EVALUATION OF VARIATION IN MATERIAL COST FOR DESIGN OF REINFORCED CONCRETE BUILDINGS IN PENANG ISLAND CONSIDERING SEISMIC EFFECT

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by

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ABSTRAK

Malaysia terletak di kawasan yang selamat daripada gempa bumi. Walau bagaimanapun, industri pembinaan di Malaysia akan menggunakan Lampiran Nasional Malaysia (NA) untuk Eurocode 8 kerana keadaan yang menimbulkan kebimbangan mengenai integriti bangunan yang ada yang dibina tanpa mempertimbangkan beban seismik. Terdapat sedikit maklumat mengenai kenaikan kos bahan sekiranya reka bentuk tahan gempa dilaksanakan di Malaysia. Kajian ini bertujuan untuk menentukan kenaikan kos bahan akibat beban seismik, serta pengaruh ketinggian bangunan dan jenis tanah terhadap kos bahan. Bangunan 10 tingkat, 15 tingkat, 20 tingkat, 25 tingkat, dan 30 tingkat dimodelkan untuk reka bentuk tanpa seismik dan reka bentuk seismik di bawah jenis tanah A, D, dan E. Peningkatan kos bahan antara reka bentuk bukan seismik dan reka bentuk seismik ditentukan. Selain itu, kenaikan kos bahan reka bentuk seismik dalam pelbagai jenis tanah juga akan ditentukan. Bangunan konkrit bertetulang dirancang berdasarkan EC2 dan direka semula mengikut EC 8 dengan pecutan tanah puncak yang mencerminkan bahaya seismik di Pulau Pinang. Penggunaan keluli penguat yang lebih tinggi di EC 8 berbanding reka bentuk EC 2 menyebabkan kenaikan kos bahan. Walau bagaimanapun, penyediaan bar tetulang di EC2 lebih tinggi daripada EC8 apabila ketinggian tingkat hingga 30 tingkat. Peratusan kenaikan kos didapati masing-masing 11.45%, 20.05%, 10.02%, 5.08% dan -10.22% untuk bangunan 10 tingkat, 15 tingkat, 20 tingkat, 25 tingkat dan 30 tingkat. Selain itu, penggunaan keluli penguat yang lebih tinggi di EC8 di bawah tanah jenis D berbanding dengan tanah jenis A dan E menyebabkan kenaikan kos bahan. Berbanding dengan jenis tanah D, kos bahan untuk jenis tanah A menurun 5.24%, 2.06%, 4.84%, 9.10%, dan 6.64% untuk bangunan 10 tingkat, 15 tingkat, 20 tingkat, 25 tingkat, dan 30 tingkat masing-masing. Berbanding dengan jenis tanah D, kos bahan untuk jenis tanah E menurun 2.61%, 1.71%, 2.25%, 0.08%, dan 8.03% untuk bangunan 10 tingkat, 15 tingkat, 20 tingkat, 25 tingkat, dan 30 tingkat, masing-masing.

ABSTRACT

Malaysia is located in a seismically safe area except few places in Sabah. However, the construction industry in Malaysia will adopt Malaysian National Annex (NA) to Eurocode 8 due to instances that raised concerns about the integrity of existing buildings that were built without considering seismic loads. There is little information on the material cost increases if the earthquake-resistant design is implemented in Malaysia. This study aimed to determine the variation in material cost due to seismic loading, as well as the influence of building height and ground type on material cost. Building of 10 storey, 15 storey, 20 storey, 25 storey, and 30 storey were modelled for non-seismic design and seismic design in ground types A, D, and E. The material cost increment between non-seismic design and seismic design was determined. Besides that, the material cost increment of seismic design in different ground types were also determined. The reinforced concrete building was designed based on EC2 and designed according to EC 8 with peak ground acceleration reflecting the seismic hazard in Penang. The greater amount of reinforcement bar in EC 8 compared with EC 2 design leads to an increase in the material cost. However, compared with EC8, the provision of reinforcement bar according to EC2 is higher when the storey height is at 30 storey. The percentage of cost increment is found to be 11.45%, 20.05%, 10.02%, 5.08% and -10.22% for 10 storey, 15 storey, 20 storey, 25 storey and 30 storey buildings, respectively for ground type D. Besides that, the amount of reinforcement bar according to EC8 under ground type D compared to ground type A and E leads to increase in the material cost. Compared with soil type D, the material cost for ground type A decreases 5.24%, 2.06%, 4.84%, 9.10%, and 6.64% for 10 storey, 15 storey, 20 storey, 25 storey, and 30 storey buildings, respectively. Compared with soil type D, the material cost for soil type E decreases

2.61%, 1.71%, 2.25%, 0.08%, and 8.03% for 10 storey, 15 storey, 20 storey, 25 storey, and 30 storey buildings, respectively.

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LIST OF ABBREVIATION

PGA	Peak Ground Acceleration
RC	Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquakes are common occurrence that can arise unexpectedly and cause tremendous damage to the engineered facilities and structures. The incidence of earthquakes is difficult to avoid, but the risk can be minimized utilizing seismic designs. The earthquakes cannot be predicted precisely due to various factors such as tectonic plate shift, sudden fault slides and volcanic explosions. When it comes to structural engineering, an engineer's task is to ensure the best possible safety for building structures while keeping the construction costs down.

If a structure is built for a natural incidence such as an earthquake, structural engineers construct it to account for limiting conditions such as serviceability, damageability, and collapse (Shakeeb et al., 2015). The lateral forces applied during seismic analysis are highly unpredictable. As a result, the design specification should provide stringent criteria for maintaining safety against earthquakes, severe failure, and loss of life. To design a stable structure against seismic activity, the size of the member and the amount of reinforcement should be considered.

Malaysia is generally regarded as an earthquake-free area due to its distance from the affected seismic fault zones. As Malaysia has not yet suffered earthquake disasters, earthquake design has not been considered for engineering facilities and structures in low to moderate seismic regions of Southeast Asia. However, on the 5th of June 2015, a local earthquake struck Ranau, Sabah, killing 18 people and causing extensive damage to engineered facilities and buildings. As compared to the beam, in-situ observation revealed that the column sustained significant damage. The Standard Malaysia Department proposed a new design requirement to make the building more earthquake-resistant, which would result in a 5% to 10% increase in construction costs over standard design (Yuen, 2017).

Almost all of the constructed structures on Penang Island were designed and built-in compliance with British requirements, Eurocode 2, and without concern for seismic design. As a result, the seismic resistance of existing buildings on Penang Island is uncertain. In Penang Island, the most important action is to introduce seismic design following the introduction of Malaysia National Annex to Eurocode 8. The seismic design will improve the safety of engineered buildings in the future and protect human life. As a result, more research studies into the impact of seismic design considerations on construction material costs should be conducted to ensure that the construction planning budget can be effectively managed.

