and Roslan et al., (2021) showed the evaluation of the increase in reinforced concrete building materials due to seismic design for four storey reinforced concrete building and two storey hostel building in Sabah respectively. The total steel tonnage for beam and column for both studies were shown in Figure 2.9 and Figure 2.10. The author reported that the usage of steel reinforcement increases around 16% to 32% compared to the non-seismic design for beams Adiyanto et al., (2021). Likewise, the beams and columns show the similar trends in both studies. According to the results for beams and columns, models of soil types D and E often require the most steel reinforcement under seismic design. So, larger amount of steel reinforcement needs to be provided in beams and columns due to the highest magnitude of base shear force and bending moment. Nevertheless, the differences of usage of steel reinforcement among soil types B, soil type C, soil type D and soil type E are relatively less compared to previous study in Mustafa *et al.*, (2019), Roslan et al., (2019) and Adiyanto et al., (2020). The findings from those studies were linked to the amplification of soil factor with the softer soil conditions has higher level of seismicity than in denser soil conditions.



(a) (b)

Figure 2.9: Normalized total steel tonnage for (a) beams and (b) columns (Adiyanto et al., 2021)



(a) (b)

Figure 2.10: Normalized total weight of steel reinforcement per 1m^3 concrete for (a) beams and (b) columns (Roslan et al., 2021)

2.5 Ductility

Ductility is defined as the capacity of a structure to sustain substantial deformations past the yield point without rupturing after being subjected to particular loadings. Several researchers including Uang and Whittaker et al. (2003) have attempted to link behaviour factors to ductility factors but there is still no exact way to do so. A push-over analysis is one method of determining whether a structure has sufficient ductility to withstand the ultimate earthquake.

A study conducted by Awaludin & Adnan, (2016) states ductility class served as the basis for the seismic design of the structures because different ductility levels will produce varied earthquake forces. There are three types of ductility that are commonly used in Malaysia:

i) Ductility Class Low (DCL). Light 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.

Ductility class design increased the overall stiffness of the buildings with the increase in column sizes. Larger column size gives more stiffness and reduces the period due to the increment of steel reinforcement. Generally, the amount of steel bars needed for the structures increases as the ductility increases. Based on Ramli et al., (2017), less reinforcement was needed under non-seismic design than with seismic design. The design that was solely based on non-seismic design did not consider the value of ground acceleration in comparison to DCH 0.06g, DCM 0.08g, and DCM 0.14g, which resulted in a lack of shear linkages that are necessary to withstand earthquake forces.

The impact of ductility class of a reinforced concrete for six storey hospital building on the overall weight of steel reinforcement has been conducted by Adiyanto et al., (2019). Figure 2.11 shows the steel reinforcement tonnage for 1m^3 concrete for different class of ductility. It demonstrates that the overall weight of steel reinforcement for models created using DCL and DCM is equal to 260.2kg and 113.1kg per 1m^3 of concrete respectively. The results on usage of steel reinforcement among DCL and DCM show different trends with the expected outcomes. The total weight of steel reinforcement in 1 m^3 of concrete for the non-seismic model which was built without taking seismic design into account is 106.4kg. This indicates that the total weight of the steel reinforcement is significantly influenced by the ductility class.

