EFFECT OF SOIL TYPE AND LEVEL OF SEISMICITY ON SEISMIC DESIGN OF REINFORCED CONCRETE SCHOOL BUILDING

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ABSTRAK

Pertimbangan seismik tidak diambil kira untuk reka bentuk dan pembinaan di Malaysia. tetapi selepas insiden berlaku pada 5 Jun 2015, gempa bumi 6.0 magnitud telah berlaku di Ranau, Sabah, yang berlangsung selama 30 saat. Selepas kejadian itu, pihak berkuasa tempatan mula mempertimbangkan semula untuk melaksanakan reka bentuk seismik terutama bangunan sekolah. Di Malaysia, bangunan sekolah konkrit bertetulang (RC) akan menjadi tempat tumpuan perlindungan utama masyarakat apabila berlakunya bencana alam untuk kekal sehingga bencana berkurangan. Oleh itu, ianya adalah sangat penting untuk memastikan reka bentuk bangunan sekolah RC pada masa akan datang dapat menampung beban dari gempa bumi, yang bermaksud bahawa bangunan sekolah RC tetap berfungsi walaupun setelah berlakunya gempa bumi. Objektif kajian ini adalah untuk menentukan kesan jenis tanah dan kesan tahap seismicity pada jumlah pengukuhan keluli. Penggunaan model untuk kajian ini adalah empat tingkat bangunan sekolah RC yang reka bentuk berdasarkan Eurocode 8. Terdapat sejumlah sepuluh model dengan berbeza jenis tanah dan tahap seismicity. Kemudian, analisis dilakukan kepada semua model dengan menggunakan Designer Struktur Tekla untuk memperoleh kedua-dua objektif tersebut. Maklumat berdasarkan jumlah keluli yang diperlukan boleh didapati dari analisis. Ia diwakili dengan menggunakan graf Spektrum Respon Reka Bentuk dan jadual-jadual yang mengandungi maklumat seperti momen lenturan. Berdasarkan hasilnya, peratusan yang berbeza daripada berat pengukuhan keluli yang diperlukan untuk reka bentuk bukan seismik yang menimbangkan Jenis Tanah meningkat 38%, 92% dan 131% untuk Tanah Jenis A, Tanah Jenis C dan Tanah Jenis E, masing-masing. Oleh itu, dapat disimpulkan bahawa model yang dibina pada Tanah Jenis E memerlukan jumlah pengukuhan keluli yang tinggi dalam setiap 1m^3 konkrit. Walaupun bagi magnitud PGA yang berlainan, keputusan menunjukkan bahawa perbezaan peratusan pengukuhan keluli yang diperlukan berbanding dengan reka bentuk bukan seismik untuk rasuk dan lajur seluruh bangunan telah meningkat daripada 13%, 66% dan 131% untuk PGA bersamaan dengan 0.04g, 0.07g dan 0.10g masing-masing. Oleh itu, dapat disimpulkan bahawa model yang dibina di atas PGA 0.10g diperlukan jumlah tetulang keluli yang tinggi dalam setiap 1m^3 konkrit. Oleh itu, jenis tanah dan tahap seismicity perlu diambil kira untuk reka bentuk kerana pembolehubah ini mempengaruhi jumlah keluli yang digunakan.

ABSTRACT

Seismic considerations are not taken into account for design and construction in Malaysia. but after the incident happened on 5th June 2015, earthquake of 6.0 magnitudes had struck in Ranau, Sabah, which lasted for 30 seconds. After the incident happened, the local authority starts to reconsider to implement the seismic design especially school building. In Malaysia, reinforced concrete (RC) school buildings will be the main focus of the community's protection when there is a catastrophic disaster to remain until the disaster is reduced. Therefore, it is very important to ensure that RC school building design in the future will be able to accommodate the burden of the earthquake, which means that the RC school building will work even after the earthquake. The objective of the study is to determine the effect of different Soil Type and effect of Level of Seismicity on the amount of steel reinforcement. The model use for the study is four-storey RC school building which is design based on Eurocode 8. There are total of ten models with different Soil Type and Level of Seismicity. Then, the analysis is conducted to all of the models by using Tekla Structural Designer to obtain both of the objectives. The information based on the amount of steel required is provided from the analysis. It is represented by using Design Response Spectrum graph and tabulated tables that contained information like bending moment. Based on the results, the percentage different of weight of steel reinforcement required for non-seismic design which considering Soil Type is increased 38%, 92% and 131% for Soil Type A, Soil Type C and Soil Type E, respectively. Thus, it can be concluded that model built on Soil Type E required high amount of steel reinforcement per $1m^3$ concrete. While for different magnitude of PGA, the results show that the percentage difference of steel reinforcement required compared to non-seismic design for beam and column of the whole building had increased from 13%, 66% and 131% for PGA equals to 0.04g, 0.07g, and 0.10g respectively. Thus, it can be concluded that model built on PGA of 0.10g required high amount of steel reinforcement per $1m^3$ concrete Therefore, Soil Type and Level of Seismicity should be taken into consideration for design since these variables influence the amount of steel used.

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LIST OF SYMBOLS

a_{g}	Design ground acceleration
a_{gR}	Reference peak ground acceleration
$\mathrm{A}_{s,prov}$	Total area of steel provided
$\mathrm{A}_{s,req}$	Total area of steel required
F_{b}	Base shear force
f_{cd}	Design value of concrete compressive strength
f_{cu}	Characteristic cylinder strength of concrete
F_{i}	Lateral load on storey
f_{y}	Yield strength of reinforcement
g	Acceleration due to gravity, m/s^2
G_{k}	Dead load
H	Storey height
M	Bending moment
m	mass of structure
M_{Rb}	Design moment resistance of beam
M_{Rc}	Design moment resistance of column
M_{w}	Magnitude of earthquake intensity
N	Number of storey
q	Behaviour factor
Q_{k}	Live load
S	Soil factor
$S_{\mathrm{d}}(T_1)$	Ordinate of the design spectrum at period
T_1	Fundamental period of vibration
T_{B}	Lower limit of the period of the constant spectral acceleration
T_{C}	Lower limit of the period of the constant spectral acceleration
T_{D}	Beginning of the constant displacement response range of the spectrum
V	Beginning of the constant displacement response range of the spectrum

LIST OF ABBREVIATIONS

BS	British Standard
DCH	Ductility Class High
DCL	Ductility Class Low
DCM	Ductility Class Medium
IDR	Interstorey Drift Ratio
JKR	Jabatan Kerja Raya
PGA	Peak Ground Acceleration
RC	Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.1 Background

An earthquake is a phenomenon that is difficult to expect when it will happen. This phenomena happens because of the powerful shaking from the earth's surface. This shaking was caused by movement in the outermost layers of the earth. Figure 1.1 shows the earth's layer which is made of four basic layers which are super-heated core and its thin outer layer the crust, nearly solid bulk mantle, the liquid outer core and solid inner core. Earthquakes are caused by shifts in the outermost layers of earth a region called the lithosphere. An earthquake results from the sudden release of energy stored in the lithosphere by the continuous motion of plates. Litosphere is an uncontinuos piece that wraps around the whole earth. It was actually made up of giant puzzle pieces called tectonic plates.

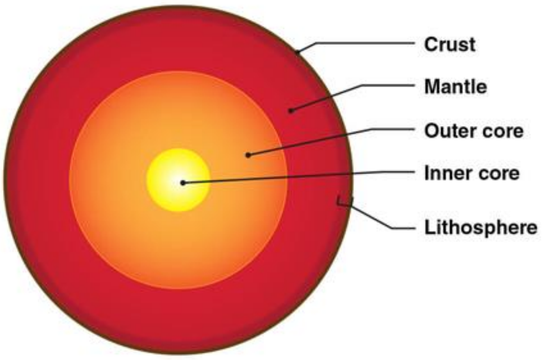


Figure 1.1 A diagram of earth's layers

In Malaysia, the major natural processes that affects its landscapes are flooding, landslides and earthquakes. However, the study on plate tectonics and earthquakes in Malaysia is minimal as the effects are still within the safe zone when compared to the other processes, and countries such as Nepal and Indonesia (Gill et al., 2015). Tectonic plates are constantly shifting as they drift around on the viscous, or slowly flowing, mantle layer below. This non -stop shifting or movements causes stress on earth’s crust. When at one point the stresses get too large, it leads to cracks called faults, releasing elastic strain energy stored in the surrounding crust, which then radiates from the fault rupture in the form of seismic waves (Elghazouli, 2009).

Peninsular Malaysia covers an area about 0.3 million km2 at the southern tip of mainland Asia and is connected by land to Thailand to the north while separated from Singapore by Johor Strait to the south and from Sumatra of Indonesia by Malacca Strait to the west. Borneo, which contains the states of Sabah and Sarawak, is located east of Peninsular Malaysia and is separated by South China Sea.

The location of Malaysia is one of the countries that are safe from earthquake as it is located at the equator of the globe which are far away from the active seismic fault zone. Moreover, Malaysia part of the complex Eurasian and Indo-Australian plate tectonics which is located on southern edge of the Eurasian Plate which is known as Sunda Plate as shown in Figure 1.2. As the earthquake happened in Southern Philippine and Sumatera, it triggered several active faults that possible for Malaysia to experienced earthquake. However, as the previous recorded earthquake that occurred in the neighbouring countries such as Thailand and Indonesia, Malaysia is occasionally subjected to tremors. Seismic design for high-rise buildings, bridges and others structure has not been practiced in Malaysia, although Malaysia experiences minor to moderate earthquakes across the country (Ramli et al., 2017). Seismicity within the Sunda Plate has been historically low with progressive collision with the Eurasian Plate relatively slow.

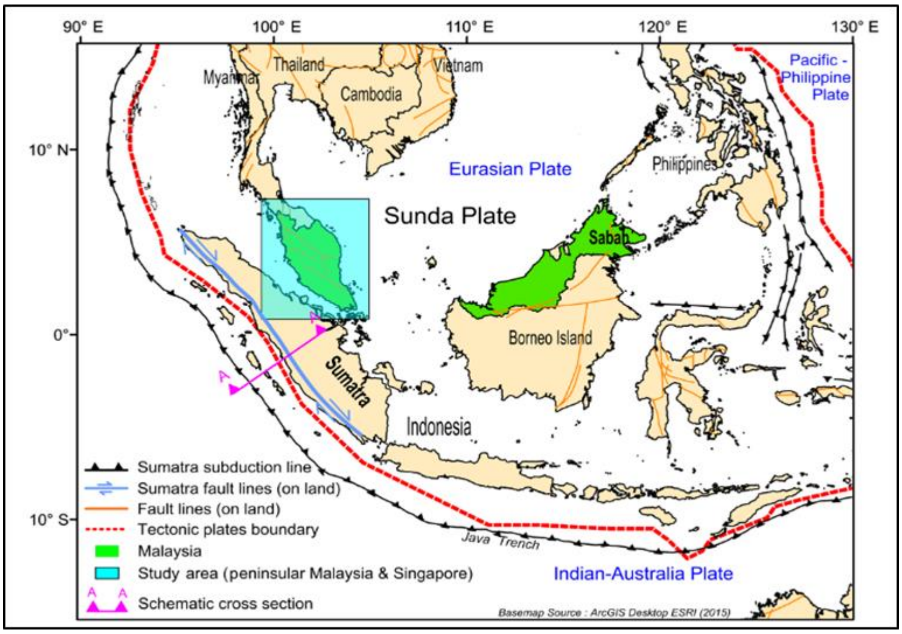


Figure 1.2 Location of Malaysia on the Sunda Plate and the seismic sources around it (modified from Loi et al., 2016). The subduction lines, fault lines and tectonic boundary.

Source: (ArcGIS Desktop ESRI (2015))

During the earthquake, when the seismic waves reach the earth’s surfaces it will shake all the structures on the ground to be unstable due to the sudden force resulted from the movement and ground motion caused by earthquake and can lead to destruction. The vibrations caused by the movement of the plates bring bad impacts to the earth surface. Based on our daily life, we can see clearly people may lost their sources of income while wild life lost their habitat. Meanwhile, man-made structures like buildings, bridges, roads and slopes will be affected by this natural disaster. This situation also may contributes to lots of injury and fatality, lost of property, fire, flooding, and the most affliction is it can induce tsunami.

In a conclusion, every structural building is able to withstand seismic action and safe to use. This is a safe step to avoid injuries and fatality caused by earthquake strike. Therefore, the future design of buildings as well as the inspection and assessment of existing buildings shall be designed according by referring to seismic provision code such as Eurocode 8 (2004).

1.2 Problem Statement

Malaysia had experienced several local tremors from earthquake that occurred in Sabah and Peninsular Malaysia and also far fields earthquakes from Philippine and Indonesia. Earthquake had occurred locally and worldwide whether it is small or large magnitude. However, the awareness level of Malaysian people about earthquake still very little until one of strongest earthquakes happened in Malaysia. Through the events, people start to questioning the ability of structural buildings in Malaysia whether it is strong enough to withstand or resist the tremors.

East Malaysia is considered as a stable continental shield region at the triple junction zone of convergence between the Philippine, Indian-Australian and Eurasian Plates with moderate seismicity (Alexander Y et al, 2006). In the reference as seen in local report of Malaysian Meteorological Department (MMD) (2009) mentioned that the intensity of Modified Mercalli scale in East Malaysia is VIII as shown in Figure 1.3. There are several earthquake events according to the historical records such as M_W 5.8 on 26 July 1976 centered in Lahad Datu, M_W 4.5 on 26 May 1991 in Ranau, M_W 5.2 on 12 February 1994 within Mersing line and M_W 5.2 on 1st May 2004 along Tubau fault and others. These earthquakes have caused casualties and damage to properties. There have been active fault zone in Ranau area (North-East area of East Malaysia).

On 5th June 2015, earthquake of 6.0 magnitudes had struck in Ranau, Sabah, which lasted for 30 seconds, it was one of strongest earthquakes recorded in Malaysia (Earthquake Track, 2015). A lot of structures had damaged including one of the peaks on Mount Kinabalu was broken off and a total of 18 loss life. The tremors were felt in Ranau, Kundasang, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud (Adiyanto, 2016). Hence, these states are also known as earthquake-prone area of Malaysia as the region is considered moderately active in seismic activities with the existence of at least 13 active faults in Sabah and 3 active faults in Sarawak (JMG, 2006). The severely damage of buildings due to fault movement have created enough concern to understand the seismically potential zones of the region.

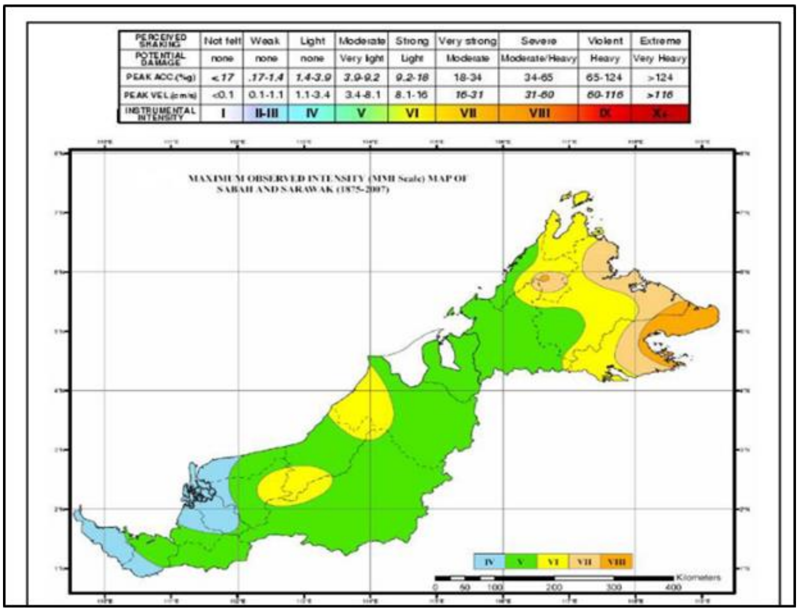


Figure 1.3 Modified Mercalli Scale mapping for East Malaysia (MMD, 2009)

School building act as a shelter for natural disaster victims and it houses young generation. Thus, school building must not only survive the shaking, but must remain in operation. Hence, the building needs special attention in design. Therefore, this study focuses on seismic design of new reinforced concrete (RC) school building in Malaysia. Thus, the strength of the building and soil type play an important role in design and it may also be of some concern in the face of earthquake tremors. Generally, building that founded on soft soil site will experience strong shaking and longer produced by an earthquake than when compared with the shaking experienced at a hard rock site.

1.3 Main Objectives

The objectives of this study are:

i. To study the influences of the soil type on the amount of steel reinforcement

ii. To study the influences of magnitude of Peak Ground Acceleration (PGA) on the amount of steel reinforcement.