1.2 Problem Statement

There is limited information about the variation of material cost between non-seismic design and seismic design in Malaysia. Besides that, there is lack of information about the seismic effect on structural member with the consideration of different number of storey and different types of ground. Lack of awareness and information about the rising cost of materials in design involving seismic load will cause difficulties and uncertainty for stakeholders in preparing the budget for a construction project on Penang Island. By carrying this study, information regarding possible range of variation in material required for concrete and steel reinforcement can be determined. This information will in turn provide reference about possible range of cost variation. Outcome of this study will also provide guidance on planning of subsequent study in terms of factors affecting the cost variation.

1.3 Objectives

The objectives of the study are:

1. To determine the effect on volume of concrete and amount of steel reinforcement among reinforced concrete buildings which are designed with and without considering seismic effect
2. To determine the cost increment between non-seismic and seismic design in Ground Type D for different number of storey
3. To determine the cost increment between seismic design in Ground Type A, D and E for different number of storey

1.4 Scope of Work

According to Eurocode 2 and the Malaysian National Annex (NA) to Eurocode 8, ETABS18 is used to generate various storey high-rise buildings models with 15 x 3 bays under different ground conditions in this study. The layout of building considered is of regular layout without any vertical and horizontal irregularities. In structural analysis, the ETABS18 version is used to design the high-rise building. A variety of multi-story high-rise buildings with 15 x 3 bays are modelled for study under various ground conditions: 10, 15, 20, 25 and 30 storey with ground types A, D and E considered.

Wind load is considered in analysis of high-rise building models following Malaysian standards. The seismic parameter and impact are calculated by referring to Eurocode 8 when designing the model with seismic consideration. The seismic loading is considered in ETABS 18 for analysis in order to design the seismic resistance high-rise building. On the other hand, non-seismic high-rise building models are generated using ETABS 18 and following requirements in Eurocode 2.

The difference in material costs is calculated by comparing seismic and non-seismic models of high-rise buildings analysed using ETABS 18 under various soil conditions. The material cost in this study is primarily calculated by the volume of concrete and the amount of steel reinforcement used in both types of building designs. Aside from that, other costs such as temporary labour and materials would affect the construction cost. However, we are primarily concerned with material costs, such as concrete volume and reinforcements in columns, beams and shear walls.

1.5 Significance of Study

When the seismic design is taken into consideration in reinforced concrete buildings, material costs is expected to rise when compared to non-seismic reinforced concrete building designs. However, there is limited information on the expected rise in construction costs due to seismic loading implementation in Malaysia.

The aim of this study is to investigate the variation in material costs for reinforced concrete among reinforced concrete buildings which are designed with and without considering seismic effect. Besides that, this study is also carried out to determine the variation among reinforced concrete building with seismic design consideration with various type of ground condition. The volume of concrete and the amount of reinforcement for the column and beam are the most critical factors determining the material cost. This evaluation of material cost is crucial because it can help to assess cost variations based on the number of storey and various construction factors such as seismic and non-seismic design and different types of ground. Engineers, developers, and contractors may use this information to estimate building material costs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In Malaysia, there is very little information on the potential rise in construction costs as a result of seismic loading. Furthermore, fundamental design and detailing as required by the code of practice, particularly with regard to minimum member size and steel reinforcement, having a significant impact on cost analysis. This chapter provides an overview of reinforced concrete building design based on Eurocode 2, Eurocode 8, and the Malaysia National Annex to MS EN 1998-1:2015. This chapter also includes previous studies on earthquake-resistant construction in Malaysia.

2.2 Seismicity of Malaysia

Malaysia is situated on a stable Sunda platform on the Eurasian plate, bordered by two seismically active plate boundaries: the Indo-Australian Plate and the Philippine Sea Plate (Figure 2.1). However, tremors have been felt in tall buildings in Singapore and Kuala Lumpur, Malaysia's capital, many times in recent years due to strong earthquakes in Sumatra. The mechanism of those tremors is shown in Figure 2.2. Seismic waves produced by a Sumatra earthquake travel a long distance before reaching Malaysia bedrock. The high-frequency earthquake waves were quickly dampened out during propagation, while the low-frequency or long-duration earthquake waves were more resistant to energy dissipation and thus traveled a greater distance. As a result, seismic waves hitting the bedrock of Singapore or the Peninsular Malaysia are rich in long-duration waves, and when they spread upward through soft soil sites with a period similar to the prevailing period of the seismic waves, they are greatly intensified due to resonance (Balendra & Li, 2008).

While Malaysia is not in an active fault zone, buildings built on soft soils are frequently subjected to the far-field effects of earthquakes caused by Sumatran subduction and fault zones, especially in areas along Peninsular Malaysia's west coast, such as Penang, Johor Bharu, and Kuala Lumpur. The epicentres of earthquakes in neighbouring countries and other locations near Penang recorded are as shown in Figure 2.3 (Tan et al., 2014).

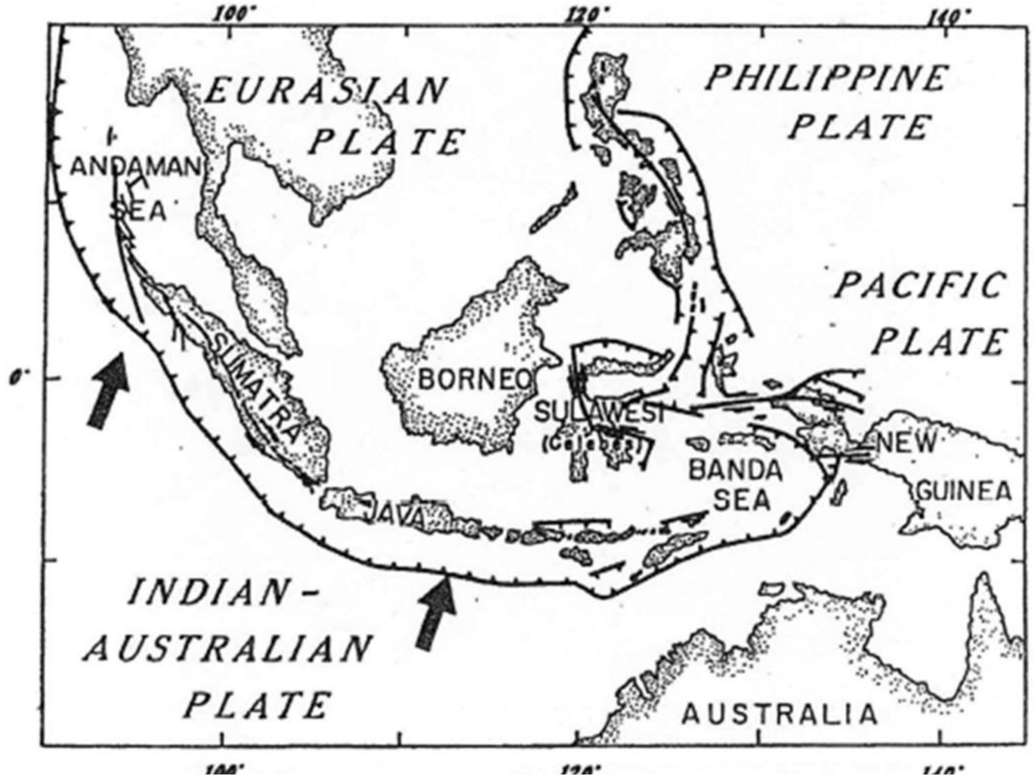

Figure 2.1 Sumatran Fault and Subduction of The Indo-Australian Plate into The Eurasian Plate (Tan et al., 2014)

