COST COMPARISON FOR NON-SEISMIC AND SEISMIC DESIGN OF A RECTANGULAR BUILDING STRUCTURE LOCATED ON DIFFERENT SOIL TYPES BASED ON MALAYSIAN ANNEX

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
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by

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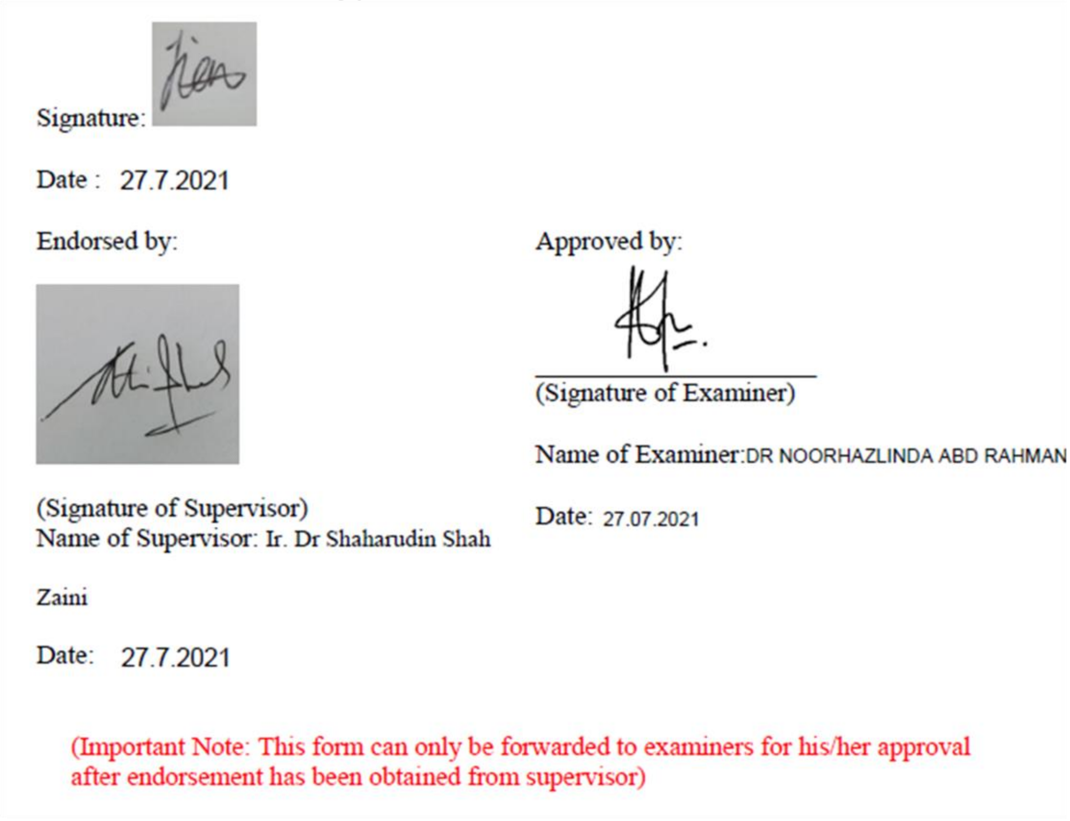
I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.



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ABSTRAK

Malaysia terletak di zon bebas gempa. Namun, disebabkan oleh insiden yang mempersoalkan integriti bangunan sedia ada yang direkabentuk tanpa mempertimbangkan beban gempa, industri pembinaan di Malaysia akan menggunakan Lampiran Nasional Malaysia (NA) ke Eurocode 8. Walau bagaimanapun, terdapat sedikit maklumat mengenai perubahan kos bahan sekiranya reka bentuk tahan gempa dilaksanakan di Malaysia. Objektif kajian ini adalah untuk menentukan perbezaan kos antara struktur bangunan dengan reka bentuk seismik dan non-seismik dan untuk menilai pengaruh jenis tanah yang berbeza terhadap keseluruhan kos bahan kerangka struktur utama bangunan. Lima jenis kerangka bangunan RC yang dikategorikan sebagai 10 tingkat, 15 tingkat, 20 tingkat, 25 tingkat dan 30 tingkat telah dianalisa dan direkabentuk menggunakan perisian ETABS. Bangunan konkrit bertetulang yang dirancang berdasarkan EC 2 dan direka semula mengikut EC 8 dengan pecutan tanah puncak, *agR* 0.06g mencerminkan zon seismik rendah di Malaysia untuk kelas kemuluran rendah (DCL) dan juga dengan jenis tanah A, D dan E yang mencerminkan jenis tanah biasa di Malaysia. Keputusan menunjukkan kos keseluruhan untuk model bangunan yang terletak diatas Tanah Jenis A dan dikenakan beban seismik berkurangan pada julat 3% - 13% berbanding dengan reka bentuk bukan seismik. Tanah Jenis D menunjukkan peningkatan perbezaan peratusan dari 10 tingkat hingga 25 tingkat, yang berada dalam julat 2% - 15%. Selepas 25 tingkat, perbezaan peratusan kos bahan didapati berkurang sebanyak 2% pada 30 tingkat. Selain itu, tanah E jenis menunjukkan peningkatan perbezaan peratusan dari 10 tingkat hingga 20 tingkat, yang berada dalam lingkungan 0% - 8%. Perbezaan peratusan kos bahan cenderung menurun sebanyak 3% -7% pada 25 tingkat dan seterusnya. Ini disebabkan oleh kesan beban angin yang ketara pada bangunan tinggi.

Kesimpulannnya, Tanah Jenis D menunjukkan kenaikan kos tertinggi di antara jenis tanah berbanding dengan reka bentuk bukan gempa disebabkan oleh nilai daya geser asas yang tinggi, F_b dan pecutan spektrum pada tempoh asas T_1.