1.4 Scope of Work

This study covered and focused in the following aspect:

i. A 4 storey RC school building served as the main model.
ii. Three different magnitude of PGA equal to 0.04g, 0.07g and 0.10g to represent the seismicity in Ipoh (Perak), Seremban (Negeri Sembilan) and Semporna (Sabah) as proposed by National Annex (2017) has been considered for design.
iii. All models have been designed for Soil Type A, Soil Type C and Soil Type E.
iv. The design load has been designed by referring to Eurocode 8 (2004) for ductility class medium.
v. Tekla Structural Design software has been used for analysis and design. The design has been conducted for compressive strength of concrete, f_{cu} equal to 30 N/mm^3.
vi. The result has been discussed in term of comparison of steel required as reinforcement influenced by soil type and magnitude of PGA.

CHAPTER 2

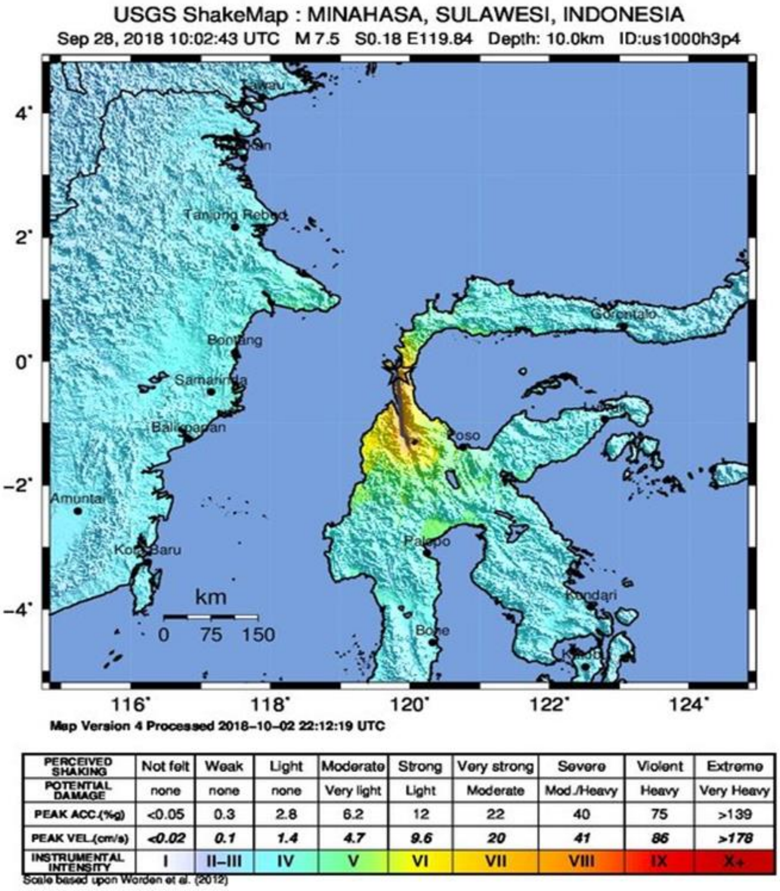
LITERATURE REVIEW

2.1 Introduction

School buildings are among the public facilities that are prone to the impacts of natural disasters. Therefore, it is very important to design a disaster-resistant school building. A number of disaster events have caused damage or destruction to many schools, the impacts may intensify and potentially claim many lives when disasters strike during school hours, such as the earthquake that hit Padang, West Sumatra, Indonesia in 2009 that took lives of many school children. According to national Agency for disaster Management (BnPB) and the World Bank indicated that 75 percent of school buildings in Indonesia are located in disaster prone areas. The national Agency for disaster Management guideline defines safe school as a school that complies with predetermined standards for facilities and infrastructure and implements a culture that may protect school communities and their environment from hazards. The study on school building and natural disasters like earthquake also has been conducted by Vickery (1892) where it is important for school building to be able to resist the disaster during an earthquake. It must be made safe not only for safety but also for the purpose as a shelter for refuge during the disaster.

2.2 Earthquakes effect on school building

On 28th September 2018, an earthquake of 7.5 magnitude struck Palu, Indonesia as a result of strike-slip faulting at shallow depths within the interior of the Molucca Sea microplate, part of the broader Sunda tectonic plate as shown in Figure 2.1. Focal mechanism solutions for the earthquake indicate rupture occurred on either a left-lateral north-south striking fault, or along a right-lateral east-west striking fault and have brought down many buildings in the small city on Sulawesi island, 1,500 km northeast of Jakarta, while tsunami waves smashed into its beachfront. The combined effects of the earthquake and tsunami led to the deaths of at least 2,100 people. According Head of BNPB Data Center, Information and Public Relations Sutopo Purwo Nugroho 2,736 schools were damaged in his statement on Sunday, October 7. The school collapsed is caused by a poor structural design, substandard construction and the failure to meet earthquake prevention standards.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Figure 2.1 Level of Shaking Movement during Earthquake

On 7th October 2018, earthquake of 5.9 magnitudes had struck 19 kilometers northwest of Port-de-Paix, Haiti. Haiti lies at the boundary between the Caribbean Plate and North American Plate as shown in Figure 2.2. The major left-lateral strike slip fault zones movement across this boundary is partitioned across several major structures. According to The U.S. Geological Survey said the quake was centered 12 miles (19 kilometers) northwest of Port-de-Paix, which is about 136 miles (219 kilometers) from the capital of Port-au-Prince. The quake was 7.3 miles (11.7 kilometers) below the surface. The earthquake killed 18 people and 548 people were injured. Nine of the deaths occurred in Port-de-Paix, seven in Gros-Morne and one in Saint-Louis du Nord. The earthquake caused part of a school to collapse in Gros-Morne, Overall, at total of 2,102 houses were destroyed and a further 15,932 were damaged. According to director of the San Gabriel National School in Gros-Morne, where several classrooms were severely damaged and she said that about 500 students would not be able to return to school. The earthquake was the strongest to hit Haiti since January 12, 2010, not including the aftershocks of the 2010 earthquake, and the shaking was felt as far away as Port-au-Prince and killed an estimated 300,000 people.

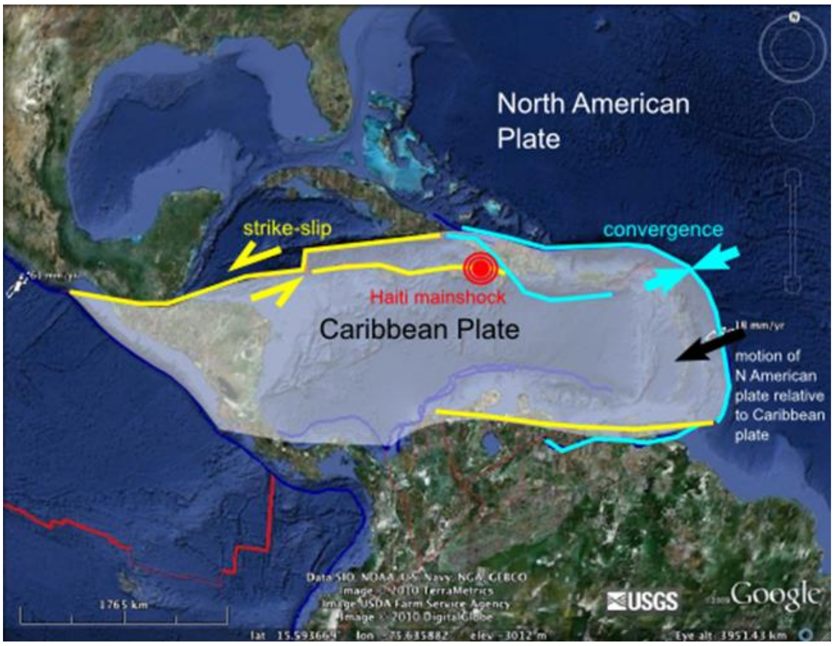


Figure 2.2 Tectonic plates and fault zones of the Caribbean. Port-au-Prince is the red star

2.3 Ductility

According to Elnashai and Sarno (2008), ductility is the ability of a material, component, connection or structure to undergo inelastic deformations with acceptable stiffness and strength reduction. Most structures are designed to behave inelastically as reasons of economy during the strong earthquake. There are four types of ductility such as material ductility, curvature ductility, rotation ductility and displacement ductility. The ductility is the structures', elements' and constituent materials' property to deform beyond the elastic limit without any strength loss and energy accumulation during the loading cycles.

The frames designed for high ductility are likely to attract more extensive damage than those designed for lower ductility, due to large yield excursion, under the "ductility for seismic force reduction" trade-off scheme. The difficulty for the high ductility class designs to meet specific displacement performance criteria would increase if the performance is based design considered than merely for non-collapse or life-safety concerns (Lu et al., 2001). The medium ductility design demonstrated most satisfactory performance with reduced overall damage and a good hysteretic behaviour under a comparable base motion for which the design q-factor and overall ductility requirement.

2.4 Ground Motion

Ground motion is the movement of the earth's surface from earthquakes or explosions. Ground motion is produced by seismic waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface. The strength of ground shaking is measured in the velocity of ground motion, the acceleration of ground motion and the displacement of ground motion. There are three types of fault are known as strike-slip, reverse and normal as illustrated in the Figure 2.3. Furthermore, the characteristics of waves produced by an earthquake rupture are also strongly influenced by the type of faulting that generates the seismic waves.

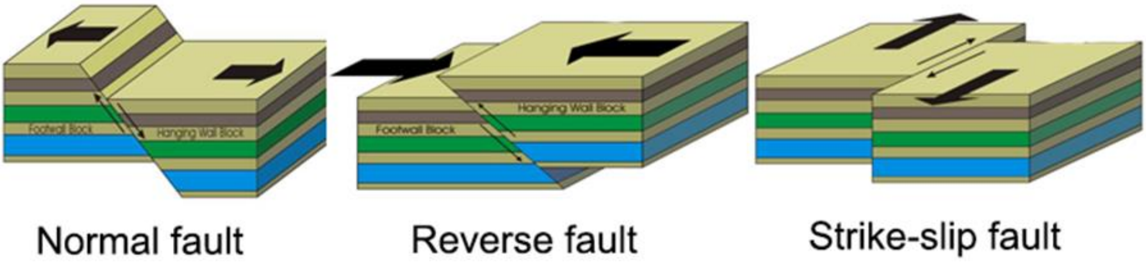


Figure 2.3 Types of fault

The concept of inertia will apply to every structure where it tends to keep on doing what they are doing. In fact, it is the natural tendency of objects to resist changes in their state of motion. The structure will remain at rest as the structure's base is vibrated resulting in deformation of the structure. The structure's load carrying members will try to restore the structure to its initial. In the process of material deformation the energy is absorbed as the structure rapidly deforms.

The study of the effect of ground motion duration on earthquake induced structural collapse was proposed by Raghunandan and Liel (2013). The effect of the performance structure has an adverse effect towards the ground motion duration. From the result obtained, the buildings with severe damage undergo a long duration of ground motion. Meanwhile the structure under a short duration of ground motion has a little damage although these 2 models experience the same intensity of ground motions because the longer duration ground motion imposes higher energy demands on the structure. Therefore, it is recommended to acknowledge the duration of the ground motion in addition to its intensity and frequency content in structural design and assessment of seismic risk.

2.5 Reviews from past studies

According to Taresh (2010), the study of seismic design of reinforced concrete school buildings in Malaysia based on UBC 97 and ACI 95 was performed to study the difference in percentage in term of steel tonnage and concrete volume between the existing structural design of school buildings in Malaysia and the seismic design based on UBC 97 and ACI 95. For the study, he considered two models and for the first model is School 1 which is rectangular in plan consisting of 4 storey that is commonly used in Malaysia and the second model is School 2 that is L shape in plan which consisting of 5 storeys. The seismic analysis was performed by using STAAD-Pro 2006. By referring the UBC 97 and ACI 95 the structures are designed using Intermediate Moment Resisting Frame (IMRF). The results show that the total percentage difference of the steel tonnage is in the range of 11.8-21.0%, while the total percentage difference of the concrete volume for School 1 and School 2 between the existing and seismic design is in the range of 0-1.5%.

The study of the effect of Soil Type on seismic performance for RC school building conducted by Nasai (2016). Based on BS8110, 2 and 4 storey of RC school buildings have designed and ESTEEM software has been used as the model in this research. In this study, nonlinear values of ground motion and two type of earthquake motion where motion 1 is single ground motion which is main shock and motion 2 is repeated ground motion which are foreshock, mainshock and aftershock. In this analysis, he considered two different Soil Types which are Soil Type B (soft rock) and Soil Type D (soft soil) been referred to Eurocode 8. The seismicity used is 0.12g represent in PGA in Sabah as ground motion. For the seismic performance, IDR has been the aspect to evaluate it. From the study, repeated earthquake has higher IDR value compared to single earthquake which is increased from single tremor to repeated tremors about 5.0% to 6.0%. Soil Type D has higher IDR value about 14% than Soil Type B while the pattern for both single and repeated earthquake remained the same. Therefore, type of soil is one of aspect that should be consider in seismic design.

According to Yaakup (2018), the study of seismic design of reinforced concrete school was performed to determine the effect of grade concrete and effect of magnitude of Peak Ground Acceleration (PGA) of RC school building on the amount of steel reinforcement. In this study, the model was designed with two-storey based on the Eurocode 8 (2004) to represent the RC school building that built in Sabah region. The analysis is done by using Tekla Structural Designer software use the values of PGA of 0.08g and 0.16g on three different grade of concrete which are G25, G30 and G35. It also assumed to have Soil Type B and ductility class of Ductility Class Medium (DCM). As a result, the higher the magnitude of PGA subjected to the RC school building, the total amount of reinforcement required. The increment shows of around 1.27% to 11.28% according to different values of a_{gR} of 0.08g and 0.16g, respectively. Furthermore, the total amount of steel reinforcement required for RC school building with higher concrete grade is lower. The decrement shows of around 3.24% to 13.16% according to different concrete grade. This is because as the concrete grade higher, it possessed higher compressive strength which resulted in lower amount of steel reinforcement required.

The study of seismic design of reinforced concrete school building in Sabah affected by soil type and ductility class performed by Safie (2018). This study was conducted to determine the effect of different soil type and different class of ductility on the amount of steel reinforcement. In this study, the analysis is done by using Tekla Structural Designer software use two types of soil used namely as Soil Type B and Soil Type D which represent the stiff and soft soil respectively while ductility class used are Ductility Class Low (DCL) and Ductility Class Medium (DCM). The model was designed with two-storey based on the Eurocode 8 (2004) which assume to be located at Ranau, Sabah. Other than that, the value of Peak Ground Acceleration (PGA) and concrete grade is fixed as 0.065g and G30 respectively. As a result, RC school building built on Soil type D (soft soil) are always has highest weight of steel reinforcement used than Soil type B (stiff soil). The increment percentage of models which considering DCL and DCM are 9% and 7% respectively. Thus, it is sensible and essential to consider soil type when design the building. Furthermore, ductility class low required high amount of steel reinforcement compared to ductility class medium. In this study, the percentage different between low ductility class and medium ductility class of required amount of steel reinforcement in soil type D and soil type B are 2% and 0% respectively. The fact is that ductility class low has lower behaviour factor, which increase the value of design spectrum.

According to Saka (2018), the study of the effect of soil type and grade of concrete for RC hospital building with seismic design was conducted to determine the amount of steel reinforcement required. In this study, the building was constructed on four different types of soil which are Soil Type A, Soil Type B, Soil Type C, and Soil Type D by using two different grade of concrete which are concrete grade G30 and concrete grade G40.

The models also designed with peak ground acceleration of 0.10g, DCM, behaviour factor of 3.9 and designed based on Eurocode 8 (2004). The analysis and design of the models for both seismic design and non-seismic design conducted by using Tekla Structural Design Software. As a result, for the effect of soil type, based on the overall beam and column element for the whole building, it shows that the total amount of steel reinforcement for the beam and column element per 1m^3 of concrete for Soil Type D when constructed by using grade of concrete G30 and concrete grade G40 is about 110% and 78.4%, higher compared to the non-seismic design, respectively. Thus, it proves that Soil Type D with seismic design consideration required large amount of steel reinforcement since its soil texture is the softer compared others and it can be classified as critical Soil Type and it is not strong enough to hold the building structure. Furthermore, for the effect of grade of concrete the amount of steel reinforcement for RC hospital building per 1m^3 of concrete for G40 required about 41.5% lower than grade of concrete G30 when built on Soil Type D with seismic design consideration. While for non-seismic design building which there is no seismic design consideration, the concrete grade G30 is 20.5% higher than concrete grade G40. It proves that when the higher of grade of concrete, the compressive strength also become more strong and it didn’t need a large amount of steel reinforcement to support it since its compressive strength of concrete itself can cover up the strength to hold the building structure.