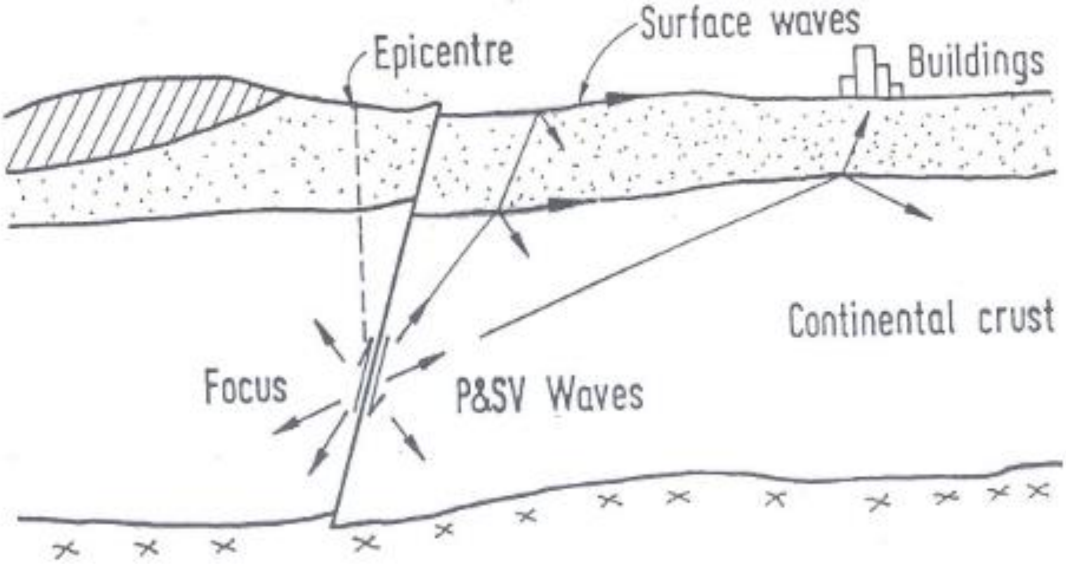

Figure 2.2 Schematic Diagram for Far-field Effects of Earthquakes (Balendra & Li, 2008)

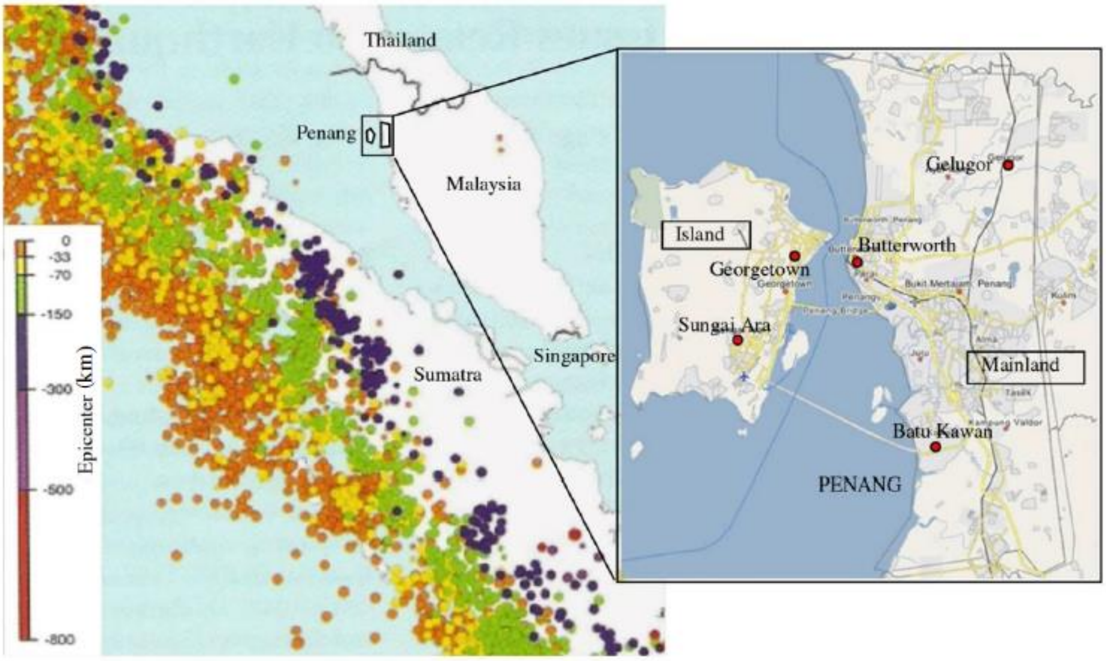

Figure 2.3 Record of The Earthquake Epicenter and Location of The Study Area (Tan et al., 2014)

According to Chiang & Mun (2011) study on local earthquakes in Peninsular Malaysia, a new 80-kilometer-long fault line was discovered at Bukit Tinggi, which is about 200 kilometres from Penang. More earthquakes are likely to occur in the immediate future, given that the Bukit Tinggi fault has already been subjected to an earthquake. Even though intra-plate fault earthquakes have smaller magnitudes, they are extremely difficult to predict and should not be underestimated (Chiang & Mun 2011). 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). High-rise buildings in Georgetown swayed, according to the Malaysian Meteorological Agency and the media.

A broad source zone modelling method was used in the analysis for Peninsular Malaysia so that the recurrence modelling of potentially damaging earthquakes could be predicted directly. Sabah's seismicity is divided into two zones: Zone 1 is a low seismicity zone bounded by the Sarawak border and a dividing line west of Kota Kinabalu, and Zone 2 is the rest of Sabah from the middle to the northeast of the dividing line (Figure 2.4). Zone 1 is part of the Sarawak zone, while the level of hazard for Zone 2 will be determined based on earthquake activity reported in this part of Sabah (Looi et al., 2018).