ABSTRACT

Malaysia is situated in an earthquake-free zone. However, due to incidents that questioned the integrity of the existing buildings that were designed without considering seismic load, the construction industry in Malaysia will be adopting Malaysian National Annex (NA) to Eurocode 8 (EC 8). However, there is limited information on the material cost change if earthquake resistant design implemented in Malaysia. Objective of this study are to determine the cost difference between building structure with seismic and non- seismic design and to evaluate the effect of different soil type to the overall material cost of the main building structural frame. Five types of RC building frame categorised as 10 storeys, 15 storeys, 20 storeys, 25 storeys and 30 storeys were analysed and designed using ETABS software. The reinforced concrete building designed based on EC 2 and redesigned according to EC 8 with peak ground acceleration, α_{gR} 0.06g reflecting the low seismic zone in Malaysia for ductility class low (DCL) and also with soil type A, D and E which reflecting the common soil type in Malaysia. The results showed that overall cost for building models situated on soil type A and subjected to seismic load decreased in the range of 3% - 13% compared to the non-seismic design. Soil type D showed an increase in the percentage difference from 10 storeys until 25 storeys, which is in the range of 2% - 15%. After 25 storeys, the percentage difference of cost of material was found to reduce by 2% for 30 storeys. Other than that, soil type E showed an increase in the percentage difference from 10 storeys until 20 storeys, which is in the range of 0% - 8%. The percentage difference of cost of material tends to reduce by 3% -7 % on 25 storeys onward. This is due to the significant wind load effect on high-rise building. It can be concluded that building models situated soil type D showed the highest increase in the cost among the soil types compared to non-seismic design due to

the high value of base shear force, F_b and spectral acceleration at the fundamental period $T_{1.}$

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LIST OF ABBREVIATIONS

DCH	Ductility Class High
DCL	Ductility Class Low
DCM	Ductility Class Medium
EC	Eurocode
IEM	Institute of Engineer Malaysia
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
USM	University Sains Malaysia

LIST OF SYMBOLS

F_b	Base Shear Force
T_1	Fundamental Period
α_{gR}	Reference Peak Ground Acceleration
q	Behaviour Factor

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake is one of the most dangerous natural phenomena. Earthquake can be described in the simplest way as the sudden shift of the earth's surface caused by the release of energy into the earth's crust (Awaludin and Adnan, 2016). Malaysia is situated on the Sunda Plate, close to the Pacific Ring of Fire, the most active region of regular earthquakes and volcanic eruptions in the world (USGS, 2019). However, due to Malaysia's strategic position, which is situated away from the main boundary plate and the Ring of Fire, only the eastern part of Malaysia is experiencing the earthquake events such as Ranau Earthquake in 2015. In addition to that, West Malaysia especially Penang Island experienced several tremors from the neighbouring country such as Indonesia. Table 1.1 shows some of the earthquake tremors or events that struck Malaysia.

Table 1.1: Earthquake Tremors or Events in Malaysia

Year	Earthquake event	Place involved
2 Nov 2002	Sumatera Earthquake	Penang island
25 July 2004	South Sumatera Earthquake	Penang island
26 Dec 2004	Indian Ocean Earthquake	Penang island
5 June 2015	Ranau Earthquake	Ranau, Sabah
26 March 2017	Lahad Datu Earthquake	Lahad Datu, Sabah

These earthquakes from the neighbouring countries had caused several effects to Penang Island (MinDef, 2019). First, the large magnitude of earthquake generated the ground shaking and cracked some non-structural walls of the buildings. Furthermore, many people died due to the tsunami caused by the Indian Ocean Earthquake in 2014 and Malaysia was also affected by this event (MinDef, 2019). Figure 1.1 shows the damage caused by the Indian Ocean Earthquake that triggered the devastating tsunami.

Other than Penang, local earthquake with a magnitude of 6.0 hit Ranau, Sabah on 5th June 2015 (USGS, 2015).

Figure 1.1: Damaged from Indian Ocean Earthquake 2014 (MinDef, 2019)

Penang being the state with the second highest population density in Malaysia is located in a low seismic region, while Sabah is located in a high seismic region. However, because of the amplification of long-period seismic waves by local soft alluvium deposits, far-field earthquakes pose a potential risk (Tan *et al.*, 2014). In particular, high-rise building would be damage by this event, since most of the RC buildings in Malaysia were built under Eurocode 2/ BS8110 instead of Eurocode 8. Building with Eurocode 8 consists of the consideration of seismic forces.

Figure 1.2 shows the seismic hazard map of Malaysia. The highest PGA is located in Sabah (0.165g) and the lowest PGA is located in inner land of Sarawak (0.01g). Soil type would also influence the building's design. When subjected to earthquake load, Soil type also affects the seismic efficiency of buildings (Singh *et al.*, 2019). Compared to harder soil, buildings constructed on soft soil appeared to experience greater damage and as such, for buildings to be constructed on different Soil types, it is necessary to adopt different design and details (Mustafa *et al.*, 2019).