According to Ahmad Jani (2018), the study of seismic design for RC hospital building was performed to determine the influences of PGA and class of ductility on the amount of steel reinforcement required for the building. The analysis and design of the models using Tekla Structural Designer software. A 6 storey RC hospital building has been considered. The model is assumed to be constructed on Soil Type D with compressive strength of concrete, f_{cu} equal to 30 N/mm^2. A non-seismic model has also been generated with similar fix variables as used for seismic design analysis. Four different magnitude of PGA has been used which are 0.04g, 0.08g, 0.12g, and 0.16g has been design based on DCM. While model of PGA equal to 0.04g has been designed for DCL. As a result, total amount of reinforcement required in a building is higher when it is subjected to higher magnitude of PGA. The percentage of difference from non-seismic model is 19% to 330%. For more detail, the increment percentage is 19%, 125%, 272%, and 330% for reference peak ground acceleration, a_{gR} = 0.04g, 0.08g, 0.12g, and 0.16g respectively. Furthermore, total amount of reinforcement required in a building is higher when it is subjected to low class of ductility. The percentage of difference compared to non-seismic model is 6% to 145% for DCM and DCL respectively.

2.6 Summary

According to the past research studies, there are very few researches on earthquake have been carried out in Malaysia. As previously mentioned, recently, on June 5 2015, the earthquake that occur at Ranau, Sabah has caused tremors in Ranau, Kundasang, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud which has caused a lot of casualties. Therefore, it is important for structural engineer to take a serious consideration to study the seismic design of existing structure such as public structure like school building in Malaysia. The design of school building in Malaysia still designed according to BS8110. However, this study will present the soil type and PGA is influencing the seismic performance of building. Tekla Structure Software will be used in design a model of four-storey RC school building by referring to Eurocode 8 (2004). Therefore, this study needs to be carried out for further understanding and future reference as it would be beneficial to many.

CHAPTER 3

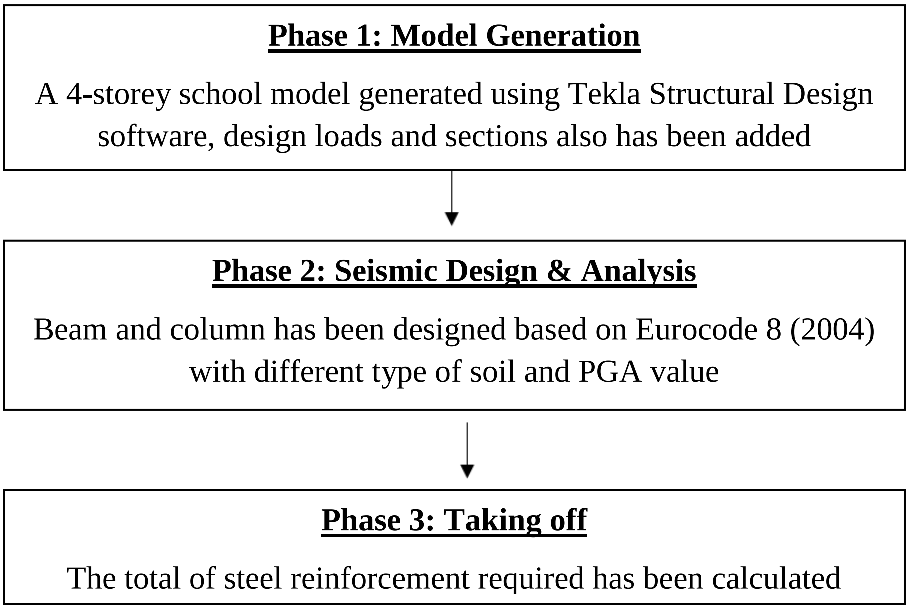
METHODOLOGY

3.1 Introduction

This chapter explains the steps that has been carried out for this research study. The building structure as the model for this study is reinforced concrete (RC) school building. Hence, this chapter is dedicated to discuss on the steps carried out to determine the influence of different parameter of type of soil and Peak Ground Acceleration (PGA) on the amount of steel reinforcement. This study used Tekla Structural Designer software for the analysis and Eurocode 8 (2004) as basic reference when modelling the RC school building. In this study, there are three phases and it will be explained more detailed in the following section. The summary for research methodology is shown in Figure 3.1.

3.2 Flowchart of Research Methodology

There are three phases has been carried out for this research. For the first phase is model generation by using Tekla structural software. Next, for the second phase is seismic design based on Eurocode 8 (2004) for earthquake resistance. The design has been carried out with different type of soil and PGA value. The result has been total for amount of steel reinforcement for each member. Lastly, after getting the flexural and shear reinforcement design requirement at phase 2, the final phase is seismic analysis and taking off has been performed. Taking off process has been performed on the beam and column elements to calculate total steel reinforcement for seismic design building.



Phase 1: Model Generation

A 4-storey school model generated using Tekla Structural Design software, design loads and sections also has been added

Phase 2: Seismic Design & Analysis

Beam and column has been designed based on Eurocode 8 (2004) with different type of soil and PGA value

Phase 3: Taking off

The total of steel reinforcement required has been calculated

Figure 3.1 Flowchart of seismic design and analysis

3.3 Phase 1: Model Generation

The main model for this study is a four (4) storey RC school building. All models has been designed and modelled according to Eurocode 8 (2004) and using Tekla structural software. Table 3.1 shows the summary of the member cross section for beam and column. Floor to floor height of the models is 3.5 m and the RC school building frame is multi-bays. The concrete strength was assumed to be 30 MPa. Figure 3.2 and Figure 3.3 shows plan view and the side of school building model generated in Tekla software.

Table 3.1 Cross section of Structural Member

Beam	**Dimension (mm)**
B1	300x600
B2	200x450
B3	200x225
Column	**Dimension (mm)**
C1	350x350
C2	450x450

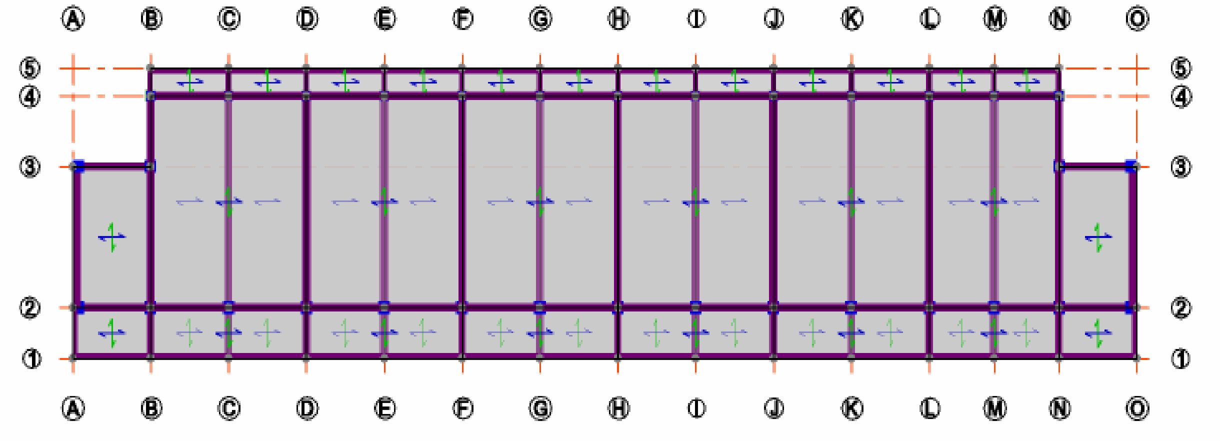


Figure 3.2 Plan View of RC School Building

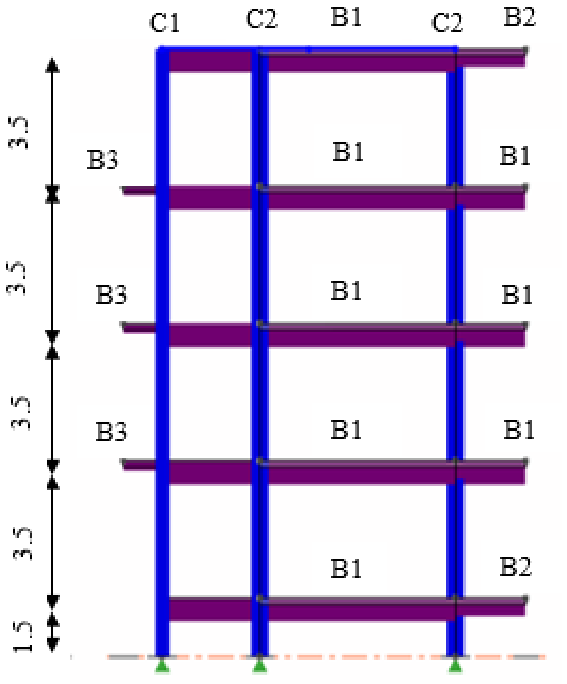


Figure 3.3 Side view of RC school building frame generated in Tekla structural software

3.4 Phase 2: Seismic Design & Analysis

In this phase, the RC school building has been designed based on Eurocode 8 (2004) by using Tekla structural software. Beam and column were designed in order to get the total steel reinforcement required. The design model also has various values of PGA of 0.04g, 0.07g and 0.10g which covers for both at Peninsular and eastern Malaysia with soil type A, C and E. It also assumed to have a concrete grade 30 MPa and ductility class of Ductility Class Medium (DCM). According to Miska (2015), in designing the structural members for seismic design, the concrete strength should not be less than 20 MPa. The material properties for the RC school building is shown in Table 3.2 in accordance to Mc Kenzie (2004).

Table 3.2 Weight of materials (Mc Kenzie, 2004)

Material	Weight	Unit
Concrete	24.0	kN/m^3
Finishing	1.0	kN/m^2
Water proofing	0.5	kN/m^2
Suspended ceiling	0.15	kN/m^2
Mechanical and electrical	0.30	kN/m^2
Brick wall	3.0	kN/m^2/m height

3.4.1 Computation of Load

3.4.1.1 Dead Load for Beam

The dead load on the beam is defined as follow:

Total dead load of the beam = Self-weight of beam + Wall load on the beam

- Self-weight of the beam is given by the Tekla Structural Designer.
- The dead load from wall is calculated to be 7.54 kN/m^2 for all the beams.

3.4.1.2 Dead Load for Slab

The dead load on the slab is tabulated in Table 3.3.

Total dead load on slab = Thickness of slab x Concrete density

Table 3.3 Total Dead Load on Slabs

Thickness of slab, t (mm)	Concrete density, γ_c (kN/ m^2)	Total dead load, kN/m^2
150	25	3.75

3.4.1.3 Imposed Load for Slab

According to Eurocode 1 (2002), Clause 6.3.1.1, the imposed loads values are depends on the various categories of building which are tabulated in Table 3.4 and Table 3.5 where it shows the categories and the values of uniformly distributed load, q_k and concentrated load, Q_k, respectively.

Table 3.4 Categories of Use (Eurocode 1, 2002)

Category	Specific use	Example
A	Areas for domestic and residential areas	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilet.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B, and D1)	**C1**: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions. **C2**: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms. **C3**: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts. **C4**: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages. **C5**: Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.
D	Shopping areas	**D1: Areas in general retail shops** **D2: Areas in department stores**

Table 3.5 Imposed Loads on Floors, Balconies and Stairs in Buildings (Eurocode 1, 2002)

Categories of loaded areas	*q*k (kN/m^2)	*Q*k (kN)
Category A		
- Floors	1.5 to 2.0	2.0 to 3.0
- Stairs	2.0 to 4.0	2.0 to 4.0
- Balconies	2.5 to 4.0	2.0 to 3.0
Category B	2.0 to 3.0	1.5 to 4.5
Category C		
- C1	2.0 to 3.0	3.0 to 4.0
- C2	3.0 to 4.0	2.5 to 7.0 (4.0)
- C3	3.0 to 5.0	4.0 to 7.0
- C4	4.5 to 5.0	3.5 to 7.0
- C5	5.0 to 7.5	3.5 to 4.5
Category D		
- D1	4.0 to 5.0	3.5 to 7.0 (4.0)
- D2	4.0 to 5.0	3.5 to 7.0

Based on the Table 3.5, the model of RC school building is categorized in Category C1 and from the Table 3.5, the imposed load on the slab is in range of 2.0kN/m^2 to 3.0kN/m^2. The imposed load taken for the slab in ground floor to the first floor is equals to 3.0kN/m^2.

3.4.1.4 Imposed Load for Roof

The imposed load for the roofs is categorized in three categories as shown in Table 3.6.

Table 3.6 Categorization of Roofs (Eurocode 1, 2002)

Categories of loaded area	Specific use
H	Roofs not accessible except for normal maintenance and repair
I	Roofs accessible with occupancy according to Categories A to D
K	Roofs accessible for special services, such as helicopter landing area

According to Eurocode 1, 2002, Clause 6.3.4.2, the minimum characteristic values Q_k and q_k for roofs in Category H should be use are tabulated in Table 3.7. Based on the Table 3.7, the imposed load for roof is taken as 1.0 kN/m^2.

Table 3.7 Imposed Load on Roofs for Category H (Eurocode 1, 2002)

<table>
<tr><th>Roofs</th><th>q_k (kN/m^2)</th><th>Q_k (kN)</th></tr>
<tr><td>Category H</td><td colspan="2">NOTE 1 For category H q_k may be selected within the range 0.00 kN/m^2 to 1.0 kN/m^2 and Q_k may be selected within the range 0.9 kN to 1.5 kN.
Where a range is given the values may be set by the National Annex. The recommended values are:
q_k = 0.4 kN/m^2, Q_k = 1.0kN
NOTE 2 q_k may be varied by the National Annex dependent upon the roof slope.
NOTE 3 q_k may be assumed to act on an area A which may be set by the National Annex. The recommended value for A is 10 m^2, within the range of zero to the whole area of the roof.</td></tr>
</table>

3.4.2 Type of soil

Earth surface consist of various type of soil. It is important to know the type of soil as soil is responsible for allowing the stress coming from the structure. Otherwise, the whole building or structure is collapsed. Hence, to identify the physical properties of soil and the rock beneath the soil inspection is done. The sub surface and surface characteristics of soil is explored with various tests are carried out such as boring and Standard Penetration Test (SPT).

In seismic design, soil type is taken into account as it influence the amount of steel needed for the RC school building. In this study, Soil Type A, Soil Type C and Soil Type E are used evaluate the performance of school building frame on different soil type. In response spectrum, the parameter of soil type is considered in its calculation equation as shown in Equation 3.3 to 3.6. Further details about response spectrum are discussed in next section.

3.4.3 Ductility Class

Ductility class influenced the value of behaviour factor. According to Eurocode 8, 2004, Clause 6.1.2.1, the Table 3.8 shows the classified of ductility class with their behaviour factors. The value of behaviour factor is used to determine the design response spectrum as shown in the next section.

Table 3.8 Design concepts, structural ductility classes and upper limit of reference values of the behavior factors (Eurocode 8, 2004)

Design concept	**Structural ductility class**	**Range of the reference values of the behaviour factor, q**
Concept a) Low dissipative structural behaviour	DCL (Low)	≤ 1.5 – 2
Concept b) Dissipative structural behaviour	DCM (Medium)	≤ 4 also limited by the values of Table 6.2
	DCH (High)	only limited by the values of Table 6.2

3.4.4 Seismic Base Shear Force, F_b

In this study all models has been subjected to the same gravitational load (dead load and imposed load). However, the models has been subjected to different lateral load as the parameter of this study which are behaviour factor, q and magnitude of PGA are varies. As proposed in Eurocode 8, the seismic action on building for each horizontal direction in which the building is analysed can be represented by the base shear force, F_b which can be determine using the following expression:

$$F_b = S_d\,(T_1).m.\lambda \qquad 3.1$$

Where,

$S_d(T_1)$ correspond to the ordinate of the design spectrum at period T_1,

m the total mass of the building above the foundation or above the top of a rigid basement,

λ correction factor.

The fundamental period of vibration, $T_1 \leq 2T_C$ is for building that has more than two storeys, the value of correction factor, λ equal to 0.85. Otherwise, the correction factor, λ is equal to 1.0.

3.4.5 Lateral Load

After the determination the magnitude of base shear force, F_b, it has to be proportionally distributed along the height of the frame as lateral load to simulate the action of earthquake. By following the expression stated below, the distribution of the lateral seismic loads can be made, which is stated in Clause 4.3.3.2.3, Eurocode 8 (2004):

$$F_i = F_b.\frac{z_i.m_j}{\Sigma\, z_i.m_j} \qquad 3.2$$

Where,

F_i is the horizontal force acting on storey, i

F_b	is the seismic base shear force
z_i , z_j	are the height of masses m_i ,m_j above the level of application of the seismic action
m_i , m_j	are the storey masses computed

3.4.6 Design Response Spectrum

In order to determine the base shear force, F_b acting on the building, the ordinate of the design spectrum at period T_1, $S_d(T_1)$ is required as from Equation 3.1 in previous section. Based on Eurocode 8 (2004), To avoid explicit inelastic structural analysis in design, elastic analysis based on a response spectrum reduced with respect to the elastic one is performed. Response spectrum also need to be identified first to get base shear force, F_b. In Clause 3.2.2.5, for this purpose, a series of design response spectrum had been developed. For seismic hazard in East Malaysia, this study considers the Type 1 of response spectrum which is compatible for Soil Type A, Soil Type C and Soil Type E. Equations 3.3 to 3.6 are used as a reference to develop design response spectrum.