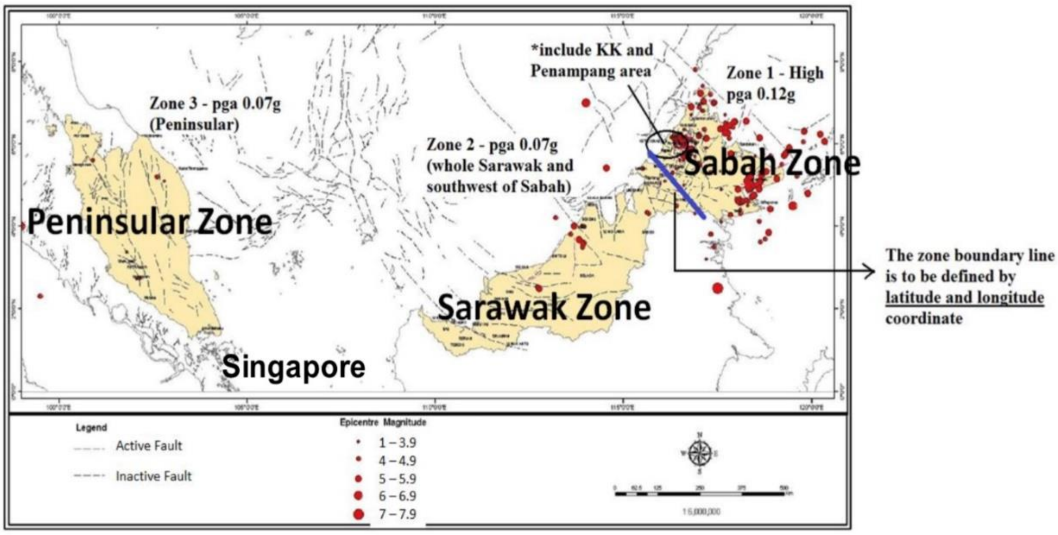

Figure 2.4 Seismic Hazard Zonation across Malaysia and Singapore (Looi et al., 2018)

Within Peninsular Malaysia, near-field earthquakes are earthquakes that originate locally. As shown in Table 2.1, these earthquakes have been occurring since 2007. The Bentong Fault Zone, which includes the Bukit Tinggi Fault and the Kuala Lumpur Fault, is most active seismic feature in Peninsular Malaysia. According to Chiang (2008), near-field earthquakes, especially those within the vicinity of the 80-kilometer-long Bentong Fault, should be carefully considered. The research on the focal mechanisms of the Bukit Tinggi earthquakes is crucial in determining the seismic pattern and fault behaviour (Marto et al., 2013).

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

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 Eurocode 8 and Malaysia National Annex

According to Daily Express Online, it was reported that the Malaysian National Annex to MS EN 1998-1:2015 for earthquake-resistant building design code is set to be applied to Sabah by the end of October 2017. The MS EN 1998-1:2015, Eurocode 8 is a set of guidelines for designing earthquake-resistant structures. Most building structures in Malaysia, especially in Sabah, were not designed or constructed to withstand earthquakes, so the guideline is crucial.

The Malaysia National Annex to MS EN 1998-1:2015 (National Annex:2017) was published with a seismic hazard map of Malaysia as shown in Figure 2.5 to Figure

2.7. Besides that, the Peak Ground Acceleration (PGA) value is represented using contour lines. Figure 2.5 to Figure 2.7 show that Sabah has the highest Peak Ground Acceleration (PGA), which is 16%g in Ranau. Besides that, Sarawak has a lower relative PGA compared with Sabah and has the highest PGA of 9%g in Niah. In addition, Peninsular Malaysia has a high PGA, which is 9%g at Kuala Lumpur. For Penang Island, the PGA is 5%g which is relatively lower than Kuala Lumpur (MS EN 1998-1:2015).

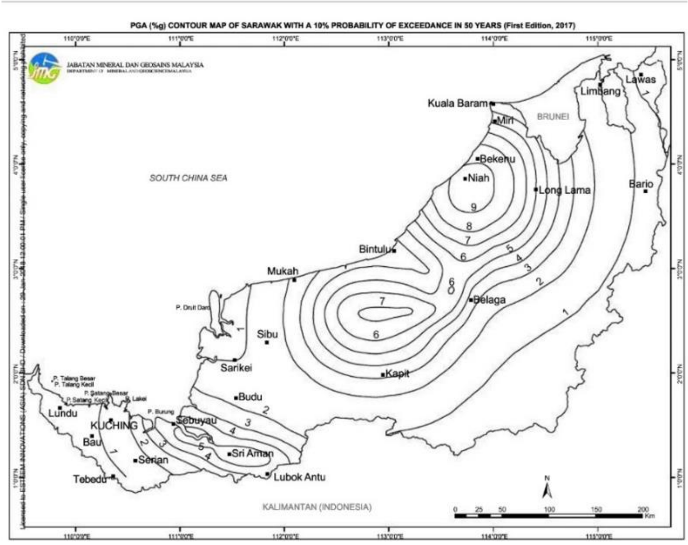

Figure 2.5 Seismic Hazard Map of Sarawak (MS EN 1998-1:2015)

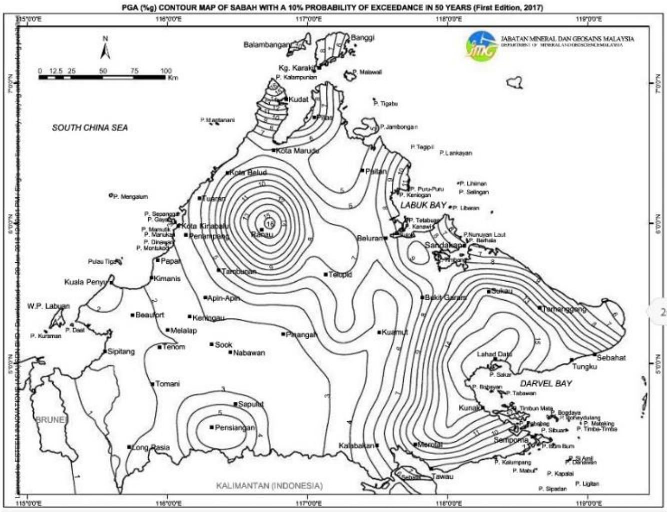

Figure 2.6 Seismic Hazard Map of Sabah (MS EN 1998-1:2015)

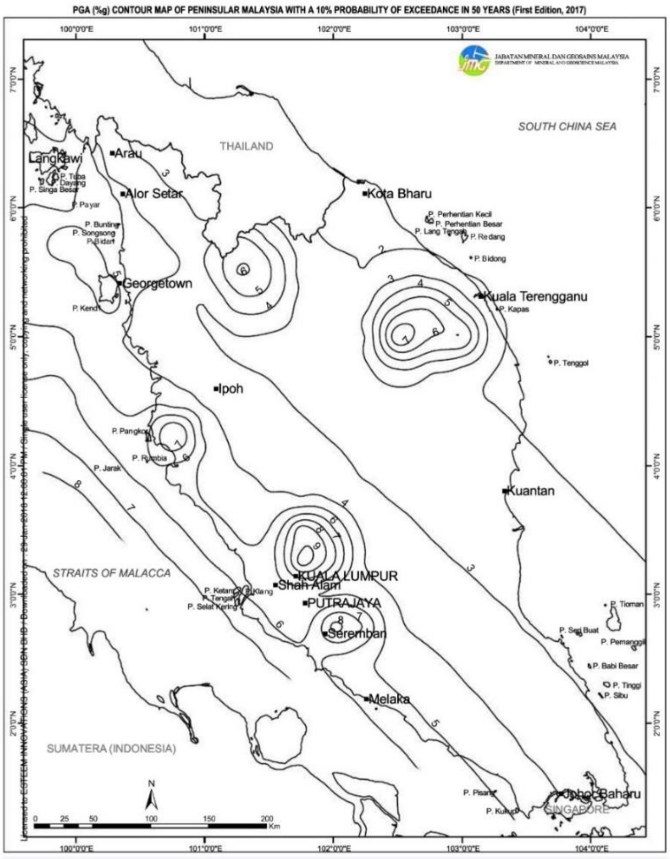

Figure 2.7 Seismic Hazard Map of Peninsular Malaysia (MS EN 1998-1:2015)

2.4 Ground Condition of Penang

Penang is situated on the northeastern coast of Peninsular Malaysia and consists of two geographically distinct entities: Penang Island and the mainland part. As shown in Figure 2.8, the majority of Penang Island is covered by granite, and there is no sedimentary rock on the island. Except where alluvium deposits (clay, silt, sand, and gravel) are found, the granite hills are elevated above the sea to the highest point from the seawater level. On the slopes and at the foot of the granite hills, alluvium deposits, which are granite weathering products, can be found. Huge deposits of marine clay and silt have been discovered along the coasts of the Penang mainland's western region (Tan et al., 2014).