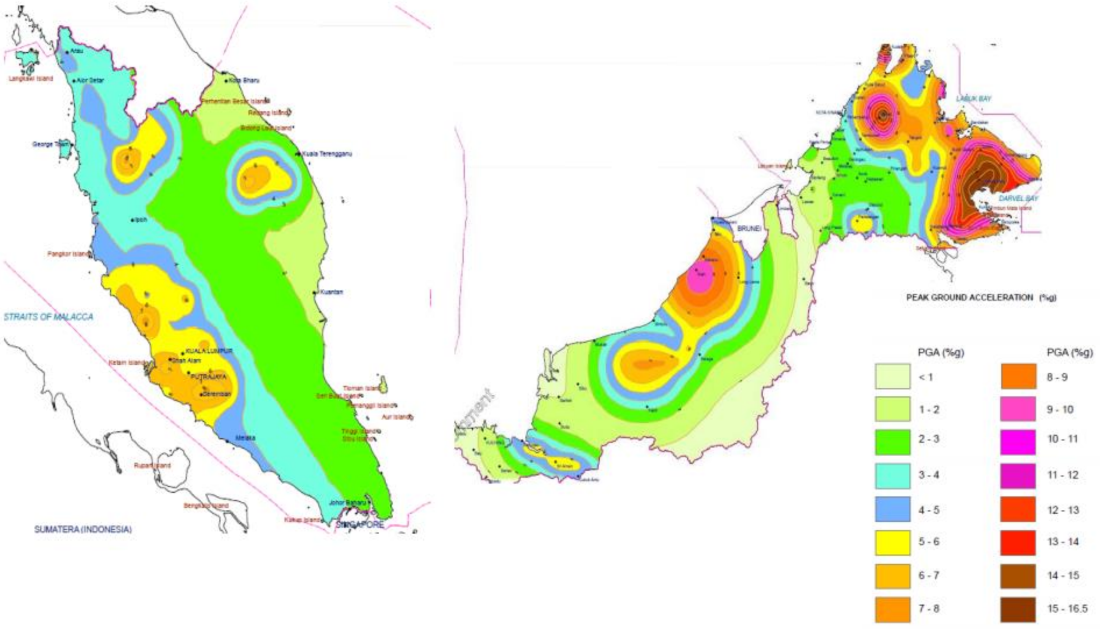


Figure 1.2: Seismic Hazard Map of Malaysia (MS EN 1998-1:2015 First Edition, 2017)

1.2 Problem Statement

Malaysia is gradually adopting seismic design for building new structures. However, the percentage increase in cost for incorporating seismic design compared to non-seismic design is scattered depending on many factors such as soil type, peak ground acceleration, behaviour factor and type of building.

It is important to know, from an economic point of view, the impact of seismic force on the cost of construction materials. Seismic design appears to cause an increase in total steel reinforcement, which would increase the cost directly. However, it is still not clear, for a specific building type, 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 recognize the effects of the earthquake on the construction structure in Malaysia in particular, at area where high rise buildings are relatively a common construction. The findings from this study is valuable to the players in the construction industry for budget preparation, costing and sales.

1.3 Objectives

The objectives of the study are:

1. To determine the material demand for the main structural members of building models subjected to non-seismic and seismic design.

2. To evaluate the effect of different soil types to the overall material cost.

1.4 Scope of Work

In this study, ETABS software is used for the analysis and design of the rectangular office building models provided by IEM Penang Section. The dimension of the floor plan for the office building is 99 m x 27 m and varies at 10, 15, 20, 25 and 30 storeys. All the details of the element used such as beam, column, slabs, shear walls are given by IEM. The design is based on Eurocode 2 (conventional design) and Eurocode 8 (seismic design). In the case of the earthquake resistant building, seismic load and wind load are generated with the aid of ETABS 2018 software.

This study only covers building located on Soil type A, D and E. This selection covers rock and soft soil. Hence, a total of 20 models is generated with varying number of storeys and soil types.

The total cost is calculated mainly based on the design demand of the two main construction materials namely, concrete volume and the weight of steel reinforcement. The quantity and cost of the materials only focus on beams, columns and RC walls for both non-seismic and seismic design considerations. These structural members formed the main frame of the building model.

1.5 Significance of Study

This study provides information on the cost comparison of the main frame of a building subjected to non-seismic and seismic load. Several building heights are selected that covers mid-rise to high-rise structures. The results from this study broaden the spectrum of the cost analysis data currently available in the open literature. Therefore, 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 contains another 4 chapters and the description for every chapter is as follows:

Chapter 2: Literature Review

This chapter 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: Methodology

This chapter describes the procedures of this study to achieve the research objectives. The description of the models, building data, loading intensity, load combination and the steps involved using ETABS 2018 software are presented in this chapter.

Chapter 4: Results and Discussions

This chapter 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 software. The discussion pertaining to the percentage difference and the overall cost of the building main frame also presented accordingly.

Chapter 5: Conclusions

This chapter summarizes the important findings of this research based on the objectives of the study before the conclusion can be made. To further appreciate the study on EC8 of the buildings, recommendations for the work in the future are listed.