The behaviour factor, q in this study is equal to 3.9. For the horizontal components of the seismic action the design spectrum, $S_d(T_1)$, is defined by the following equations:

$$0 \leq T \leq T_B \quad : \quad S_d\,(T_1) = \alpha_g \,.\, S \,.\, \frac{2}{3} + \frac{T}{T_B} \,.\, \left(\frac{2.5}{q} - \frac{2}{3}\right) \tag{3.3}$$

$$T_B \leq T \leq T_C \quad : \quad S_d\,(T) = \alpha_g \,.\, S \,.\, \frac{2.5}{q} \tag{3.4}$$

$$T_C \leq T \leq T_D \quad : \quad S_d\,(T) = \begin{cases} = \alpha_g \,.\, S \,.\, \frac{2.5}{q} \,.\, \left[\frac{T_c}{T}\right] \\ \geq \beta . \alpha_g \end{cases} \tag{3.5}$$

$$T_D \leq T \quad : \quad S_d\,(T) = \begin{cases} = \alpha_g \,.\, S \,.\, \frac{2.5}{q} . \left[\frac{T_C T_D}{T^2}\right] \\ \geq \beta \,.\, \alpha_g \end{cases} \tag{3.6}$$

Where,

T is vibration period of a linear single-degree-of-freedom system

a_g is the design ground acceleration ($\alpha_g = \gamma_I . \alpha_{gR}$)

T_B is the lower limit of the period of the constant spectral acceleration branch

T_C is the upper limit of the period of the constant spectral acceleration branch

T_D is the value defining the beginning of the constant displacement response range

of the spectrum

S is the soil factor

β is lower bound factor for the horizontal design spectrum (0.2)

By referring to Eurocode 8, the recommended values of the parameters S, T_B, T_C, and T_D based on Soil Type A, Soil Type C and Soil Type E in Table 3.9 for the Type 1 Spectrum.

Table 3.9 Values of the parameters describing the recommended Type 1 elastic response spectra

Ground Type	***S***	***T_B (s)***	***T_C (s)***	***T_D (s)***
A	1.00	0.15	0.40	2.00
C	1.15	0.20	0.60	2.00
E	1.40	0.15	0.50	2.00

3.4.7 Design Ground Acceleration

Based on Clause 3.2.1 (3) in Eurocode 8 (2004), the value of design ground acceleration can be calculated as shown in Equation 3.7.

$$\alpha_g = \gamma_I . \alpha_{gR} \qquad 3.7$$

where,

γ_I is the importance factor which is depends on the importance classes of building in Clause 4.2.5

α_{gR} is reference peak ground acceleration

There are four importance classes of building are classified based on various factors which is depending on the consequences of collapse for human life, on their importance for public safety and civil protection in the immediate post-earthquake period, and on the social and economic consequence of collapse by Clause 4.2.5 in Eurocode 8 (2004). In this study, the importance class for model in this study is class III as categorize in Table 3.10. Thus, the importance factor involved in this study is 1.2.

Table 3.10 Importance classes and importance factor for buildings (Eurocode 8, 2004)

Importance class	Buildings	Importance factor
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8
II	Ordinary buildings, not belonging in the other categories.	1.0
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc	1.2
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1.4

According to MOSTI (2009) and Adnan et. al., (2008), seismic hazard map for Malaysia is shown in Figure 3.4 and Figure 3.5 for Peninsular and Eastern Malaysia. The value of reference peak ground acceleration (PGA), a_{gR} is based on PGA for Malaysia. In this study, the value of reference peak ground acceleration, a_{gR} is taken as 0.04g, 0.07g and 0.10g which covers for both at Peninsular and eastern Malaysia. Location for PGA of 0.04g which are located at Ipoh (Perak), Sebuyau (Sarawak), Alor Setar (Kedah). While for PGA 0.07g and 0.10g is located at Seremban (Negeri Sembilan) and Semporna (Sabah), respectively. The seismic hazard map used unit gal as a standard unit which is 1 gal is equal to 0.001g. The class of ductility used for seismic design are Ductility Class Medium (DCM). The improved version of the seismic hazard map for Malaysia as proposed by National Annex (2017) is presented in Appendix A.

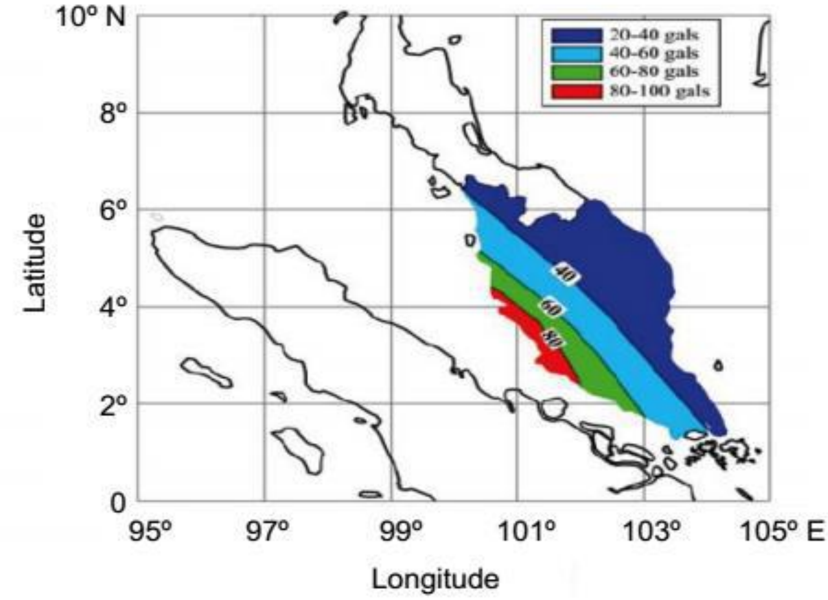


Figure 3.4 Seismic hazard map on Peninsular Malaysia (MOSTI, 2009)

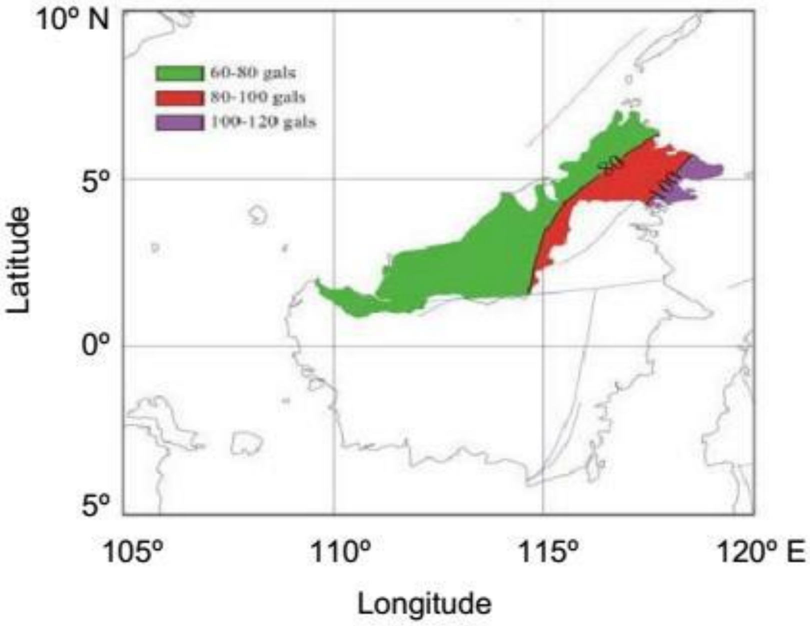


Figure 3.5 Seismic hazard map on Eastern Malaysia (Adnan et al., 2008)

In order to compare the influence of different type of soil and PGA value on the amount of steel reinforcement, three different value of PGA were used which are 0.04g, 0.07g, and 0.10g considering on ductility class medium (DCM). On the other hand, to compare the influence of different type of soil, Soil Type A, Soil Type C and Soil Type E has been recommended for design consideration. Non-seismic model also has been generated to compare the percentage difference of amount of steel reinforcement for seismic building and non-seismic building. Table 3.11 shows all models of the school building that had been considered in this study. Figure 3.6 shows 3D model of the building generated from Tekla structural software.

Table 3.11 All models of the RC school building

Model	**Soil Type**	**PGA (g)**
Non- seismic	None	None
A – 0.04	A	0.04
A – 0.07	A	0.07
A – 0.10	A	0.10
C – 0.04	C	0.04
C – 0.07	C	0.07
C –0.10	C	0.10
E – 0.04	E	0.04
E – 0.07	E	0.07
E – 0.10	E	0.10

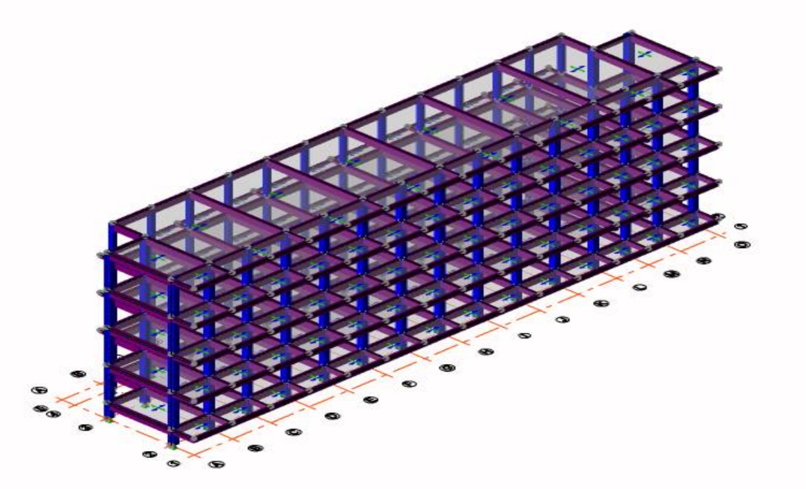


Figure 3.6 3D model of the building generated from Tekla structural software

3.4.8 Beam Design

Beam design was carried out according to Eurocode 8. In this study, the maximum bending moment is chosen as design moment for the analysis. The amount of steel reinforcement proposed will be depending on the maximum bending moment at the section. The higher the bending moment, the higher amount of steel reinforcement required. Figure 3.7 shows the flow chart of beam design to Eurocode 8 (2004).

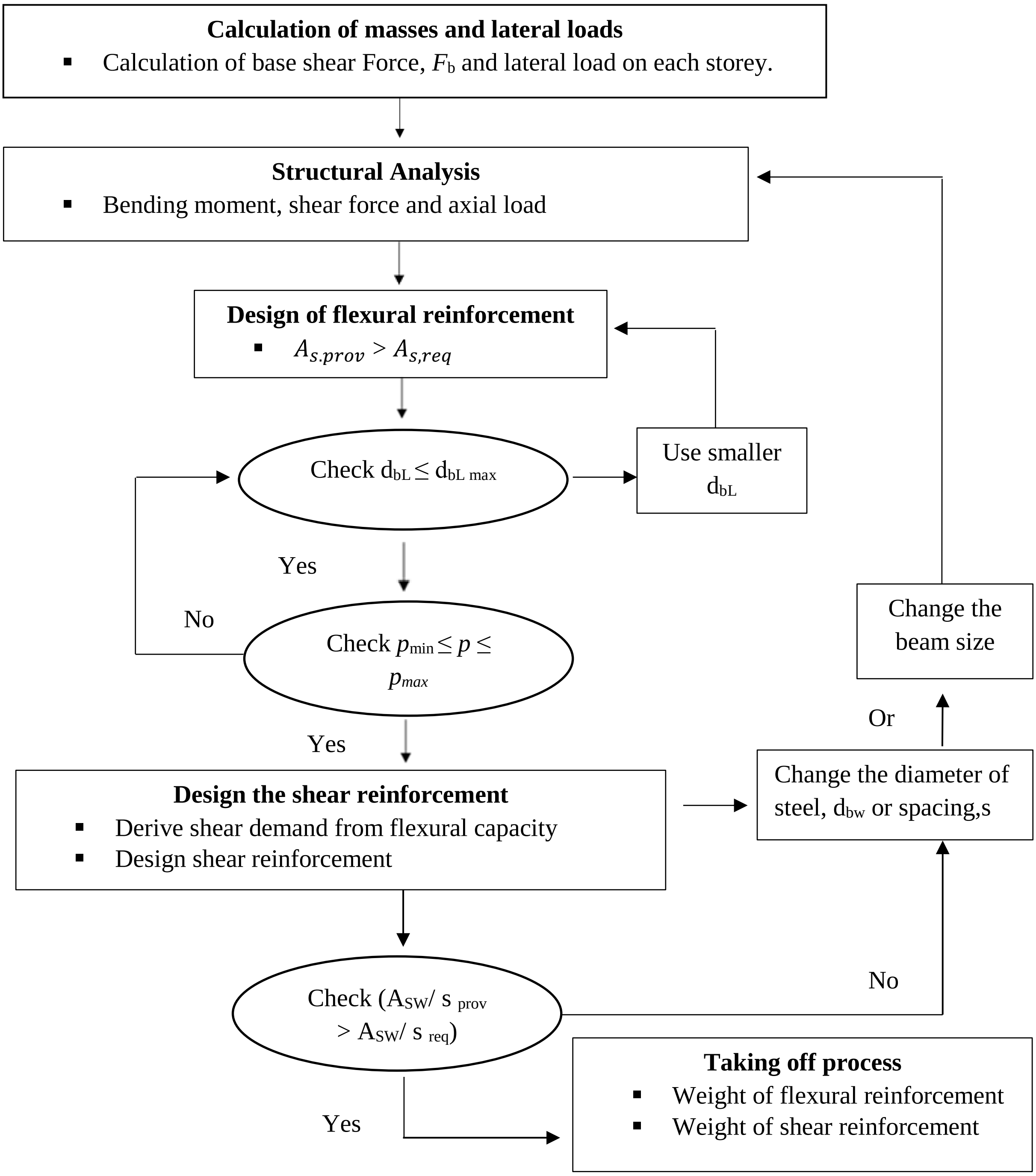


Figure 3.7 Flow chart of beam design according to Eurocode 8 (Adiyanto, 2016)

3.4.9 Column Design

Column play an important role to ensure the structure of building is strong and safe. Column design was carried out according to Eurocode 8. Maximum bending moment was used to determine the column size and amount of steel reinforcement needed. Figure 3.8 shows the flow chart of column design to Eurocode 8 (2004).

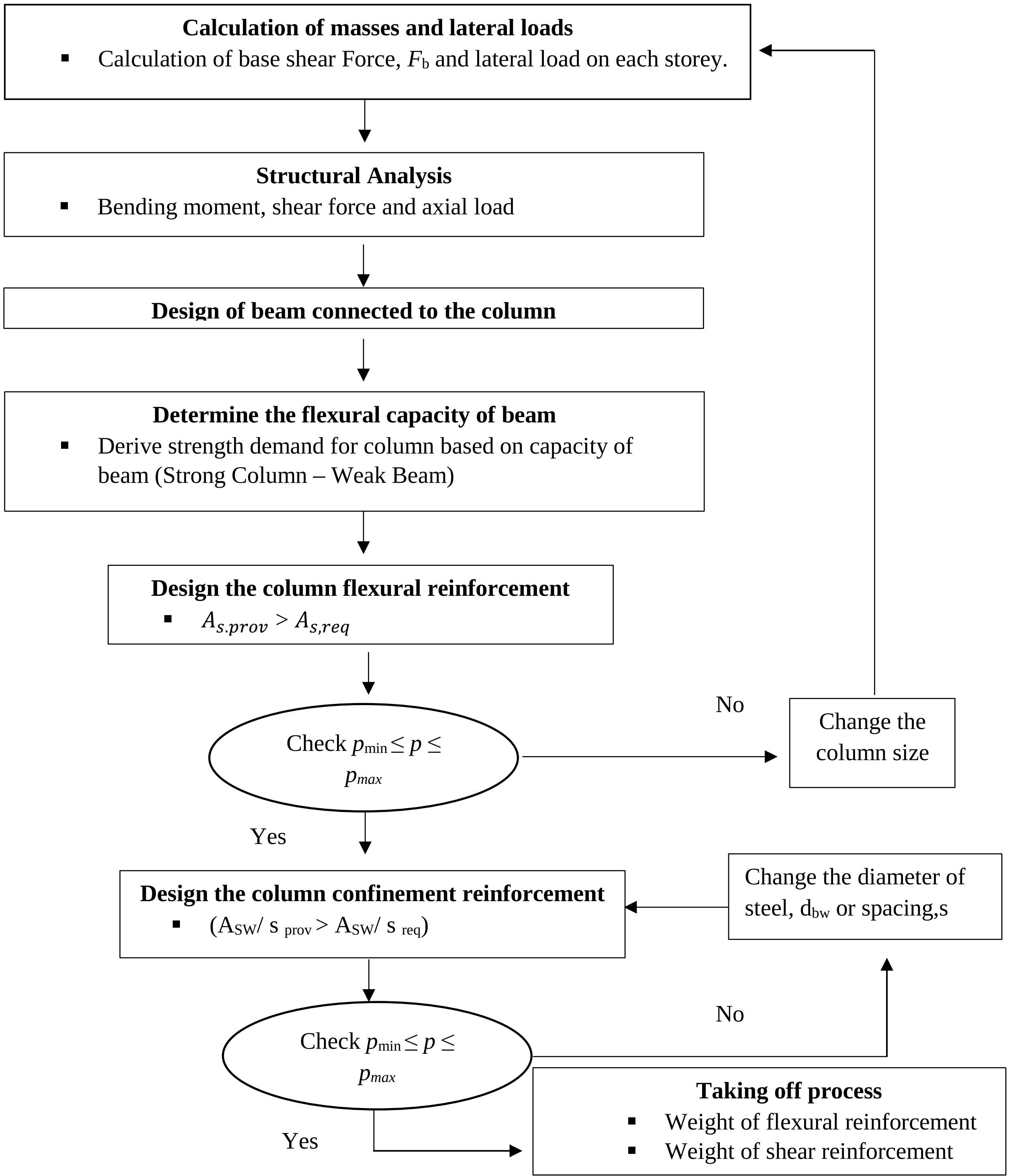


Figure 3.8 Flow chart of column design to Eurocode 8 (Adiyanto, 2016)

3.5 Phase 3: Taking Off

In the last phase of the research methodology, seismic design on the building frames designed based on various value of reference peak ground acceleration and type of soil was carried out using Tekla structural software. Total mass of the frames was calculated based on the size of the structural member (beam and column) determined in Phase 2.