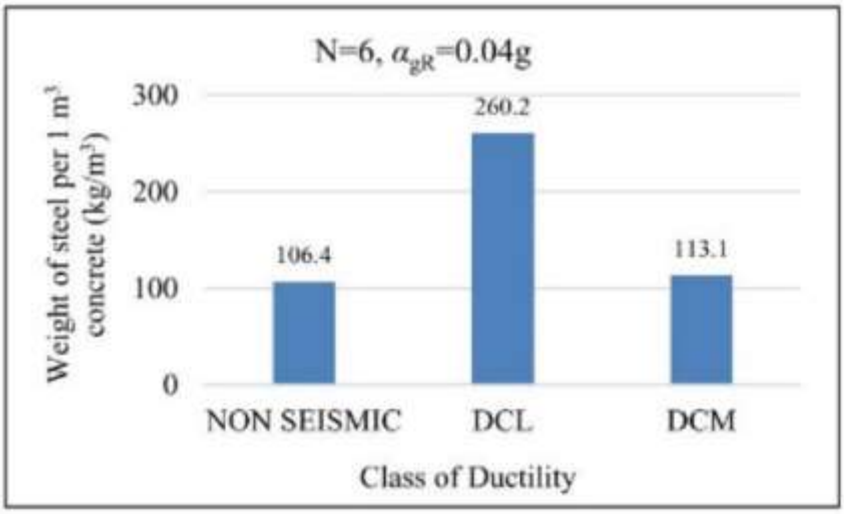


Figure 2.11: Total weight of steel reinforcement for 1m^3 concrete for different class of ductility (Adiyanto et al., 2019)

Basically, Ductility Class High is for the Sabah while Ductility Class Medium and Class Low is for Peninsular Malaysia. This consideration is due to the low Peak Ground Acceleration (PGA) in Peninsular Malaysia compared to Sabah.

2.6 Lateral Load

Lateral loading can cause a material to shear or bend in the direction of the force, resulting in material failure. Wind load, seismic load, water, and earth pressure are some of the most typical types of lateral load.

2.6.1 Wind Load

Wind is a major load in high-rise buildings that must be considered for structural safety and serviceability. It is also necessary to comprehend important consequences and assess the dynamic behaviour of structures in accordance with specified standards.

According to Aejaz et al., (2015), the findings show that wind and earthquake loads differ from one another which imply that earthquake loads create less inter-storey drift than wind loads. The main force resisting system of structure does not show significant issue although slightly small inter-story drift ratios occurs in tall buildings. Identical conclusions were reached in both 16-storey and 31-storey buildings in the study.

Both earthquake and wind load may be approximated in a specific zone and based on the fundamental wind speed (Reddy & Tupat, 2014). On the other hand, wind velocity is difficult to anticipate and is dependent on time. As a result, a study was conducted to examine the design of multistorey buildings using IS 1893 and IS 875, which are Indian codes of practice for seismic and non-seismic design respectively. The wind loads were calculated based on the zone's design wind speed which was varied by 20%. In most situations, the data revealed that wind load is more important than seismic load. The study came to the conclusion that any construction in India would have to account for significant wind and seismic pressures separately. A similar finding concluded that wind load was more important than seismic load was found in the study of (Reddy & Kumar, 2020).

2.6.2 Seismic Load

Hosseini & Rao, (2017) states that total weight of all the floors is the seismic weight of a buildings. The appropriate amount of imposed load required to add together with dead load of each floor to determine its seismic load at the moment of earthquake shaking. It takes into account the weight of fixed and movable partitions, permanent equipment and a portion of the living load, among other things. The seismic load of columns and walls in any storey must be distributed equally to the floors above and below the storey when estimating the seismic load.

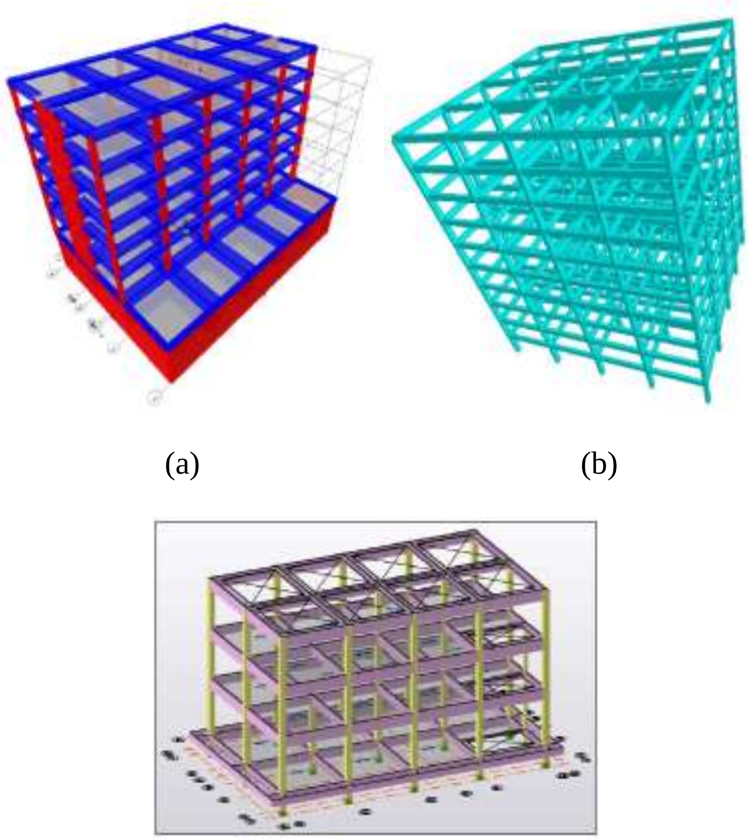
The seismic impact on a structure can be computed using CEN Eurocode 8 (2004) and the structure's linear-elastic behaviour. According to EC8, lateral force technique of analysis and modal response spectrum analysis are two forms of linear-elastic analysis methods that can be used to determine the seismic impact. As an alternative to the linear method, non-linear methods such as non-linear static (pushover) analysis and non-linear time history (dynamic) analysis can be utilized.