CHAPTER 2

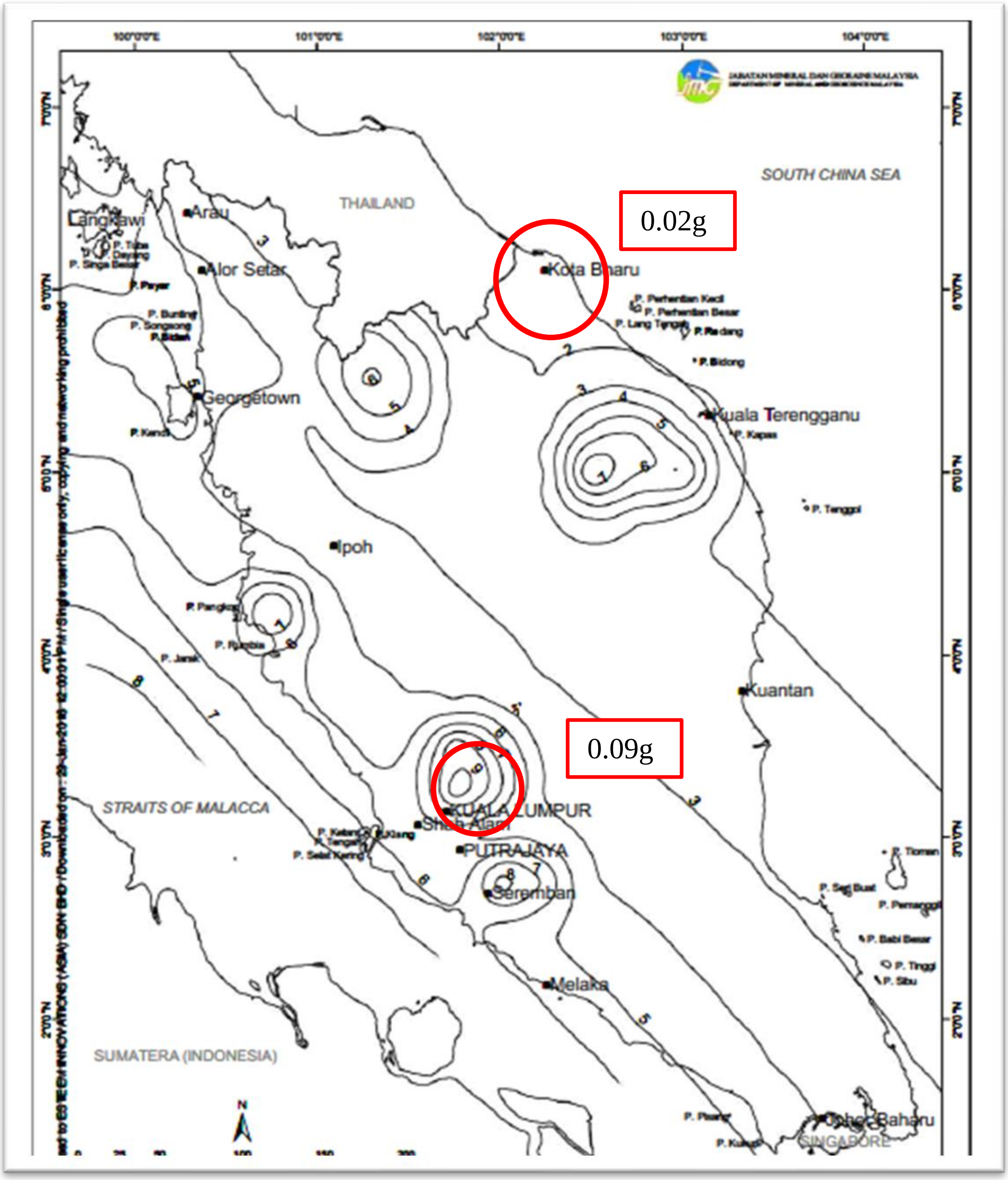
LITERATURE REVIEW

2.1 Overview

This chapter discusses some of the predicted rise in the construction costs due to the seismic loading integration in Malaysia. Prior to that, this chapter briefly introduces the development of EC8 and Malaysia National Annex, ground types classifications and effects of earthquake toward buildings. This chapter also includes overview on designing of reinforced concrete building according to conventional design (Eurocode 2) and seismic design (Eurocode 8). In addition, this chapter also covers the factor affecting the damage of reinforced building due to earthquake, incorporation of seismic load in design practice and cost analysis for earthquake resistant structures.

2.2 Malaysia National Annex to Eurocode 8

The development of this National Annex was initiated in 2007 until its publication in 2017. In 2009, relevant international and foreign standards had been studied as part of the preparation of the draft in conjunction to the implementation of seismic design in Malaysia. Figure 2.1(a) to 2.1(c) show the seismic map of Peninsula Malaysia, Sabah and Sarawak in this Malaysia National Annex.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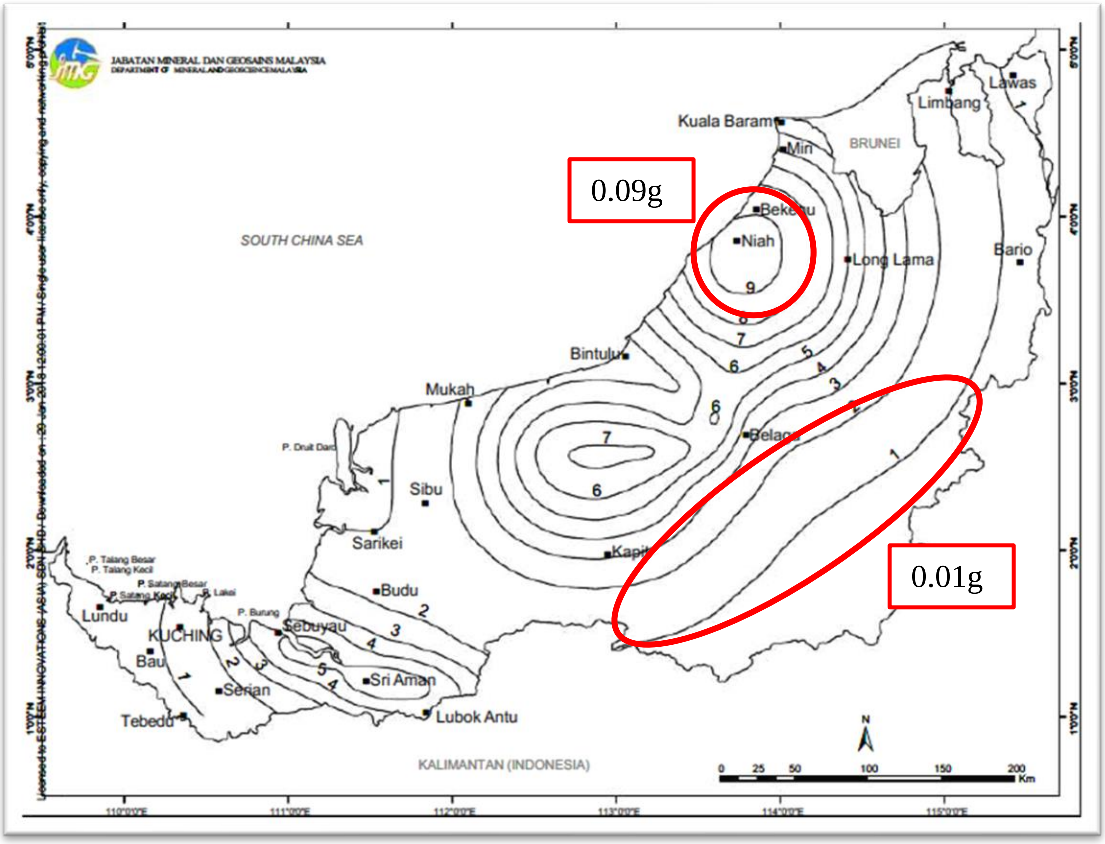
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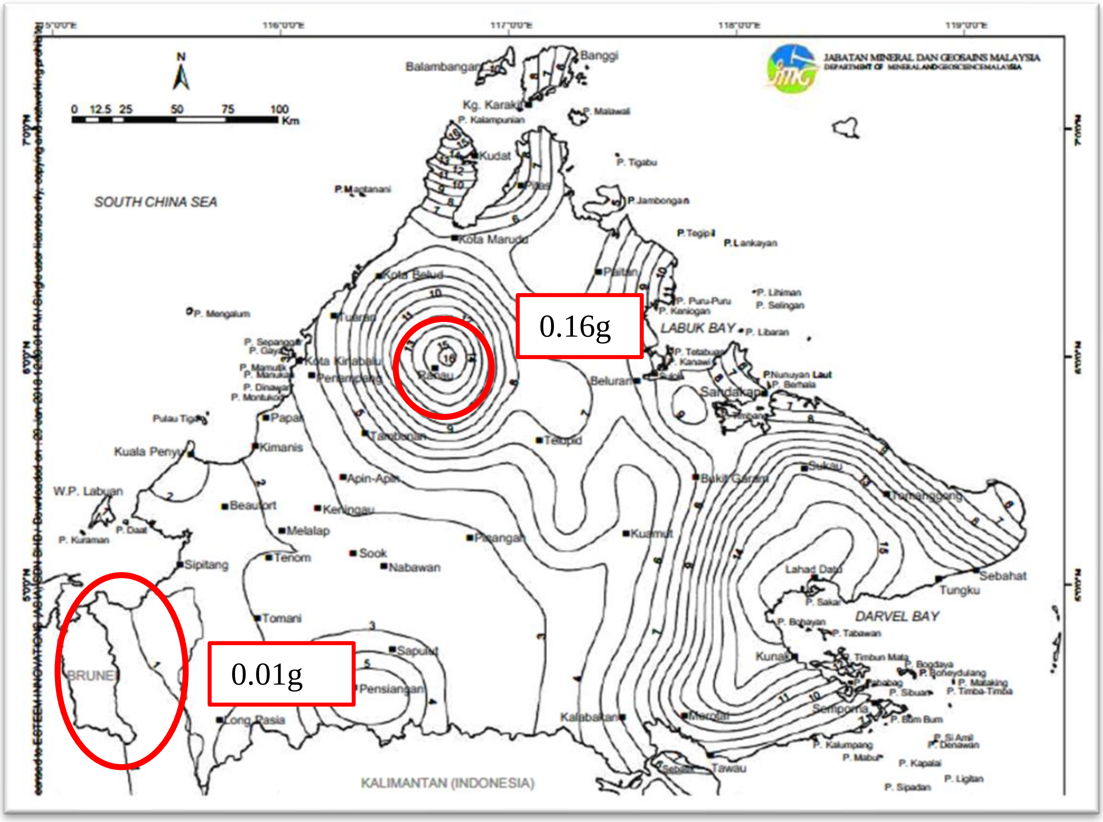
(b)