Taking off process has been performed once the flexural and shear reinforcement had satisfied all the design process. Total amount of steel reinforcement required for $1m^3$ of concrete for main and link reinforcement for both beam and column of the buildings has been calculated.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the influence of Soil Type and Level of Seismicity on amount of steel is discussed based on the result obtained and design from analysis done by using Tekla Structure designer software. The analysis is done by four-storey reinforced concrete (RC) school building which is designed based on Eurocode 8 (2004). The model also assumed to be built with a compressive strength of concrete 30 N/mm^3 and for Ductility Class Medium (DCM) as previously discussed in Chapter 1.

The variables that had been considered are Soil Type and Level of Seismicity as discussed in Chapter 3. The results have been compared and the comparison will be based on the required amount of steel for the RC school building. Furthermore, the comparison also includes the design response spectrum, $S_d(T_1)$, of the model.

4.2 Design Response Spectrum Graph and Base Shear Force, F_b

The design response spectrum is developed to avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and/or other mechanisms. In order to produce design response spectrum graph, parameters such as importance factor, γ_1 and reference peak ground acceleration, α_{gR} are required. However, as the model is assumed to be built on Soil Type A, C and E, the other parameter that should be considered is Type 1 of response spectrum. The seismic action of the design spectrum, $S_d(T_1)$, which is defined using the equations that are previously mentioned in Chapter 3 also considered.

A design response spectrum graph is constructed first to obtain the base shear force, F_b and also the value $S_d(T_1)$ can be defined. By referring to Chapter 3, Equation 3.1 the value of design response spectrum graph will also varied as the value of parameter varied. This is because the value of reference peak ground acceleration and behaviour factor, q required as in equation 3.1 are varied which will then affect the base shear force, F_b acting on the building.

According to Eurocode 8 (2004), Clause 4.3.3.2.2, the following equation can be used for building with height of up to 40m to determine the value of T_1 (s).

$$T_1 = C_t . H^{3/4} \tag{4.1}$$

Where,

Ct is 0.085 for moment resistance space steel frames, 0.075 for moment resistance space concrete frames and for eccentrically braced steel frames and 0.05 for all other structures.

H is the height of the building in m, from the foundation or from the top of a rigid basement.

By using Equation 4.1, Ct is equal to 0.075 and the height of the RC school building, H of 15.5m, the fundamental period of vibration period, T_1 resulted in 0.6 sec. As known, in this study all models will be subjected to the same gravitational load (dead load and imposed load). However, the models will be subjected to different lateral load as the parameter of this study which are magnitude of peak ground acceleration (PGA) are varies.

The parameters are comply with the objective of analysis, to determine the influence of different Soil Type and Level of Seismicity on amount of steel reinforcement, respectively. The overall design response spectrum for reference peak ground acceleration, α_{gR}=0.04g, α_{gR}=0.07g and α_{gR}=0.10g, importance factor, γ_1=1.2 and Soil Type A, C and E have been developed for the analysis and design.

The combination design response spectrum for three different Soil Type shows three different values of design spectrum, $S_d(T_1)$. The lowest design spectrum, $S_d(T_1)$ value is from Soil Type A and the highest one is from Soil Type E. The design spectrum, $S_d(T_1)$ value is 0.04g, 0.07g and 0.10g when defined by using Soil Type A, Soil Type C, and Soil Type E, respectively.

In Figure 4.1 shows the design response spectrum for Soil type E with different Level of seismicity. Soil Type E (soft soil) considered as a building that built on this soil type tend to have greater effect on tremor compared to Soil Type A and C. Furthermore, to indicate high seismicity region, a design response spectrum for PGA of 0.10g with different soil type can be referred to Appendix B.

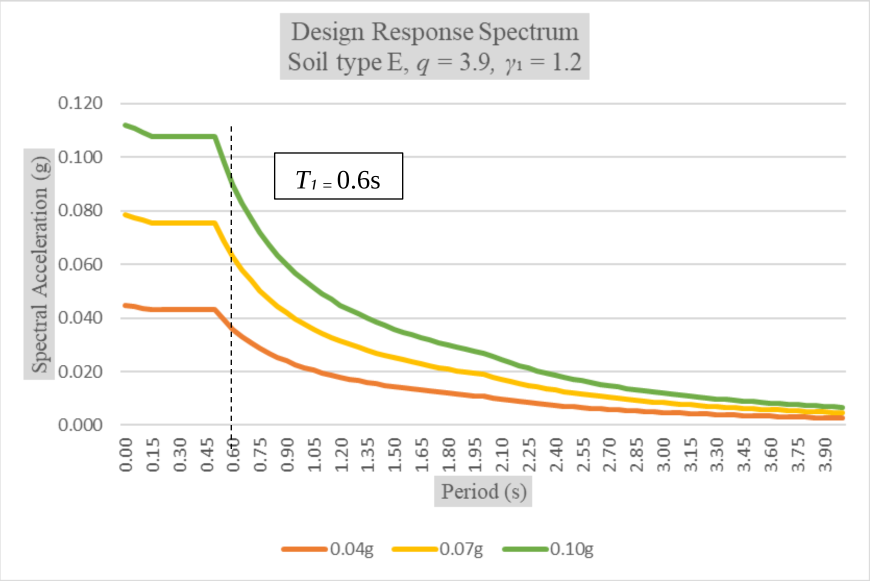


Figure 4.1 Design response spectrum for Soil type E with different magnitude of PGA

From Figure 4.1, the value of design spectrum, $S_d(T_1)$ can be defined by determine the value of period, T_1 by using equation 3.1. The period, T_1 defined is equal to 0.6 sec and it makes the value of design spectrum, $S_d(T_1)$ is equal to 0.10g which is on Soil Type E. The value of design spectrum is strongly related with the base shear force, F_b as mentioned on equation 3.1 in Chapter 3 where when the mass of the element, m, and correction factor, λ, is constant, the base shear force, F_b related directly to the design spectrum, $S_d(T_1)$. Table 4.1 shows the value of design spectrum, $S_d(T_1)$ and base shear force, F_b for every model. As a result, we can conclude that as the value of design spectrum, $S_d(T_1)$ increase, the value of base shear force, F_b also will increase.

Table 4.1 Design Response Spectrum, $S_d(T_1)$ and Base Shear Force, F_b for every model

Model Name	**Soil Type**	**PGA**	**$S_d(T_1)$, m/s^2**	**Mass, m**	**F_b, kN**
NS	-	-	-	2454.74	-
A-0.04	A	0.04	0.206	2454.74	429.8
A-0.07		0.07	0.361	2454.74	752.2
A-0.10		0.10	0.515	2454.74	1074.6
C-0.04	C	0.04	0.347	2454.74	724.0
C-0.07		0.07	0.607	2454.74	1267.1
C-0.10		0.10	0.868	2454.74	1810.1
E-0.04	E	0.04	0.361	2454.74	752.2
E-0.07		0.07	0.631	2454.74	1316.4
E-0.10		0.10	0.901	2454.74	1880.6

4.3 Influence of Soil Type and Level of Seismicity on concrete volume

In the discussion, the model used is four-storey RC school building that is using different Soil Type which are Soil Type A, C and E. The model also using different value of α_{gR}, which are 0.04g, 0.07g and 0.10g. As stated in the scope of work in Chapter 1, the analysis also using various parameters such as concrete grade of G30 and Ductility Class Medium (DCM). The behaviour factor is equal to 3.9 for DCM. The result of steel reinforcement for beam, column and for beam and column (overall) reinforcement is obtained and discuss as shown in Figure 4.2, 4.3 and 4.4, respectively.

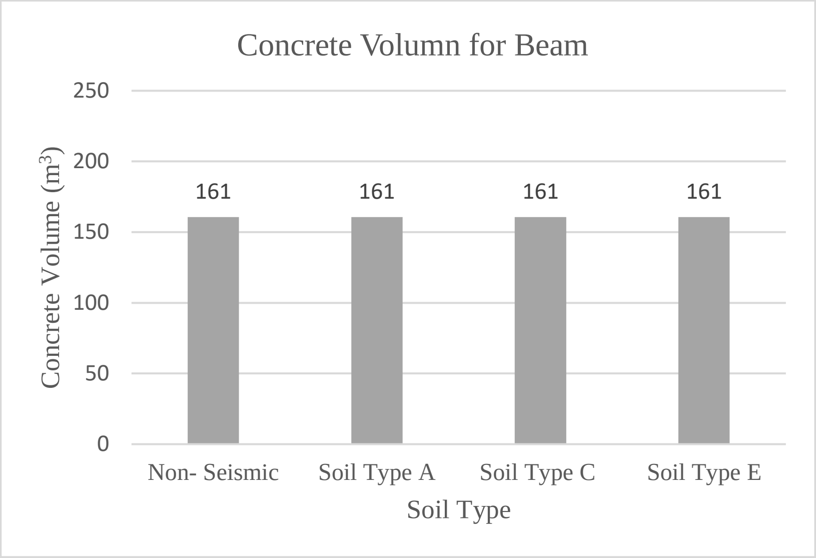


Figure 4.2 Concrete volume for Beam

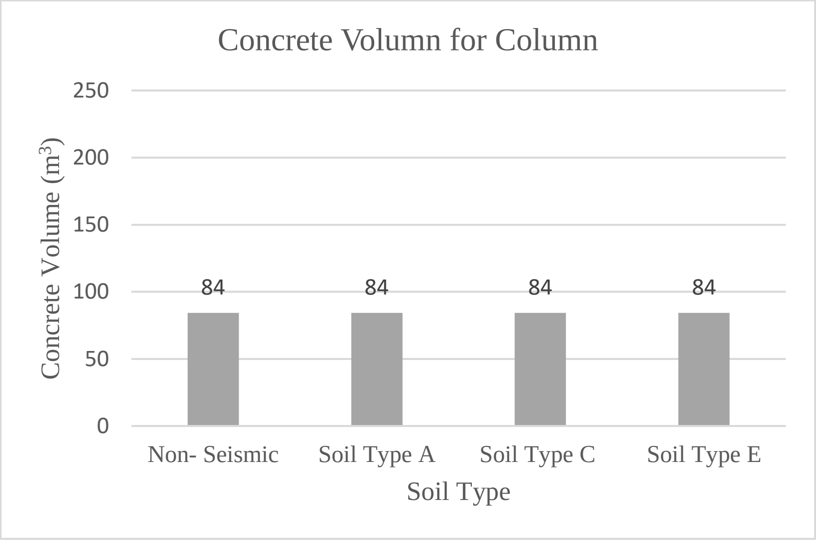


Figure 4.3 Concrete volume for Column

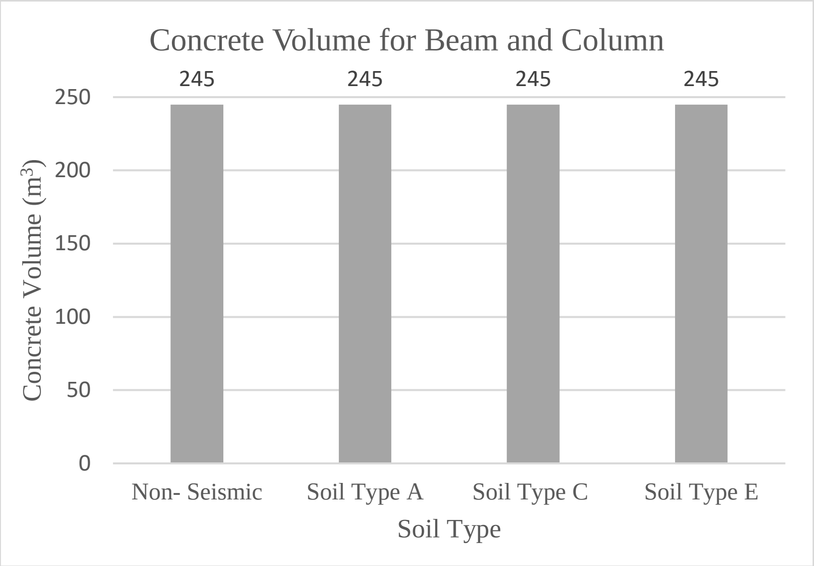


Figure 4.4 Concrete volume for Beam and Column (Overall)

As a result as shown in Figure 4.2, 4.3 and 4.4, the amount of concrete volume for all models are same because all models using same dimension for every structural element.

4.4 Influence of Soil Type on Amount of Steel Reinforcement

There are two type of element considered for discussion namely as beam and column. Beam at grid line C/1-5 labeled as Beam C and column at grid line C/2 level 1 to level 4 labeled as Column C are selected for discussion. The position of the selected beam and column are shown in Appendix C.

The different Soil Type gives different impact on the amount of steel required per 1m³ for the building as discussed in Chapter 3. So, in this section, comparison between Soil Type A, C and E and non-seismic model is made in term of the amount of steel reinforcement used for beam, column and for beam and column (overall). To indicate high seismicity region, the fix value of reference peak ground acceleration, a_{gR} used is 0.10g. The result for a_{gR}=0.04g and a_{gR}=0.07g can be referred to Appendix D for beam, column and beam and column (overall).

4.4.1 Influence of Soil Type on Amount of Steel Reinforcement for Beam

Figure 4.5 present the results on total amount of steel required for 1m^3 of concrete of beam influenced by Soil Type. From the results, the percentage difference of weight of steel required for Soil Type A, Soil Type C and Soil Type E with a_{gR} = 0.10g is made in comparison with non-seismic design.

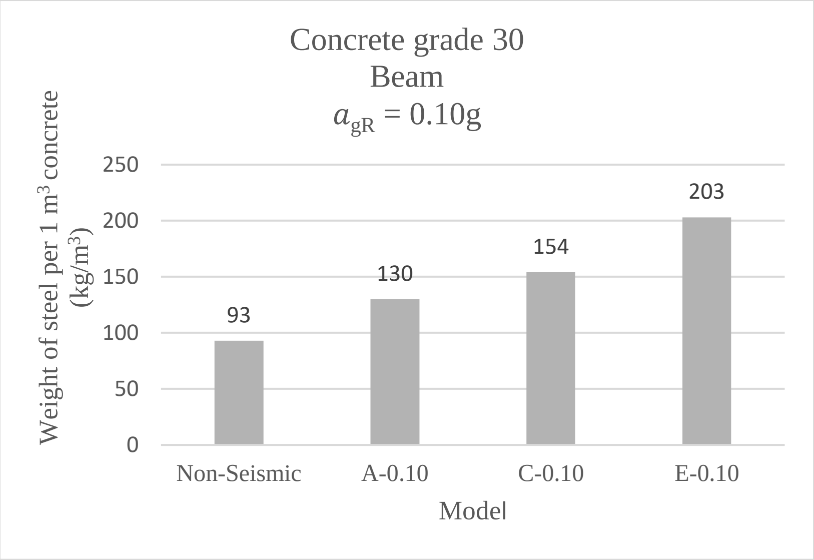


Figure 4.5 Total amount of steel required for 1m^3 of concrete of beam influenced by Soil Type

Table 4.2 Bending Moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement for Beam C of a_{gR} = 0.10g influenced by Soil Type

Model	Beam C			
	0.10g			
	Longitudinal bars			
	$A_{s,prov}$	$A_{s,min}$	$A_{s,req}$	M_{Ed}
Non-Seismic	1257	252	1228	262.3
A	1963	318	1384	282.4
C	1963	318	1502	303.8
E	2454	316	1976	371.9

As in the Figure 4.5, the percentage difference of weight of steel required for beam around 39% to 118% when compared to non-seismic design. For more detail, the increment is equal to 39%, 65% and 118% when built on Soil Type A, Soil Type C, and Soil Type E, respectively. Bending moment of an element absolutely influenced the amount of steel reinforcement required where the strength of the steel reinforcement help to resist or reduce the element from bend which cause by the shear force. The highest the bending moment of the element, the amount of steel reinforcement required increase, vice versa. Table 4.2 shows the bending moment, M_{Ed}, and area of steel, $A_{s,req}$ of reinforcement of Beam C, when considering non- seismic design, Soil Type A, Soil Type C and Soil Type E. As a result, Soil Type E has the highest bending moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement, respectively, compared to others.