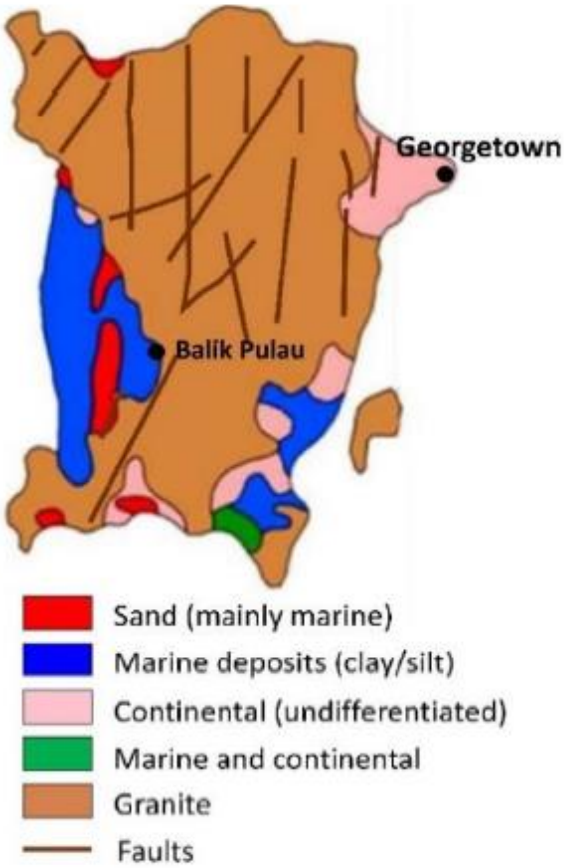

Figure 2.8 Geology Map of Penang Island based on 1:500 000 scale 2007 GMGDM Geology Map (Tan et al., 2014)

Figure 2.9 shows Penang Island is mountainous, with a granitic range running north-south through the middle. On both the east and west coasts, low-lying plains can be found. The Quaternary of Peninsular Malaysia coastal deposits are mostly marine clays and sands, sand beach ridges, and woody peat, with some locally mottled stiff clays under marine clay sequences along the west coast and on Penang Island (Avar et al., 2019).

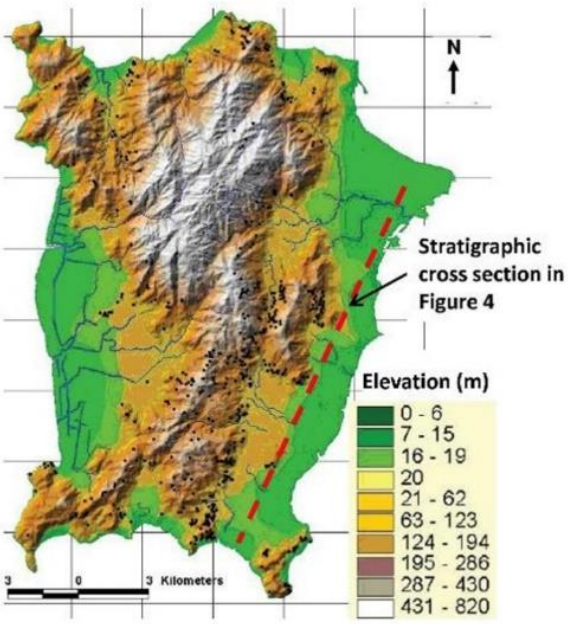

Figure 2.9 Topographic Map of Penang Island (after Lee and Pradhan, 2006)

2.5 Seismic Hazard Assessment

Probabilistic Seismic Hazard Analysis is a statistical tool for quantifying uncertainty in the degree of shaking and understanding site activity during an earthquake. Using historical earthquake data from a specific region, Probabilistic Seismic Hazard Analysis can map the distribution of potential shaking. Identifying all earthquake sources capable of causing damaging ground motions, characterizing these earthquakes and the distributions of source-to-site distances associated with possible earthquakes, and predicting the distribution of ground motion strength as a function of these magnitudes and distances are the basic steps in PSHA. Finally, total likelihood method was used to combine both uncertainties (Azmi et al., 2013).

Random earthquakes without mapped faults and small earthquakes with mapped faults were repressed in PSHA model using both the area and context source modeling approaches (Shoushtari et al., 2018). In Peninsular Malaysia, however, there are inadequate studies on intraplate faults. The PGA values in the Malaysia National Annex indicate a degree of conservatism as compared to the calculated low acceleration values at rock sites around the peninsular. Significant uncertainties in ground motion prediction equations may have resulted from low seismic activity and a limited number of events by interpolated faults. Difficulty in locating and characterizing near-field seismic sources was reported by Ake (2008). This increased risk sensitivity in areas with low intraplate seismicity (Shoushtari et al., 2018) may have influenced the Malaysian National Annex's design response spectrum at low periods. Given that no structural damage was confirmed on the island, it is safe to say that the well-engineered structures withstood recent far-field earthquakes without failing to meet code ductility requirements (Avar et al., 2019).

2.6 Soil Type

Many significant studies have been carried out to examine the effects of various soil types on the amplification of seismic loads and how this affects the requirement for steel reinforcement in columns and beams. The result from all authors is shown in Table 2.2. Due to the soil factor, S, as listed in MS EN1998-1:2015, it can be seen that the ordinate of the design spectrum at Period T_1 varies for a different types of soil. Compared with dense or rock conditions, the degree of seismicity in the softer soil state is amplified by a higher soil factor, which contributes to a higher seismic intensity. T_1 is the spectral acceleration at the fundamental period. F_b is the base shear force.

In softer soil conditions, the amount of seismicity is enhanced by a larger soil factor, which contributes to a higher seismic force than in rock conditions. Furthermore, despite the fact that the reference PGA is different, the model with soil class E experiences the second largest horizontal lateral load after the model with soil type D. As a result, the model with softer soil requires more steel reinforcement and a wider diameter to accommodate the higher bending moment, shear force, and axial load.