(c)

Figure 2.1: PGA (%g) Contour Map of (a) Peninsula Malaysia, (b) Sarawak, (c) Sabah with a 10% Probability of Exceedance in 50 Years (MS EN 1998-1:2015 First Edition, 2017)

Based on Figure 2.1(a), the highest contour in Peninsula Malaysia is located in Kuala Lumpur and the lowest contour is located in Kota Bahru. The PGA value for Kuala Lumpur and Kota Bahru is 0.09g and 0.02g, respectively. On the other hand, based on Figure 2.1(b), the highest contour in Sarawak is located in Niah and the lowest contour is located in inner land of Sarawak. The PGA value for Niah and inner land of Sarawak is 0.09g and 0.01g, respectively. Finally, as shown in Figure 2.1(c), the highest contour in Sabah is located in Ranau and the lowest contour is located near Brunei. The PGA value for both places is 0.16g and 0.01g, respectively.

The European Standard EN 1998-1, Eurocode 8: Design of structures for earthquake resistance: General rules, seismic actions and rules for buildings, was prepared by Technical Committee Commission of European Community, CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by British Standard Institution (BSI). CEN/TC 250 is responsible for all Structural Eurocodes. Eurocode 8 applies to the design of buildings and civil engineering works in seismic regions.

Eurocode 8 consists of seven ground types varied with A, B, C, D, E, S_1 and S_2 for soil sediments with depth less than or equal to 30 m. On the other hand, Malaysia National Annex only considers five ground types namely A, B, C, D and E for soil deposit exceeding 30 m in depth. Table 2.1 and 2.2 show the ground type classification scheme based on Table 3.1 of Eurocode 8 and Table A1 of Malaysia National Annex.

Table 2.1: Ground Type Classification (Table 3.1, MS EN 1998-1:2015)

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	-	-	-

In the table above, $v_{s,30}$ is the average shear wave velocity, and computed in accordance with the following expression:

$$V_{S,30} = \frac{30}{\sum_i^n \frac{h_i}{V_i}}$$

where:

h_i = Thickness of soil layer

V_i = Shear-wave velocity (at a shear strain level of 10 – 5 or less) of the *i-th* formation or layer, in a total of N, existing in the top 30m

Table 2.2: Ground Type Classification (Table A1, Malaysia NA to MS EN 1998-1:2015)

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)

2.3 Factors Affecting the Damage of Reinforced Concrete Building due to Earthquake

Earthquake will cause damage to the structure when the structure is not strong enough. There are several factors affect the level of damages of a structure such as soft and weak stories mechanism, strong-beam weak-column mechanism, ductility class, height of building, short columns and etc.