4.4.2 Influence of Soil Type on Amount of Steel Reinforcement for Column

Figure 4.6 shows the results on the total amount of steel required for 1m^3 of concrete of column influenced by Soil Type. From the results, the percentage difference of weight of steel required for Soil Type A, Soil Type C and Soil Type E with $a_{gR} = 0.10g$ is made in comparison with non-seismic design.

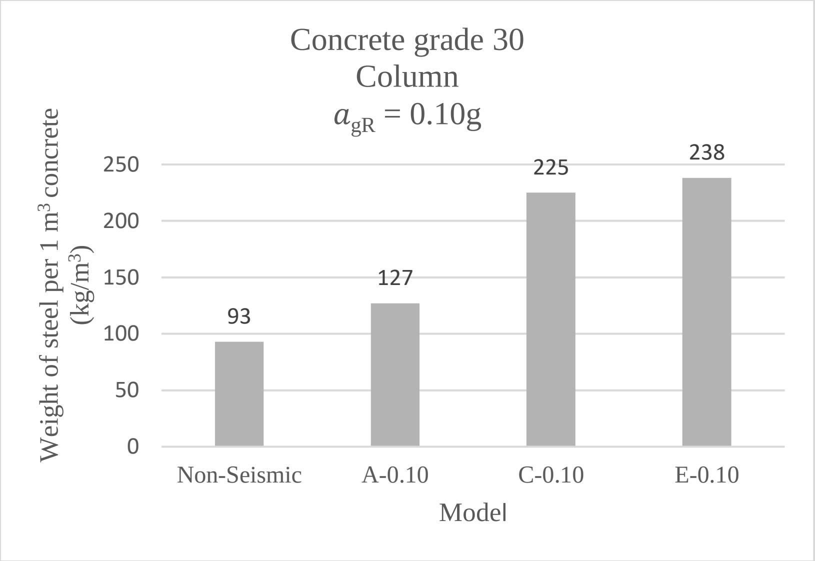


Figure 4.6 Total amount of steel reinforcement for 1m^3 of concrete of column influenced by Soil Type

Table 4.3 Bending Moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement for Column C of a_{gR} = 0.10g influenced by Soil Type

Model	Column C							
	0.10g							
	Longitudinal bars							
	M_{res}	M_{Ed}	N_{max}	N_{Ed}	$A_{s,min}$	$A_{s,max}$	$A_{s, prov}$	$A_{s\ req}$
Non-Seismic	201.1	57.3	3945.4	860.5	810	8100	1608	894
A	219.1	86.8	4179.0	863.9	810	8100	1608	894
C	329.7	122.0	4948.8	863.9	810	8100	3927	894
E	330.1	126.0	4948.8	863.9	810	8100	3927	894

As in the Figure 4.6, the percentage difference of weight of steel required for column around 36% to 155% when compared to non-seismic design. For more detail, the increment is equal to 36%, 141% and 155% when built on Soil Type A, Soil Type C, and Soil Type E, respectively. Bending moment of an element absolutely influenced the amount of steel reinforcement required where the strength of the steel reinforcement help to resist or reduce the element from bend which cause by the shear force. The highest the bending moment of the element, the amount of steel reinforcement required increase, respectively. Table 4.3 show the bending moment, M_{Ed}, and area of steel, $A_{s,req}$ of reinforcement of Column C, respectively, when built on non- seismic design, Soil Type A, Soil Type C and Soil Type E. As a result, Soil Type E has the highest bending moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement, respectively, compared to others.

4.4.3 Influence of Soil Type on Amount of Steel Reinforcement for Beam and Column (Overall)

Figure 4.7 present the results on the total amount of steel reinforcement for $1m^3$ of concrete of Beam and Column (Overall) influenced by Soil Type. From the results, the percentage difference of weight of steel required for Soil Type A, Soil Type C and Soil Type E with a_{gR} = 0.10g is made in comparison with non-seismic design.

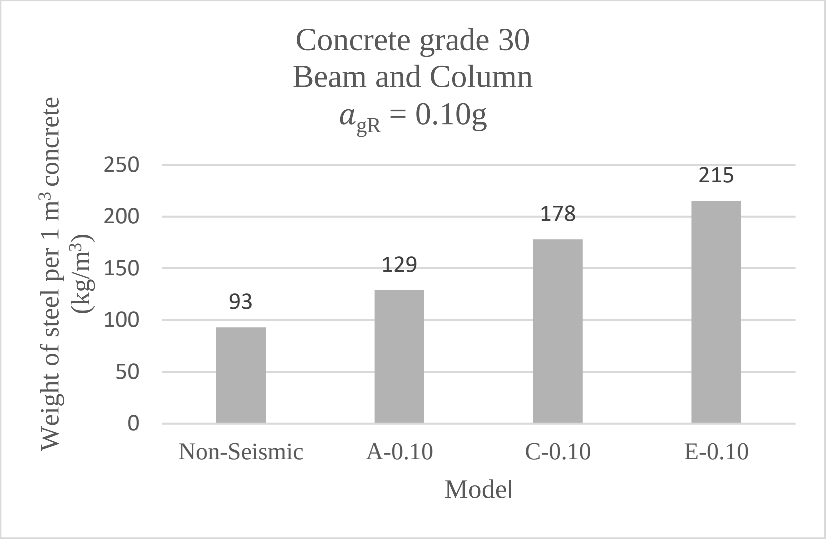


Figure 4.7 Total amount of steel reinforcement for 1m^3 of concrete of Beam and Column (Overall) influenced by Soil Type

As in the Figure 4.7, the percentage difference of weight of steel required for beam and column increase around 38% to 131% when compared to non-seismic design. For more detail, the increment is equal to 38%, 91% and 131% when built on Soil Type A, Soil Type C, and Soil Type E, respectively. Non-seismic design has the lowest amount of steel required while Soil Type E is the highest one. Therefore, the higher the Soil Type, the higher the amount of steel required. This result is in similar pattern with Saka (2018).

The result is strongly related to the value of spectrum design, $S_d(T_1)$, on various of Soil Type. Based on the previous design spectrum, $S_d(T_1)$ on Figure 4.1, Soil Type E has the highest design spectrum, $S_d(T_1)$ value. It is affect the value of base shear force, F_b of the design where the base shear force, F_b value increase perpendicularly with the design spectrum, $S_d(T_1)$ value. When base shear force increase, with fix value of total mass, *m* and correction factor, λ the bending moment and shear force will be increase and resulting in higher amount of steel reinforcement required for the whole building. From the analysis, it proves that Soil Type E has the softer soil texture which didn’t strong enough to hold the concrete without large amount of steel reinforcement used. The bending moment, M_{Ed} and area of steel required, $A_{s,req}$ for Soil Type E is the highest, so the amount of steel reinforcement required for Soil Type E for the whole building also the highest compared to others.

4.5 Influence of Level of Seismicity on Amount of Steel Reinforcement

The Level of Seismicity give different impact on the amount of steel required per 1m³ for the building as discussed in Chapter 3. So, in this section, comparison between Level of Seismicity with different value of α_{gR}, which are 0.04g, 0.07g and 0.10g and non-seismic model is made in term of the amount of steel reinforcement used for beam, column and for beam and column (overall) reinforcement. To indicate high seismicity region, the fix Soil type E is used. The result for Soil Type A and Soil Type C can be referred to Appendix E.

4.5.1 Influence of Level of Seismicity on Amount of Steel Reinforcement for Beam

Figure 4.8 present the results on the total amount of steel required for 1m^3 of concrete of beam influenced by Level of Seismicity. From the results, the percentage difference of weight of steel required for a_{gR} which are 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

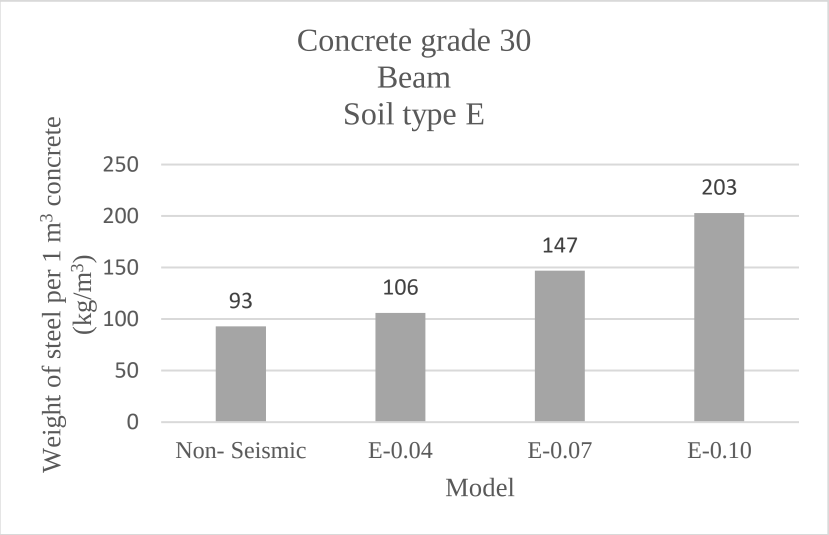


Figure 4.8 Total amount of steel required for 1m^3 of concrete of beam influenced by Level of Seismicity

Table 4.4 Bending Moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement for Beam C of a_{gR} = 0.10g influenced by Level of Seismicity

Model	Beam C			
	Soil Type E			
	Longitudinal bars			
	$A_{s,prov}$	$A_{s,min}$	$A_{s,req}$	M_{Ed}
Non-Seismic	1257	252	1228	262.3
0.04g	1257	252	1228	262.3
0.07g	1571	247	1498	309.3
0.10g	2454	316	1976	371.9

As in the Figure 4.8, the percentage difference of weight of steel required for beam around 13% to 118% when compared to non-seismic design. For more detail, the increment is equal to 13%, 58% and 118% when built on 0.04g, 0.07g and 0.10g, respectively. The amount of steel reinforcement is strongly related with the with the strength of the element to hold itself from bending which occurred caused by the shear force. The highest the bending moment of the element, the amount of steel reinforcement required increase, respectively. Table 4.4 shows the bending moment, M_{Ed}, and area of steel, $A_{s,req}$, of reinforcement of Beam C, respectively, when built on non- seismic design, 0.04g, 0.07g and 0.10g. The Level of seismicity with 0.10g has the highest bending moment, M_{Ed} and area of steel $A_{s,req}$ for reinforcement, respectively, compared to others.

4.5.2 Influence of Level of Seismicity on Amount of Steel Reinforcement for Column

Figure 4.9 present the results on the total amount of steel required for $1m^3$ of concrete of column influenced by Level of Seismicity. From the results, the percentage difference of weight of steel required for a_{gR} which are 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

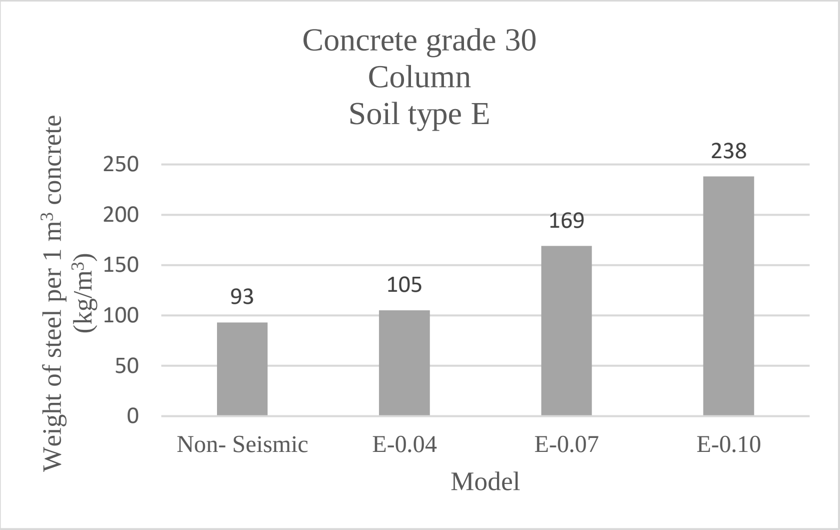


Figure 4.9 Total amount of steel reinforcement for 1m^3 of concrete of column influenced by Level of Seismicity

Table 4.5 Bending Moment, M_{Ed} and area of steel, $A_{s,req}$ for reinforcement for Column C of a_{gR} = 0.10g influenced by Level of Seismicity

Model	Column							
	Soil type E							
	Longitudinal Bars							
	M_{res}	M_{Ed}	N_{max}	N_{Ed}	$A_{s,min}$	$A_{s,max}$	$A_{s, prov}$	$A_{s\ req}$
NS	201.1	57.3	3945.4	860.5	810	8100	1608	894
0.04g	173.5	70.9	3945.4	863.6	810	8100	1608	894
0.07g	258.5	94.4	4479.4	863.9	810	8100	2513	905
0.10g	330.1	126	4948.8	863.9	810	8100	3927	905

As in the Figure 4.9, the percentage difference of weight of steel required for column around 12% to 155% when compared to non-seismic design. For more detail, the increment is equal to 12%, 81% and 155% when built on 0.04g, 0.07g, and 0.10g, respectively. Bending moment of an element absolutely influenced the amount of steel reinforcement required where the strength of the steel reinforcement help to resist or reduce the element from bend which cause by the shear force. The highest the bending moment of the element, the amount of steel reinforcement required increase, respectively. Table 4.5 show the bending moment, M_{Ed}, and area of steel, $A_{s,req}$ of reinforcement of Column C, respectively, when built on non- seismic design, 0.04g, 0.07g, and 0.10g. The Level of seismicity with 0.10g has the highest bending moment, M_{Ed} and area of steel $A_{s,req}$ for reinforcement, respectively, compared to others.

4.5.3 Influence of Level of Seismicity on Amount of Steel Reinforcement for Beam and Column (Overall)

Figure 4.10 present the results on the total amount of steel reinforcement for 1m^3 of concrete of Beam and Column (Overall) influenced by Level of Seismicity. From the results, the percentage difference of weight of steel required for a_{gR} which are 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

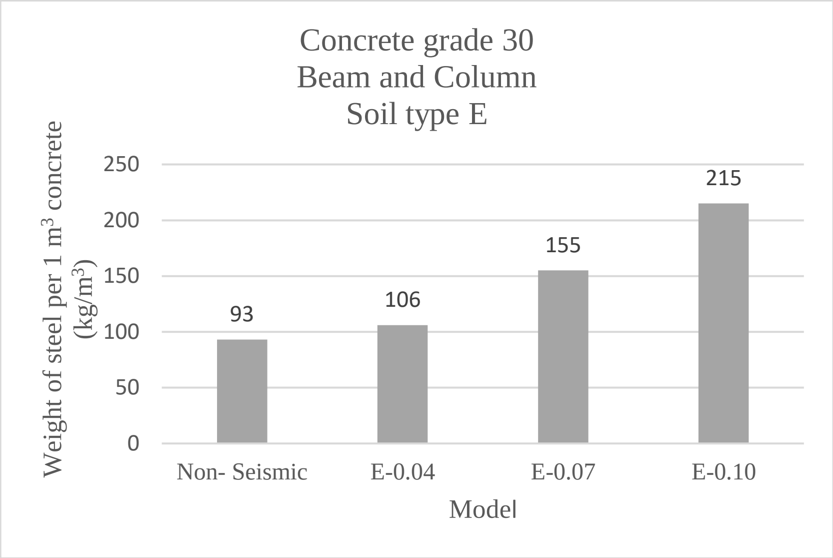


Figure 4.10 Total amount of steel reinforcement for 1m^3 of concrete of Beam and Column (Overall) influenced by Level of Seismicity

As in the Figure 4.10, the percentage difference of weight of steel required for beam and column increase around 13% to 131% when compared to non-seismic design. For more detail, the increment is equal to 13%, 66% and 131% when built on 0.04g, 0.07g and 0.10g, respectively. As a result, non-seismic design has the lowest amount of steel required while highest Level of seismicity with 0.10g is the highest one. This result is in good agreement with Ahmad Jani (2018).