Table 2.2 and Table 2.3 show the soil type A has the lowest soil factor and the lowest base shear factor, soil type E has higher soil factor and higher shear base force, as well as soil type D has the highest soil factor and the highest base shear force. S_d is the soil factor.

Table 2.2 Effect of Soil Type on T_1 and F_b at Various PGAs (Roslan et al., 2019; Azman et al., 2019)

Study	Roslan et al. (2019)				Azman et al. (2019)	
a_{gR}	0.07g		0.1g		0.12g	
Soil	S_d (T_1) (g)	F_b (kN)	S_d (T_1) (g)	F_b (kN)	S_d (T_1) (g)	F_b (kN)
A	0.0361	752.2	0.0515	1074.6	0.0615	1865.8
B	N/A	N/A	N/A	N/A	0.09923	2798.6
C	0.0607	1267.1	0.0868	1810.1	0.1062	3175.6
D	N/A	N/A	N/A	N/A	0.1246	4033.8
E	0.0631	1316.4	0.0901	1880.6	0.1077	3221.7

Table 2.3 Effect of Soil Type on T_1 and F_b at Various PGA (Adiyanto et al., 2020; Mustafa et al., 2019)

	Adiyanto et al. (2020)				Mustafa et al. (2019)	
A_{gR}	0.1g		0.16g		0.07g	
Soil	S_d (T_1) (g)	F_b (kN)	S_d (T_1) (g)	F_b (kN)	S_d (T_1) (g)	F_b (kN)
A	N/A	N/A	N/A	N/A	0.042	1050
B	0.064	2947.2	0.103	4715.5	0.063	1696
C	N/A	N/A	N/A	N/A	0.072	1869
D	0.087	4071.6	0.138	6514.6	0.085	2279
E	0.075	3438.4	0.12	5501.4	0.073	1979

As a result, the greater the area of steel bar given, the higher the cost of steel reinforcement as shown in Figure 2.10 and Figure 2.11. Due to the highest value of the base shear force and spectral acceleration at the fundamental period, building models on soil type D necessitates the use of the heaviest steel bar in beams and columns.

Furthermore, when compared to the non-seismic design condition, the increase in material cost was found to be more significant for soil types D and E. Figure 2.10 and 2.11 show the steel reinforcement in beams and column of soil type A, soil type D and soil type E are higher than non-seismic design. Among the soil type A, D and E, soil type A uses the lowest weight of steel reinforcement, soil type E uses higher weight of steel reinforcement and soil type D uses the highest weight of steel reinforcement.

The studies by Roslan et al. (2019), Azman et al. (2019), Adiyanto et al. (2020), and Mustafa et al. (2019) show that the variation of amount of steel reinforcement in beams and columns with considering seismic load and different soil types as compared to non-seismic design for constant number of storey. There is lack of information about the seismic effect on structural member with the consideration of different number of storey and different types of soil. Therefore, different number of storey should be designed to determine the seismic effect on structural member in different types of soil.

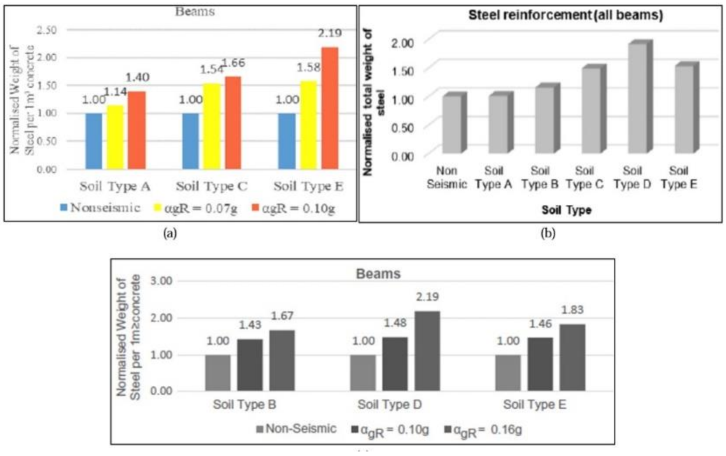

Figure 2.10 Effect of Soil Type on Normalized Weight of Steel Reinforcement for All Beams, (a) Roslan et al. (2019) (b) Mustafa et al. (2019) (c) Adiyanto et al. (2020)

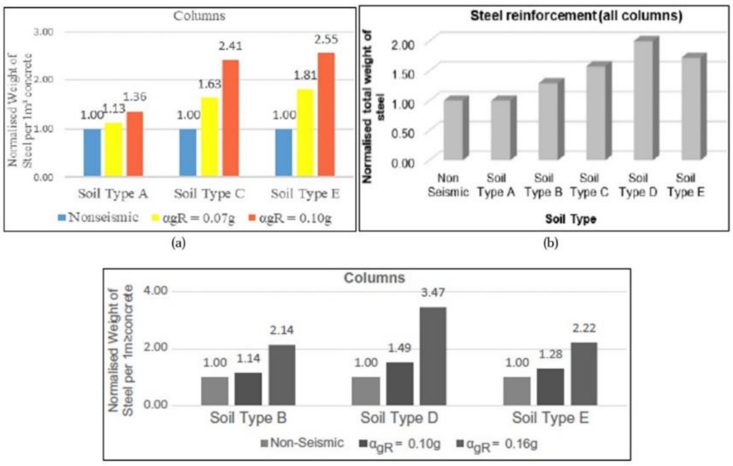

Figure 2.11 Effect of Soil Type on Normalized Weight of Steel Reinforcement for All Column, (a) Roslan et al. (2019) (b) Mustafa et al. (2019) (c) Adiyanto et al. (2020)

Based on Malaysia National Annex, a study was conducted to investigate the impact of seismic design on the increase in construction material use. This research looked at four-storey RC school buildings in Sarawak with a medium ductility class (Adiyanto et al., 2021). As shown in Table 2.4, a total of 9 models were analyzed.

Table 2.4 Model and Design Consideration (Adiyanto et al., 2021)

No.	Model	Soil Type	a_{gR} (g)	Ductility	Behaviour factor, q
1.	NS	-	-	-	-
2.	B-0.07M	B	0.07	DCM	3.9
3.	C-0.07M	C			
4.	D-0.07M	D			
5.	E-0.07M	E			
6.	B-0.09M	B	0.12	DCM	3.9
7.	C-0.09M	C			
8.	D-0.09M	D			
9.	E-0.09M	E			

Figures 2.12 and Figure 2.13 show the comparison of normalized steel tonnage used for reinforcement in beam and column. Figure 2.12 and Figure 2.13 clearly show that the seismic design consideration requires higher usage of steel reinforcement when compared with non-seismic design. Figure 2.12 shows the usage of steel reinforcement

of seismic design increases around 16% to 32% when compared with non-seismic design. For models of seismic design considerations, the use of steel reinforcement in columns increases as well. Figure 2.13 shows that the usage of steel reinforcement of seismic design increases around 1% to 14% when compared with the seismic design.