2.3.1 Soft and Weak Stories Mechanism

According to Jara *et al.*, (2020) most of the damaged buildings in Mexico City in the 2017 earthquake was due to the commonly constructed vertically irregular soft storey buildings. The damaged and collapse of this building is shown in Figure 2.2. Most of the buildings in Mexico posed a common characteristic where the ground floor serves as parking and upper floors as residential house. Therefore, the first floor had open spaces for parking and the allocation of the spaces of the residential area on other floors used masonry walls to support the slabs. During the earthquake, the upper floor frame (above the flexible ground floor) had experienced significant movement. In the damaged columns of some of the houses, it was also found that transverse reinforcement had excessive separation from the point of view of the regulation code.

Other structures with this typology that did not collapse showed column damage consisting of loss of concrete cover and buckling of the longitudinal bars and complete damage of the concrete core when lateral displacements of the first floor were important as shown in Figure 2.3. These structures confirmed previous observations about small relative displacements on upper floors, significant displacements on the first floor, and excessive hoop spacing in columns.

Figure 2.2: Collapse of the building in Mexico City (Jara *et al.*, 2020)

Figure 2.3: Loss of concrete cover and buckling of longitudinal bars (Jara *et al.*, 2020)

2.3.2 Strong-beam Weak-column Effect

Alih and Vafaei (2019) revealed that during the earthquake in Sabah on 2015, the damages of the building were due to the strong-beam weak-column condition, short column effect and, irregularity in plan and elevation. It is shown that when a column that has a smaller moment of resistance compared to beam, the plastic hinge will develop in columns rather than beams. The authors found that the beam size used was very large compared to the column size (almost three times larger). Therefore, when there is an earthquake event, a large crack appeared in the joint and transferred to the upper part of the column when the beam is intact. The authors concluded that the damage to the joint of the building can be avoided if a proportional size of the beam to column has been used. Figure 2.4 and 2.5 show the difference between these sizes.

Figure 2.4: Proportional size of beam against size of column (Alih and Vafaei, 2019)

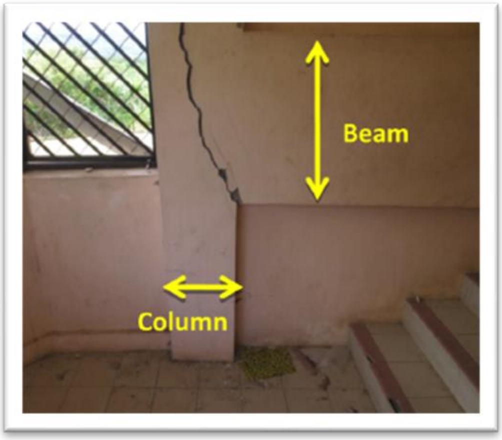


Figure 2.5: Strong-beam to weak-column (Alih and Vafaei, 2019)

In Malaysia, strong-beam weak-column construction is quite popular in RC frame buildings, and deep beams are frequently supported by flexible columns. However, this strong-beam to weak-column can be eliminated by allowing a bigger size of the column in comparison to beam. Otherwise, it can be prevented by using concrete with higher compressive strength for column than that of beams and slabs (Alih and Vafaei, 2019).

2.3.3 Ductility

Sudha and Venkateswarlu (2016) stated that for the past earthquake event, the most damage of the buildings came from the brittle materials. Compare to the building using ductile material, brittle materials such as brick and concrete blocks tend to be crack under the large magnitude of load. Furthermore, the ductility class of steel reinforcement is also one of the important factor. Zahid *et al.*, (2017) stated that there is no study to access the correlation between top displacement ductility demand with behaviour factor and fundamental period of vibration of reinforced concrete buildings. Hence, their study is more towards the investigation in the elastic and inelastic response of the low rise and high rise reinforced concrete building designed for various behaviour factor. Awaludin and Adnan (2016) stated that there are three class of ductility normally used in Malaysia, namely:

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.

Normally, Ductility Class H is for the Sabah, while Ductility Class M and Class L is for Peninsula Malaysia. This consideration is due to the low Peak Ground Acceleration (PGA) in Peninsula Malaysia compared to Sabah. Ductility Class Low is almost the same as the Eurocode 2 which is non seismic design.

2.4 Soil Type

Hong *et al.*, (2020) stated that a building's seismic performance is affected by different soil types, where the foundation soils are the key elements in the proper seismic design of structures. In their study, reinforced concrete school building of two-storey and four-storey, which under different soil types were modelled. These models were designed based on Eurocode 2 and Eurocode 8 using Tekla Structural Designer software. From the analysis, models built under soil type D and soil type E exhibited the highest seismic base shear force in the form of horizontal load. Therefore, for the structural elements of a building, a larger section size is built to resist a higher magnitude of the seismic base shear force that acts on the building due to a soft or weak condition of soil. Subsequently, the weight of steel bar in the beams and column increased due to the larger diameter of steel bar provided lead to the higher cost of the steel reinforcement.

Moreover, the increase in the material cost was shown to be more significant for soil type D and E when normalized with the non-seismic design condition.

Furthermore, Mustafa *et al.*, (2019), investigated the earthquake that hit Ranau (Sabah) on 5th June 2015. The earthquake caused damaged to the RC buildings especially on the structural elements such as beam, column and beam-column joint. In addition, these damages also occurred on the non-structural elements such as ceiling and brick wall. Therefore, in order to determine the increase in cost for adopting seismic design (preventing damage on the building in the future) the authors used a four-storey RC building in class IV in their study. The models were designed by considering 5 different soil types, namely A, B, C, D and E according to EC8. The reference Peak Ground Acceleration (PGA) was fixed as 0.07g while the behavior factor was taken as 3.9 to suit the medium ductility class.

Based on the results, the models considering the seismic design with soil type B to soil type E showed a higher amount of steel reinforcement compared to the non-seismic model. The increase in the steel reinforcement demand was found to be in the range of 1.16 to 2.11 greater compared to the non-seismic model. The increase of the steel reinforcement in both beam and column was associated to the Strong Column - Weak Beam design approach, meaning that the column was designed to be stronger than the to beam in order to achieve the design theory. The authors concluded that different soil type resulted in various steel reinforcement costs even for the identical structure layout and configuration.