The result is strongly related to the value of spectrum design, $S_d(T_1)$, on various of Level of Seismicity. Based on the previous design spectrum, $S_d(T_1)$ on Figure 4.1, from the lowest magnitude of PGA is directly related to design response spectrum as discussed in Figure 4.1. It is shown that the value of response spectrum, $S_d(T_1)$ for larger magnitude of PGA is higher compared to smaller magnitude of PGA. This is because the higher the magnitude of PGA, the higher the value of response spectrum, $S_d(T_1)$. Hence, the higher value of response spectrum, $S_d(T_1)$ resulted in higher value of base shear force, F_b. When base shear force increase, with fix value of total mass, m and correction factor, λ the bending moment and shear force will be increase and resulting in higher amount of steel reinforcement required for the whole building. From the analysis, it can be concluded that higher value of PGA of 0.10g resulted in higher amount of steel required for the overall of the building. The bending moment, M_{Ed} and area of steel required, $A_{s,req}$ for PGA of 0.10g is the highest, so the amount of steel reinforcement required for the whole building also the highest compared to others.

4.6 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model

So in this section, there will be comparison between Level of Seismicity with different value of a_{gR}, which are 0.04g, 0.07g and 0.10g and non-seismic model for every Soil Type which are Soil Type A, C and E are made in term of the total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model.

4.6.1 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type A

Figure 4.11 shows the results on the total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type A that affected by different Level of Seismicity. From the results, the percentage of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

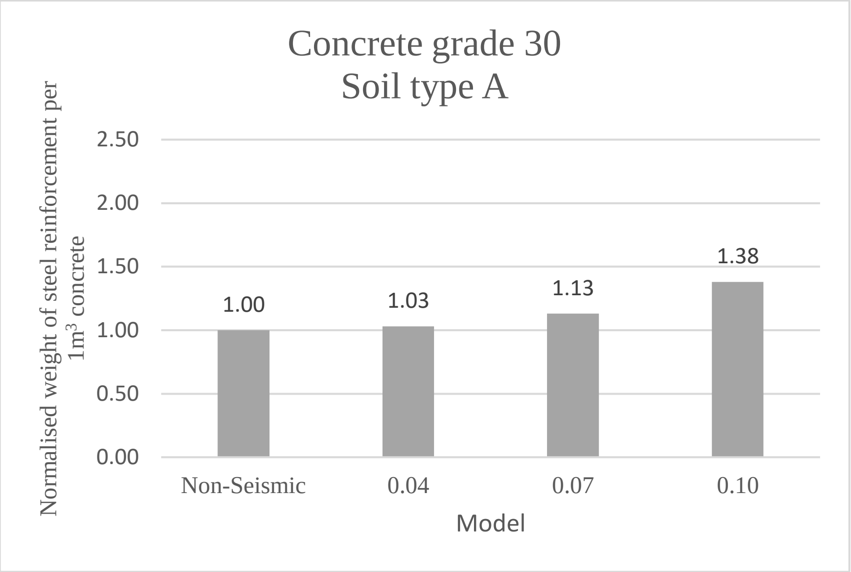


Figure 4.11 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type A

As in the Figure 4.11, the percentage difference of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type A increase around 3% to 38% when compared to non-seismic design. For more detail, the increment is equal to 3%, 13% and 38% when built on 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of steel required while highest Level of seismicity with 0.10g is the highest one.

4.6.2 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type C

Figure 4.12 shows the results on the total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type C that affected by different Level of Seismicity. From the results, the percentage of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

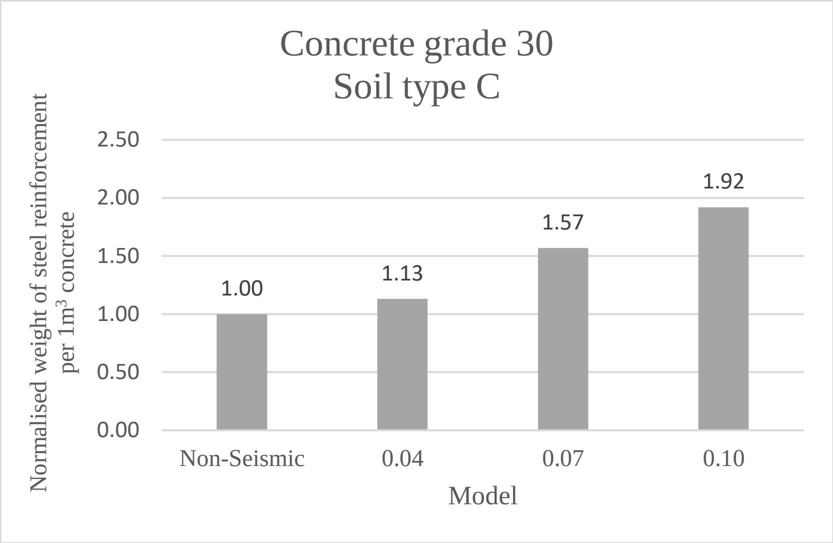


Figure 4.12 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type C

As in the Figure 4.12, the percentage difference of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type C increase around 13% to 92% when compared to non-seismic design. For more detail, the increment is equal to 13%, 57% and 92% when built on 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of steel required while highest Level of seismicity with 0.10g is the highest one.

4.6.3 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type E

Figure 4.13 shows the results on the total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type E that affected by different Level of Seismicity. From the results, the percentage of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for 0.04g, 0.07g and 0.10g is made in comparison with non-seismic design.

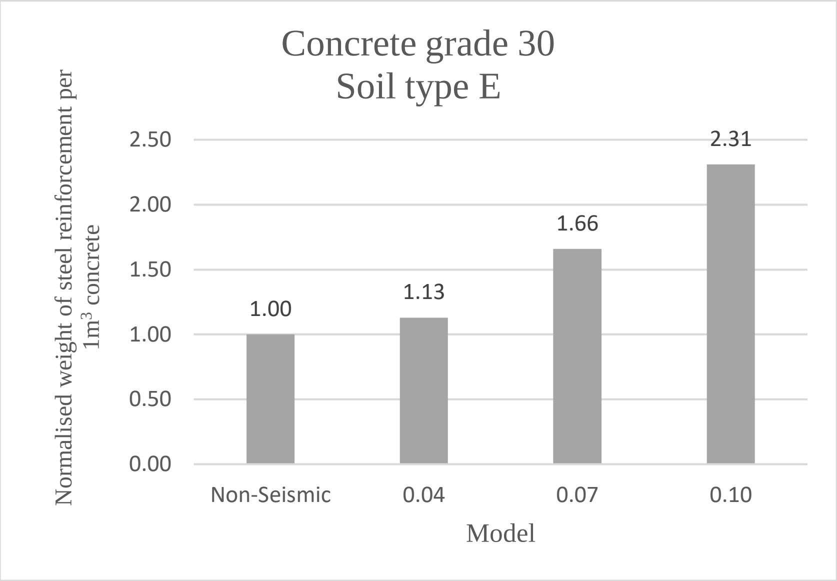


Figure 4.13 Total weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type E

As in the Figure 4.13, the percentage difference of weight of Steel Reinforcement per 1m^3 concrete normalised to non-seismic model for Soil Type E increase around 13% to 131% when compared to non-seismic design. For more detail, the increment is equal to 13%, 66% and 131% when built on 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of steel required while highest Level of seismicity with 0.10g is the highest one.

4.7 Estimation of Total Cost of Material

In this project, we had estimated the cost of materials for concrete volume and steel weight for beams and column (overall) that affected by different Soil Type and Level of Seismicity. According to JKR, the market price for 1m^3 concrete for G30 is RM 372.10/m^3 while the market price for high tensile steel weight is RM 3.50/kg.

4.7.1 Estimation of Total Cost of Material for Soil Type A

Figure 4.14 and Figure 4.15 presents the results on the total cost of concrete volume and total cost of steel weight for beam and column (overall) for Soil Type A with different Level of Seismicity which are 0.04g, 0.07g and 0.10g. From the results, the percentage difference of total cost of concrete volume and steel weight for one whole building for Soil Type A is made in comparison with non-seismic design.

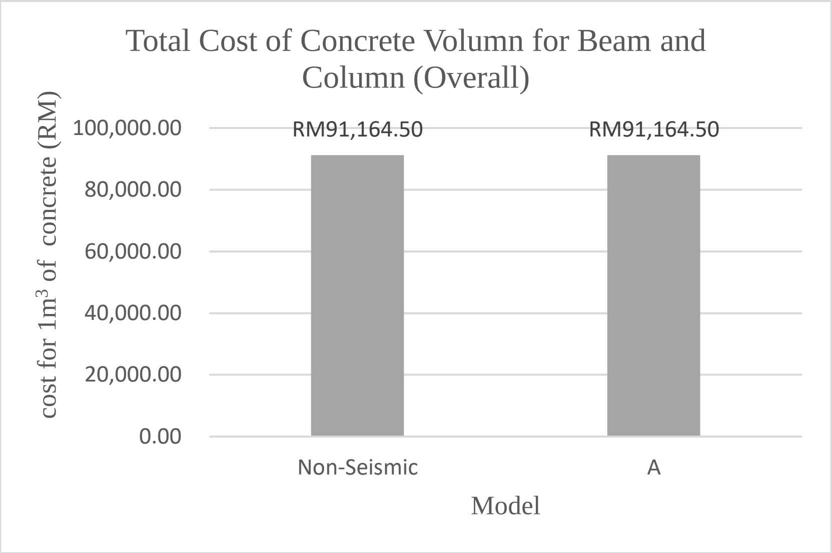


Figure 4.14 Total Cost of concrete volume for whole building for Soil Type A

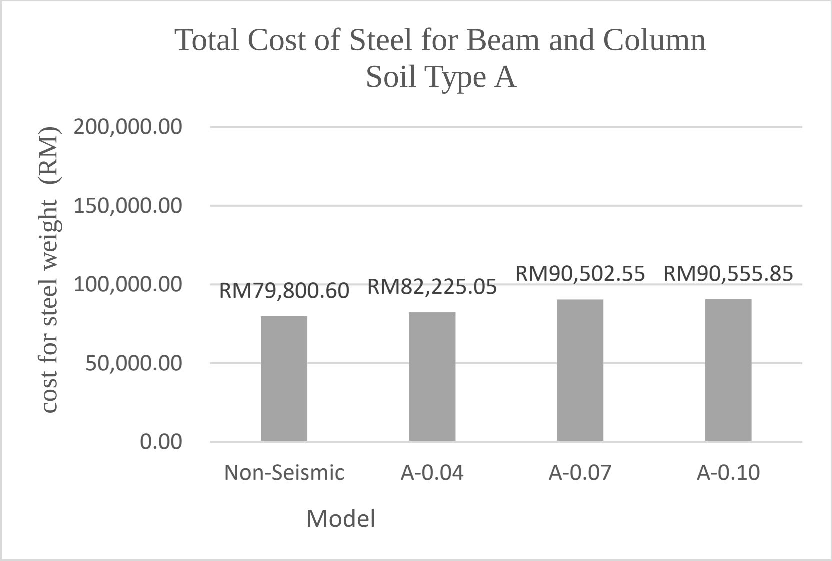


Figure 4.15 Total cost for steel for whole building for Soil Type A

As in Figure 4.14, the total cost for concrete volume is same because of the same size of beams and columns (overall) used in all model. From Figure 4.15, it can be concluded that the graph is increase linearly due to the steel weight of Soil Type A with

PGA of 0.10g is the highest among all PGA. Obviously, the increment of estimated construction cost is strongly influenced by the steel weight. As in the Figure 4.15, the percentage difference of total cost of steel weight for one whole building increase around 3.0% to 13.5% when compared to the non-seismic design. For more detail, the increment is equal to 3.0%, 13.4% and 13.5% when built on Soil Type A with PGA of 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of total cost for steel weight while Soil Type A with PGA of 0.10g is the highest one. Total Cost of Material for Soil Type A with PGA of 0.10g is RM181,720.35.

4.7.2 Estimation of Total Cost of Material for Soil Type C

Figure 4.16 and Figure 4.17 presents the results on the total cost of concrete volume and total cost of steel weight for beam and column (overall) for Soil Type C with different Level of Seismicity which are 0.04g, 0.07g and 0.10g. From the results, the percentage difference of total cost of concrete volume and steel weight for one whole building for Soil Type C is made in comparison with non-seismic design.

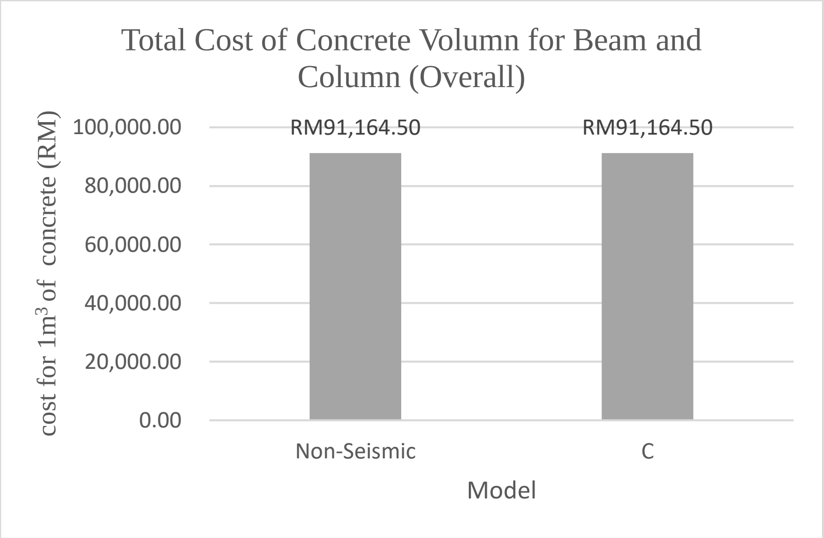


Figure 4.16 Total Cost of concrete volume for whole building for Soil Type C

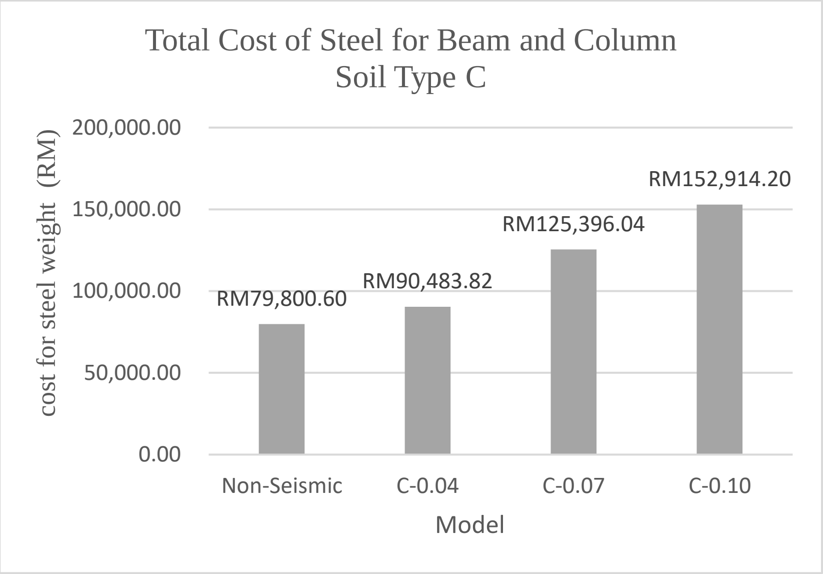


Figure 4.17 Total cost for steel for whole building for Soil Type C

As in Figure 4.16, the total cost for concrete volume is same because of the same size of beams and columns (overall) used in all model. From Figure 4.17, it can be concluded that the graph is increase linearly due to the steel weight of Soil Type C with PGA of 0.10g is the highest among all PGA. Obviously, the increment of estimated construction cost is strongly influenced by the steel weight. As in the Figure 4.17, the percentage difference of total cost of steel weight for one whole building increase around 13.3% to 91.6% when compared to the non-seismic design. For more detail, the increment is equal to 13.3%, 57.1% and 91.6% when built on Soil Type C with PGA of 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of total cost for steel weight while Soil Type C with PGA of 0.10g is the highest one. Total Cost of Material for Soil Type C with PGA of 0.10g is RM244,078.70.

4.7.3 Estimation of Total Cost of Material for Soil Type E

Figure 4.18 and Figure 4.19 presents the results on the total cost of concrete volume and total cost of steel weight for beam and column (overall) for Soil Type E with different Level of Seismicity which are 0.04g, 0.07g and 0.10g. From the results, the percentage difference of total cost of concrete volume and steel weight for one whole building for Soil Type E is made in comparison with non-seismic design.