Building is subjected to effective lateral stresses as a result of the earthquake. This effect was particularly noticeable in the connections between the columns, beams, and shear walls. To withstand the lateral forces due the earthquake, additional reinforcing has been added to these joints (Kadhum & Razzaq, 2020).

2.7 Model Analysis

Structural modelling can be carried out using a two-dimensional (2-D) or three-dimensional (3-D) model with difference in result performance and computational time. There are several softwares such as ETABS, Tekla Structural Designer and StaadPro which can be used to carry out the analysis and design of high rise building efficiently.

Based on Raoul et al., (2012), 3-D model was created by ETABS for structural analysis. The major and auxiliary axes in plan are shown in Figure 2.12 (a). The selection of an appropriate plan of 9-storry building by utilizing response spectrum analysis method considering mass irregularity with the help of StaadPro software was conducted by Srivastava & Singh, (2018). By using Tekla Structural Designer, different storey of 6 actual RC building models were converted into 3D frames during the model generation phase was carried out by Faisal, (2021).



(a) (b)

(c)

Figure 2.12: 3-D View of (a) ETABS Structural Model (Raoul et al., 2012) (b) Structure using StaadPro (Srivastava & Singh, 2018) (c) Model N3 using Tekla Structural Designer (Faisal, 2021)

In order to estimate the most likely maximum seismic response of a basically elastic structure, response-spectrum analysis (RSA), a linear-dynamic analysis method evaluates the contribution from each natural mode of vibration. Response spectra can be used to evaluate several modes of oscillation (multi-degree of freedom systems) for low degrees of damping. Modal analysis is used to determine the vibrational modes and response spectra can be used to determine each mode's response. The overall response is then calculated by adding each peak response. The common technique of combining for these responses in both horizontal directions and different modes is the square root of the sum of the squares (SRSS) and Complete Quadratic Combination (CQC) respectively (Sarkisian, 2012). According to Eurocode 8 (2004), the sum of the effective modal masses for the modes taken into account amounts to at least 90% of the total mass of the structure to satisfy the requirements in EN 1998-1/4.3.3.3(3).

2.8 Past Research Studies on Cost Increment for Design Considering Seismic Loading

The costing of the building in this research is based on the material cost used for the structural elements such as beams, columns and walls in the designed model. The main factor contributing to the cost increment of the office building is the usage of concrete volume and steel reinforcement tonnage. It is challenging to estimate the additional cost of taking seismic resistance into account while designing because buildings in various projects are created with specific designs and specifications. Although Malaysia is the region which is classified as low to moderate seismicity and it does not experience any disastrous earthquake, it is necessary to conduct related studies for practicing mitigation measures.

Adiyanto & Majid, (2014) claimed that the overall cost of material is affected by the behaviour factor, q, and the level of reference peak ground acceleration, a_{gR}. They examined 2-storey reinforced concrete building models in their study using various levels of reference PGA which simulated the Malaysian seismic zone. The findings demonstrated that the building adopting q = 1.0 had a greater normalised cost than q = 1.5 as shown in Figure 2.13. A very high increment in total cost of material by considering q = 1.0 is unacceptable within the perspective of economic considerations in Malaysia. Therefore, it is more suitable to use q = 1.5 with DCL f. Furthermore, they