Steel tonnage increases in columns follow a similar trend as steel tonnage increases in beams. On the average, models of soil type D and soil type E require the most steel reinforcement for columns, as seen in the results for beams. This is because of the highest magnitude of base shear force. F_b resulting in highest bending moment, M and shear force, V. Therefore, highest steel has to be provided in beam and column. This result is closely linked to the requirement in Eurocode 8 to have a Strong Column – Weak Beam for seismic design consideration (Adiyanto et al., 2021).

The studies by Adiyanto et al. (2020) shows that the variation of amount of steel reinforcement in beams and columns with considering seismic load in soil type B, soil type C, soil type D and soil type E. There is lack of information about variation of amount of steel reinforcement in beam and column with considering seismic load in soil type A. Therefore, seismic design in soil type A should be carried out to determine the seismic effect on structural member in different soil types.

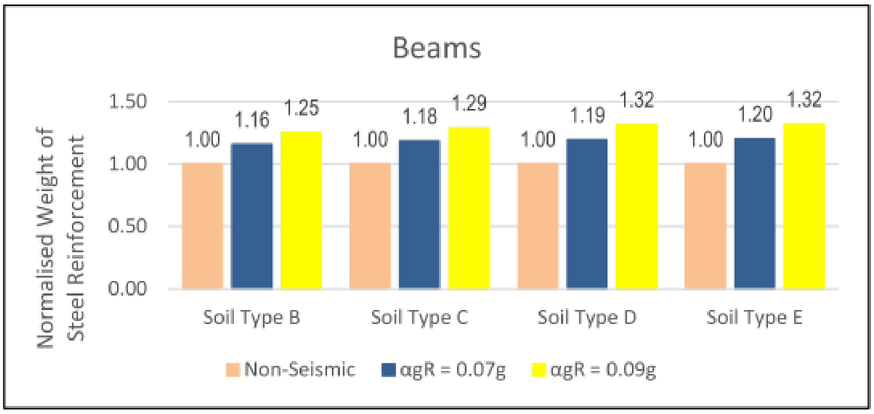

Figure 2.12 Normalized Total Steel Tonnage for Beam (Adiyanto et al., 2021)

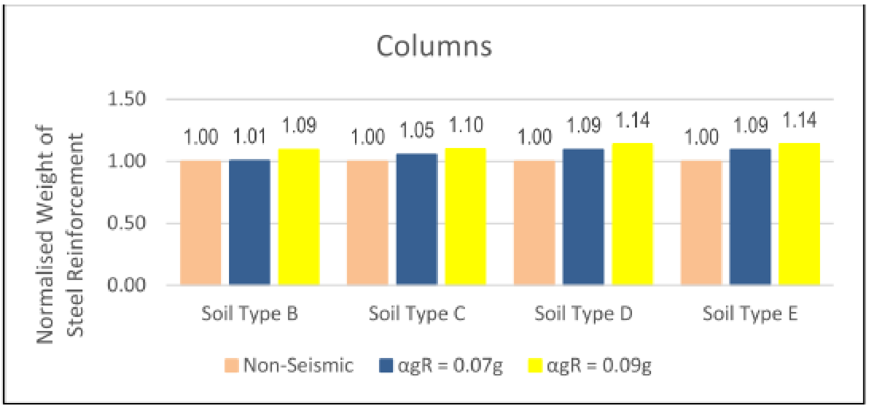

Figure 2.13 Normalized Total Steel Tonnage for Columns (Adiyanto et al., 2021)

2.7 Cost Estimation Studies

It is difficult to quantify the additional cost of design considering seismic resistance because buildings in different projects are designed with specific configurations and specifications. However, a report on seismic design and costing should be conducted so that the authority can prepare and decide its effect on future projects. It is also crucial to provide designers with a clearer understanding of how to refine their designs to be cost-effective.

Although no major earthquake has hit Malaysia, it is affected by earthquakes originating from neighbouring countries. Even though Malaysia experiences minor to moderate earthquakes across the region, seismic design for high-rise buildings, bridges, and other structures has not been practiced.

2.7.1 Cost Comparison for Non-seismic Design and Seismic Design

A study by Ramli et al. (2017) was carried out to give ideas of the costing implication for structural designers in case of using Eurocode 8 in the design. The comparison is made in terms of total reinforcement requirements between design using Eurocode 2 and a similar method incorporating Eurocode 8 requirements with DCL and

0.06g PGA. The value of PGA and type of ductility classes selected in the study of Ramli et al. (2017) is shown in Table 2.5. Besides that, Tables 2.6 and 2.7 show the difference in reinforcement quantity and percentage increase between non-seismic and seismic designs with DCL for beams and columns of 5 and 10 storey buildings, respectively. The percent quantity of reinforcement increases when seismic design with DCL is compared to Eurocode 2 design.

Based on the determination of seismic zones in Peninsular Malaysia and Sabah, the total reinforcement requirement for beams and columns has increased. According to the findings from both buildings, the different amounts of reinforcement specifications for column components showed substantial differences. This was due to the reason that Eurocode 8 (2004) increases the shear reinforcement when compared to Eurocode 2 design (Ramli et al., 2017).

Table 2.5 Different Ductility Classes and Different PGA Values (Ramli et al., 2017)

Design Type	PGA (g)	Zone/Location
EC2	None	None
Low (DCL)	0.06	Johor or Kedah

Table 2.6 Different Quantities of Reinforcement between Non-seismic and Seismic Design for 5 Storey Building (Ramli et al., 2017)

Ductility Class	Quantity of reinforcement (Tonne)			Increment (%)
	Beam	Column	Total	
EC2	117.0	8.6	125.6	-
EC8 DCL0.06g	127.5	11.0	138.5	+10.2

Table 2.7 Different Quantities of Reinforcement between Non-seismic and Seismic Design for 10 Storey Building (Ramli et al., 2017)

Ductility Class	Quantity of reinforcement (Tonne)			Increment (%)
	Beam	Column	Total	
EC2	962.3	78.7	1041.0	-
EC8 DCL0.06g	1027.8	361.0	1388.9	+33.4

Table 2.8 shows that the percentage increase in cost of construction for seismic design building compared to non-seismic design building in Malaysia. Hee et al. (2016) reported that for a 10 storey office building is the greatest cost increase of 8.1%. When the number of storey increase from 10 storey to 30 storey, the increment in cost is gradually reduced from 8.1% to 3%. The reason of the unexpectedly reduction in building cost is due to overlooked the basic design and detailing requirement of the code of practice.

Table 2.8 The Percentage Increase in Cost of Construction for Seismic Design Building Compared to Non-Seismic Design Building in Malaysia (Hee et al, 2016)

Author	Increment in Cost (%)						
	2 storey	5 storey	10 storey	15 storey	20 storey	25 storey	30 storey
Hee et al. (2016)	7	4.4	8.1	6	4.3	3.5	3

2.7.2 Cost Analysis under Different Types of Soil

A recent study by Hong et al. (2020) was carried out for cost analysis for reinforced concrete school structures under different types of soil conditions. The material cost for the structural elements in the built model is used to cost the building in the study. The main materials calculated in the reinforced concrete school building are concrete and steel reinforcement. With different soil types, 14 models of reinforced concrete school buildings, ranging in height of two and four storeys, were analyzed and designed, as shown in Table 2.9.