2.5 Lateral Load

Lateral load normally is different with gravity load whereby lateral load is an imposed load which are applied parallel to the ground. There are many types of lateral load and the most common types are wind load, seismic load, water and earth pressure.

2.5.1 Wind Load

According to Reddy and Tupat (2014), both earthquake and wind load can be estimated in the particular zone and based on the basic wind speed. However, the wind velocity is hard to predict and it is relied on time. Hence, a study was made to compare the design of multistorey building by using *IS 1893* and *IS 875* where these codes of practice are for the seismic and other than seismic design code in India, respectively. The wind loads were predicted upon the design wind speed of that zone with a variation of 20%. The results showed that wind load is more critical than seismic load in most of the cases. The authors concluded that any construction in India would have to be planned separately for substantial wind or earthquake forces. Similar finding stating that wind load was more significant than seismic load was also observed from the work of Reddy and Kumar, (2017).

Nizamani *et al.,* (2018) found that the effect of the wind load on high-rise buildings became more significant as the number of storeys increase. According to the authors, the storey shear and the moment will increase due to the accumulation of the wind pressure up height. The impact of increased wind speed on high-rise building superstructure elements is conducted through the study. Additionally, to understand how the building behaves in the presence of the fluctuation component of wind loading, dynamic wind loading and non-linear analysis could be performed. However, when the number of storeys is low, the effect of the wind load is not significant.

2.5.2 Seismic Load

Sudha and Venkateswarlu (2016) stated that the term seismic load refers to the horizontal ground motion action that is similar to the effect of a horizontal force acting on the building. Inertia forces are created throughout the mass of the building and its contents as the base of the building moves in an extremely complicated manner. These reversible forces cause the building to damage or collapse.

Awaludin and Adnan (2016), investigated the effect of the increase in the cost of building materials under different types of loads which is static and lateral loads through the design of the buildings based on the EC2 and EC8. In this study, wind load was not included in the design due to the design is only involved low-rise and medium-rise building. Through the analysis by using STAAD Pro V8i software, the result showed that the cost of the seismic design building was higher than that of non-seismic design. The finding was associated to the use of ductility class in the design is EC 8. As the ductility class increases, the steel reinforcements required in the structural elements such as column, beam also became higher. This finding concludes that when ductility increase, the steel reinforcements required also increased and subsequently cause the final cost of the building structure increase. For low-rise building, the increased of the cost for DCL, DCM, DCH are 4%, 13% and 68% when compared to conventional design, respectively. For medium-rise building, the increased of the cost for DCL, DCM, DCH are 33%, 36% and 87% when compared to conventional design, respectively. It is commonly known that higher ductility class, and higher material demand, the higher cost is needed. This is due to the larger the size of the bar used, the structure tends to deform plastically without collapse and increase the energy dissipation. Hence, it will reduce the effect of the seismic force.

Based on CEN Eurocode 8, 2004, the seismic impact on a structure can be calculated on the basis of the structure's linear- elastic behavior. In EC8, there are 2 types of linear-elastic analysis method that are suggested to determine the seismic impact namely the lateral force method of analysis and modal response spectrum analysis. While the non-linear method such as non-linear static (pushover) analysis and non-linear time history (dynamic) analysis can be used as an alternative to linear method.

2.6 Model Analysis

In order to obtain the relationship between all frames in the direction that is considered, 3D model provides accurate results. However, if time is a constraint, 2D frame can also be used to obtain the acceptable results. In addition, many commercial software have the capability to perform seismic analysis and seismic design such as Tekla Structural Designer, SAP2000, ETABS and STAADPRO V8i software.

Oggu and Gopikrishna (2020) used SAP 2000 software in the model analysis of the assessment of RC buildings under repeated earthquake. In their analysis, both irregular and non-irregular building shapes were generated in 3D. Figure 2.6 and Figure 2.7 show the side view of the frame and also the result on the hinge pattern for the building configuration. The findings of this study indicated that the collapse capacity of RC buildings under repeated earthquakes was significantly lower than that of the most severe single earthquake. This emphasizes the importance of accounting for repeated earthquake forces during the design phase when constructing a seismically resilient structure. The use of ETABS as the tools to perform seismic study on low to high rise building models was also shown in the work of Inchara and Ashwini (2016) and Chetan and Amey (2018). The model generated by Inchara and Ashwini (2016) using ETABS is shown in Figure 2.8.

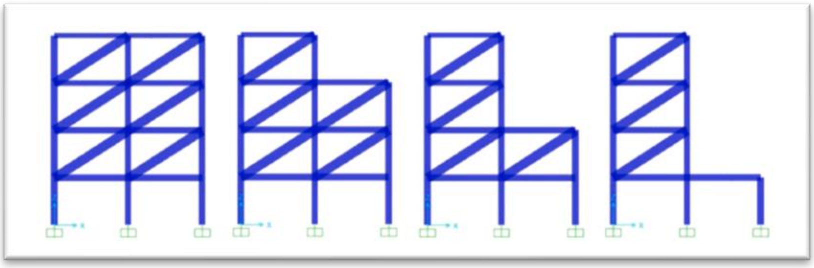


Figure 2.6: Side view of the 3D frame (Oggu and Gopikrishna, 2020)

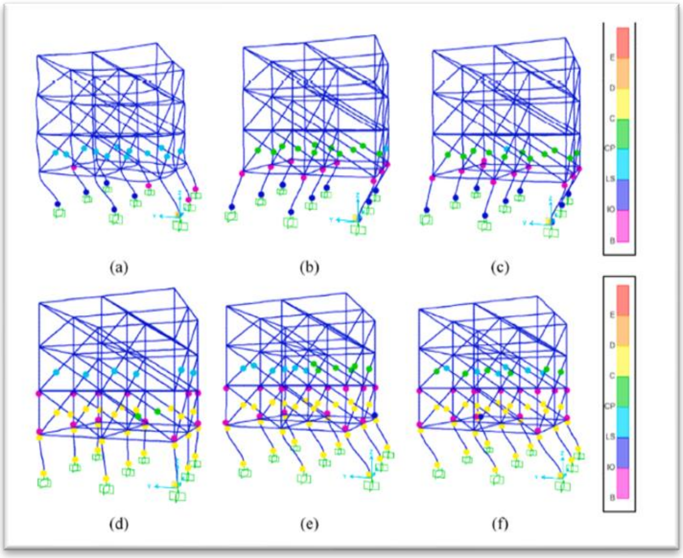


Figure 2.7: Hinge pattern of building configuration (Oggu and Gopikrishna, 2020)