Table 2.9 Model Description (Hong et al,2020)

No.	Notation	Design Loading Consideration	Ground Type	No of Storey
1.	N2S_EC2	Gravity load	-	2
2.	N4S_EC2	Gravity load	-	4
3.	N2S_EC2 + MS1553	Gravity load & Wind load	-	2
4.	N4S_EC2 + MS1553	Gravity load & Wind load	-	4
5.	N2S-A-0.16	Gravity load & Seismic load	A	2
6.	N2S_EC2	Gravity load	-	2
7.	N2S-B-0.16	Gravity load & Seismic load	B	2
8.	N4S-B-0.16	Gravity load & Seismic load	B	4
9.	N2S-C-0.16	Gravity load & Seismic load	C	2
10.	N4S-C-0.16	Gravity load & Seismic load	C	4
11.	N2S-D-0.16	Gravity load & Seismic load	D	2
12.	N4S-D-0.16	Gravity load & Seismic load	D	4
13.	N2S-E-0.16	Gravity load & Seismic load	E	2
14.	N4S-E-0.16	Gravity load & Seismic load	E	4

Figure 2.14 illustrates the overall amount of concrete used in the beam and column of the model. This finding indicates that the total concrete volume increases as the soil factor increases due to soft or weak soil. Figure 2.15 shows the total weight of steel reinforcement used in the beam and column of the model. It is evident that models of seismic construction in Ground Types D and E, which are considered soft or poor soils with a high soil factor, necessitate a greater quantity of steel reinforcement in the design. As a result, it is concluded that a higher soil factor leads to a heavier design by increasing the size of the section or increasing the amount of steel reinforcement used in seismic design. The overall cost of material used for the beam and column of the model is shown in Figure 2.16.

Compared with other two storey buildings, the two storey school building built with seismic resistance under Ground Type E has the highest overall cost of material for the superstructure. Compared with other four storey buildings, the four-storey school building built with seismic resistance under Ground Type D has the highest overall cost of material for the superstructure.

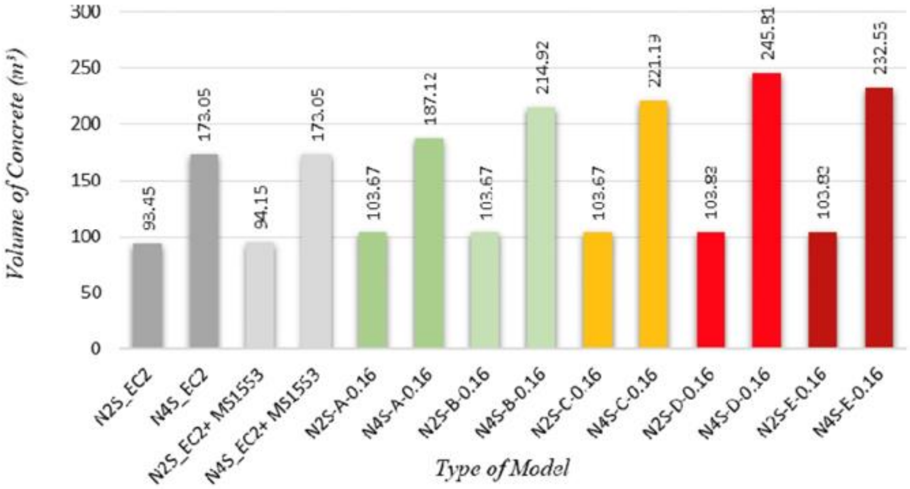

Figure 2.14 Total Volume of Concrete (Hong et al., 2020)

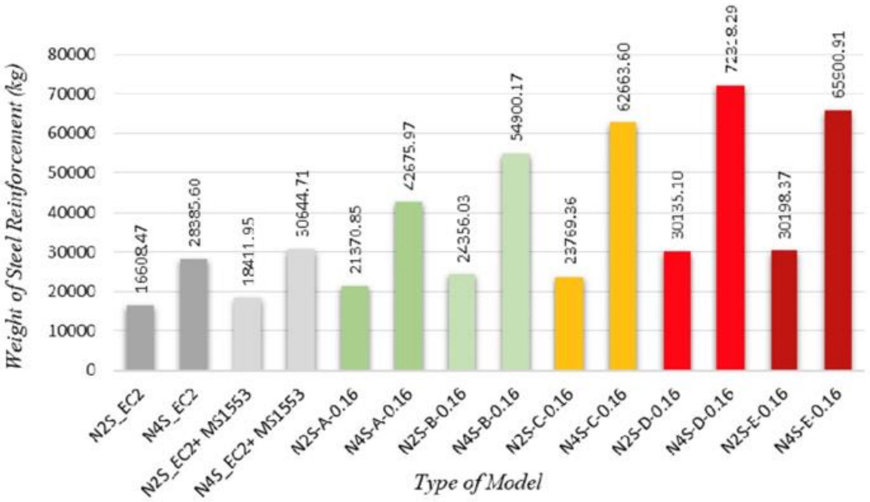

Figure 2.15 Total Volume of Reinforcement (Hong et al., 2020)

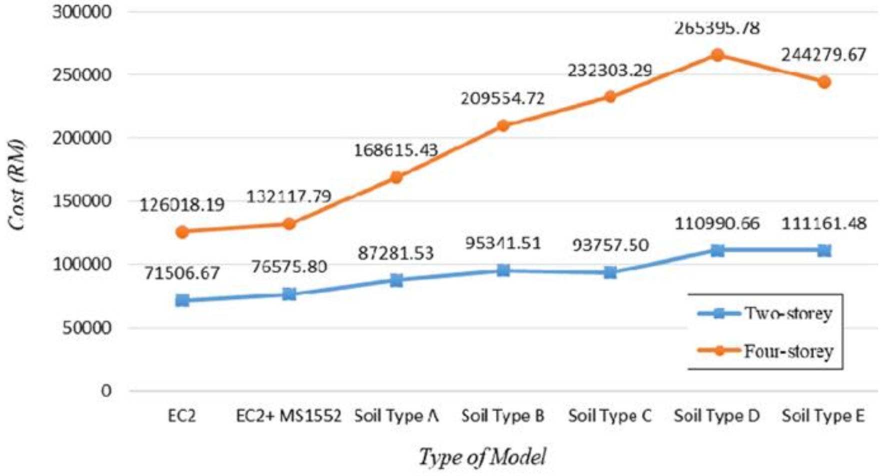

Figure 2.16 Total Cost of Material (Hong et al., 2020)

As seismic effects are considered in the structural design of a building, the overall cost would rise compared to a non-seismic built structure. As a result, due to the high increase in total cost in planning for seismic resistance, no seismic provision has been introduced as a guide for reinforced concrete design in the construction industry in Malaysia. The percentage increase in the construction cost of other models compared to the EC2 model is shown in Table 2.10.

The study by Hong et al. (2020) shows that the variation in material cost between non-seismic and seismic design in different soil types for 2 storey and 4 storey. There