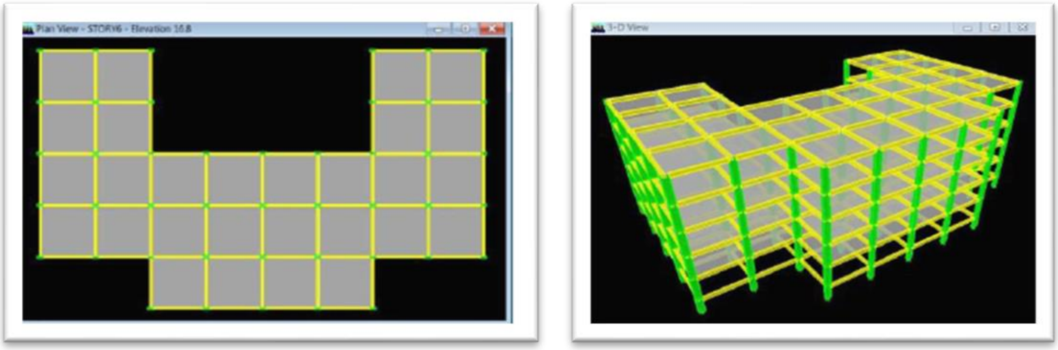


Figure 2.8: Plan view and 3D view of the model (Inchara and Ashwini, 2016)

Adiyanto *et al.*, (2019) used Tekla Structural Designer software to analyse the model of a six-storeys hospital building with seismic design consideration. The floor to floor height is 3.6m and the column to column span is 3 m and 6 m. Figure 2.9 shows the 3D view of the models.

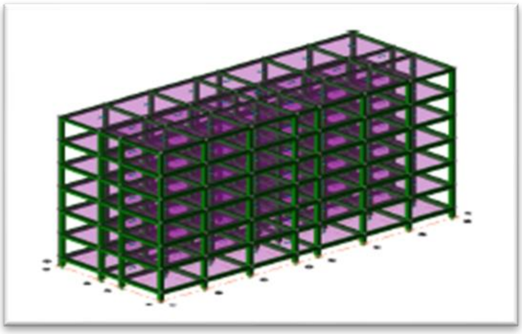


Figure 2.9: 3D view of six storey hospital RC building (Adiyanto *et al.*, 2019)

In the study of Hong *et al.*, (2020), a 4-storey school building and a 2-storey school building under the seismic design with different condition was modelled through Tekla Structural Designer software. In this case, the storey height is 3.5 m for each and regular in shape.

Other than that, Ramli *et al.*, (2017) used ETABS software in modelling residential building which consist of low rise 5-storeys and medium rise 10-storeys. The response spectrum analysis in ETABS was used to take into account the different number of modes of response of the buildings. From the combination of multiple modes, the response of a structure can be known easily. In their study, they used different ductility class as a variable to determine the quantity of steel reinforcement and concrete volume between seismic and non-seismic design.

2.7 Previous Case Study on Increment of Cost due to Seismic Design

Adiyanto *et al.*, (2019) conducted a study to determine the total tonnage of steel reinforcement through the class of ductility. Ductility class low (DCL) and ductility class medium (DCM) was considered in this study. Ductility class high (DCH) was eliminated from this study is due to it is only suit for the region with high seismic activities such as Greece, Turkey and Italy. In their study, they compared the design with the same PGA but different ductility class. For example, they compared the total steel reinforcement of the beam design for DCM by comparing to DCL under the same PGA which is 0.04g. Their findings showed that the weight of steel reinforcement for the DCL was higher than that of DCM in design as shown in Figure 2.10. The authors stated that the DCM design generated a lower base shear force, F_b and hence the internal reactions and the needs for steel reinforcement decreased.

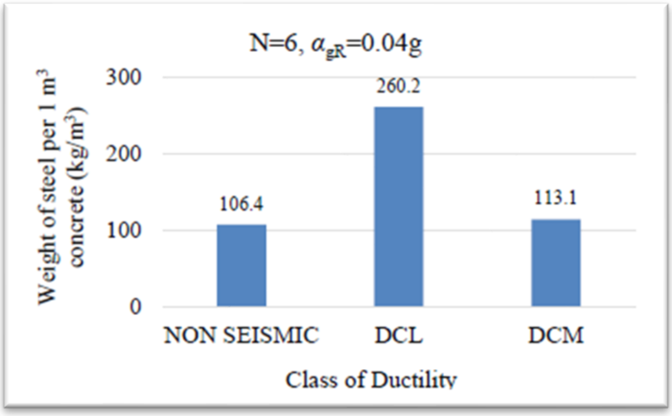


Figure 2.10: Total weight of steel reinforcement for 1m^3 concrete for different class of ductility (Adiyanto *et al.*, 2019)

According to Adiyanto and Majid, (2014), the total cost of material increased in the range of 6% to 270% depending on different PGA values. In their study, low rise building models were tested with different level of reference Peak Ground Acceleration, which represented the seismic zone in Malaysia. In addition, two behaviour factors, q =1.0 and q =1.5 were applied in the analysis. The results showed that the normalized cost of the building adopting q = 1.0 was higher than q =1.5. Although the higher the value of the behaviour factor, the higher the value of the base shear force, F_b, the authors found that the level of behaviour, q will not influence the total volume of concrete used for the