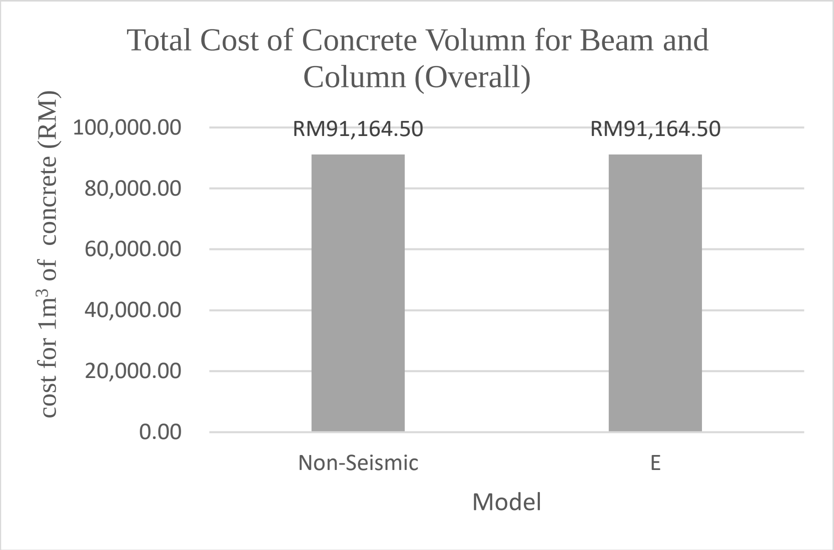


Figure 4.18 Total Cost of concrete volume for whole building for Soil Type E

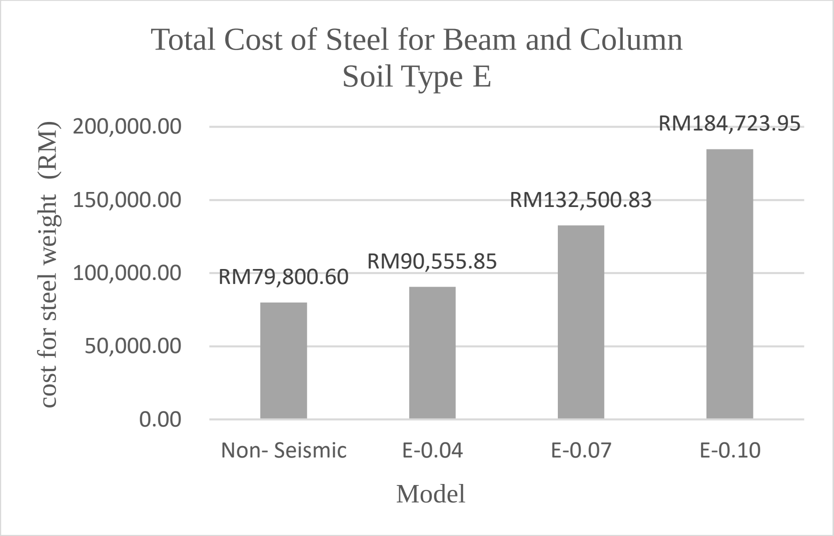


Figure 4.19 Total cost for steel for whole building for Soil Type E

As in Figure 4.18, the total cost for concrete volume is same because of the same size of beams and columns (overall) used in all model. From Figure 4.19, it can be concluded that the graph is increase linearly due to the steel weight of Soil Type E with PGA of 0.10g is the highest among all PGA. Obviously, the increment of estimated construction cost is strongly influenced by the steel weight. As in the Figure 4.19, the percentage difference of total cost of steel weight for one whole building increase around 13.4% to 131% when compared to the non-seismic design. For more detail, the increment is equal to 13.4%, 66% and 131% when built on Soil Type E with PGA of 0.04g, 0.07g and 0.10g, respectively. Non-seismic design has the lowest amount of total cost for steel weight while Soil Type E with PGA of 0.10g is the highest one. Total Cost of Material for Soil Type E is RM275,888.45.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The objectives of this study are to determine the effect of Soil Type and Level of Seismicity on design seismic of reinforced concrete school building on the amount of steel reinforcement. The seismic performance was evaluated based on the amount of weight of steel per 1m^3 for beam and column elements of the school building. The analysis is also done to obtained the design response spectrum graph where from the graph the results of $S_d(T_1)$ can be obtained. That is because, to achieve these results, the analysis is done on four-storey RC school building. The model is assumed to be built with grade of concrete of G30 and the ductility assumed is Ductility Class Medium (DCM). The model was designed based on the Eurocode 8 (2004) to represent the RC school building. The analysis is done by using Tekla Structural Designer software use the values of PGA of 0.04g, 0.07g and 0.10g on three different Soil Type which are Soil Type A, Soil Type C and Soil Type E. The conclusions obtained from the analysis are listed as follows.

- The amount of steel reinforcement for RC school building with seismic design when built on Soil Type E is higher compared to the other models built on other Soil Type and non-seismic design model. For a_{gR} = 0.10g, the percentage of difference from non-seismic model is 38% to 131%. For more detail, the increment percentage is increase around 38%, 92%, and 131% higher for Soil Type A, Soil Type C, and Soil Type E, respectively compared to non-seismic design. Thus, it proves that Soil Type E with seismic design consideration required large amount of steel reinforcement since its soil texture is the softer compared others and it can be classified as soft soil and it is not strong enough to hold the building structure.

- Total amount of reinforcement required in a building is higher when it is subjected to higher magnitude of PGA which is 0.10g compared to other models built on other PGA and non-seismic design model. For Soil Type E with a_{gR} = 0.10g, the percentage of difference from non-seismic model is 13% to 131%. For more detail, the increment percentage is 13%, 66%, and 131% for reference peak ground acceleration, a_{gR} = 0.04g, 0.07g, and 0.10g respectively. This is because higher magnitude of PGA resulted in higher value of response spectrum, S_d (T_1) which will increase the value of base shear force, F_b. When base shear force increase, the bending moment also increase. As the bending moment increase, the total amount of steel reinforcement required will increase.

5.2 Future Recommendation

There are lot of aspects and variables that can be considered in this study. This research can be further enhanced by the following recommendations:

i. The next study, the various of grade of concrete should be considered to investigate the effect of earthquake on the structural element of a building built in low and high concrete grade then compare the difference.

ii. Extend the studies using high rise building as this study focus on low rise building. The earthquake effect will be more significant to high rise building.

iii. Research related to earthquake can be carried out in future by considering different type of building such as residential building

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APPENDIX A

PENINSULAR, SABAH AND SARAWAK SEISMIC HAZARD MAP

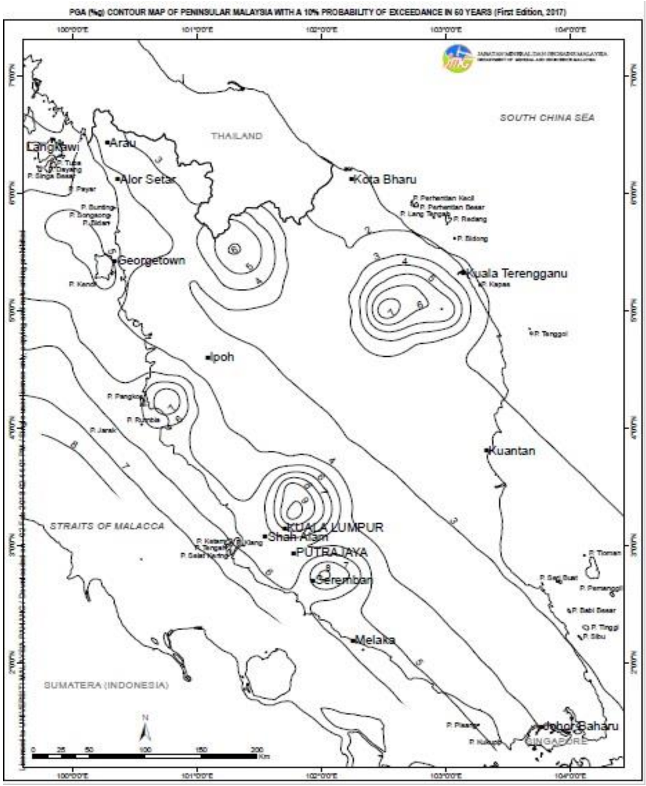

Figure A1a Peninsular Seismic Hazard Map

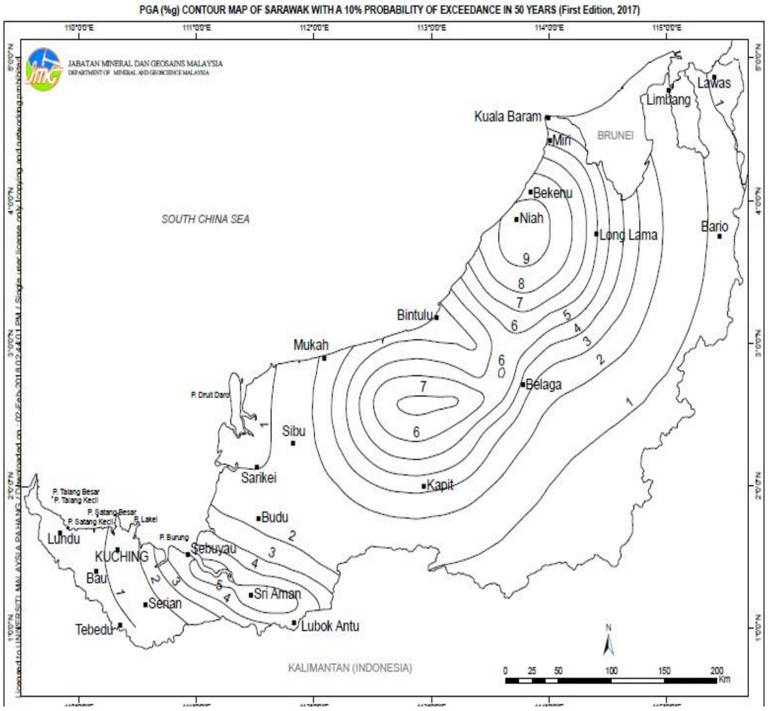

Figure A1b Sarawak Seismic Hazard Map

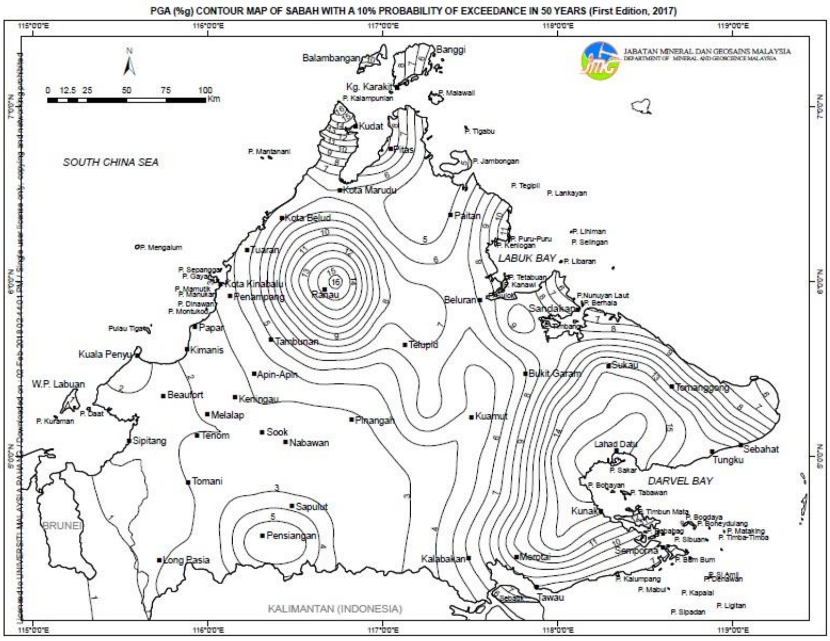

Figure A1c Sabah Seismic Hazard Map

APPENDIX B

DESIGN RESPONSE SPECTRUM

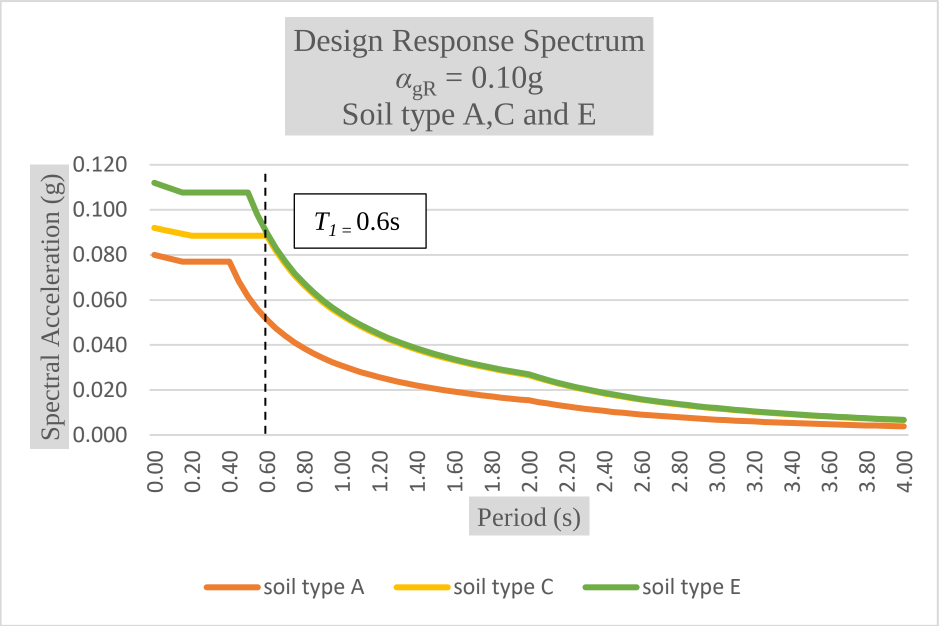

Figure B1 Design Response Spectrum for PGA 0.10g with different soil type

APPENDIX C

POSITION OF SELECTED BEAM AND COLUMN

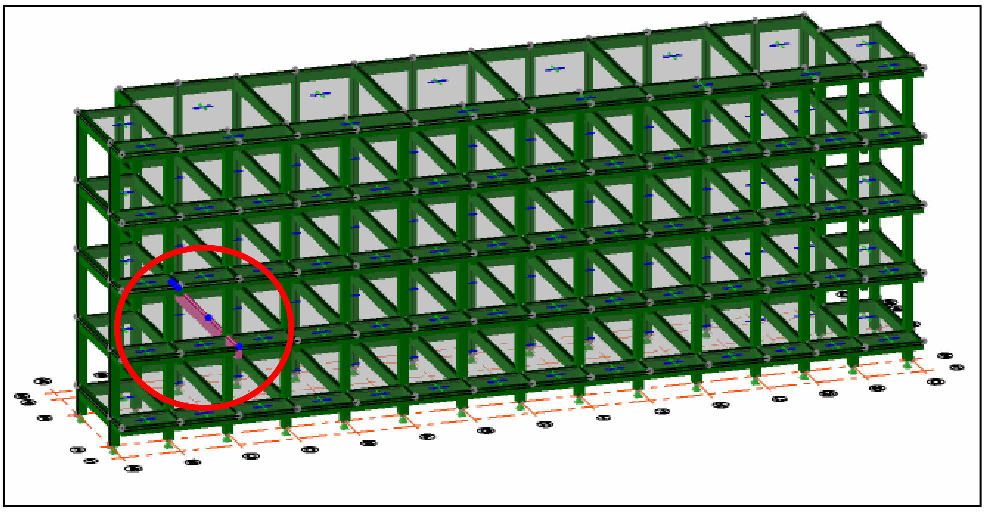

Figure C1a Position of Beam C

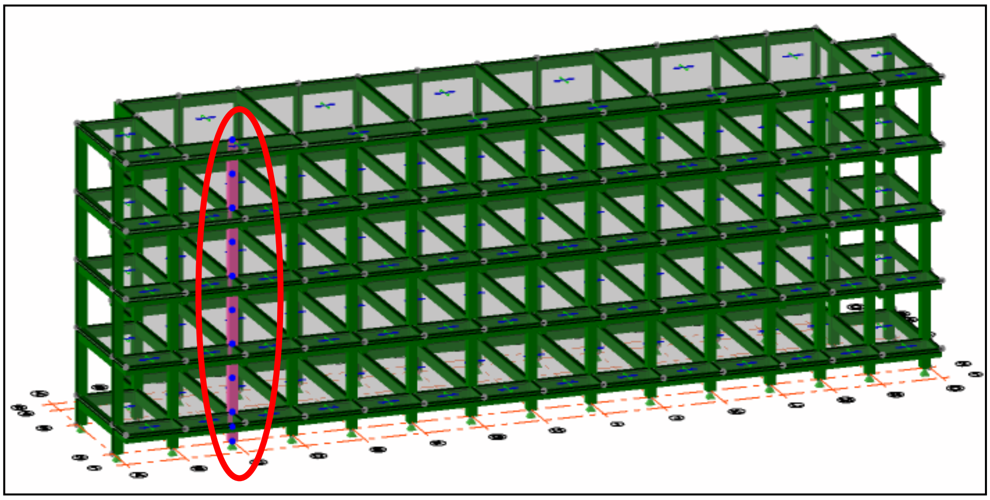

Figure C1b Position of Column C

APPENDIX D

INFLUENCE OF SOIL TYPE

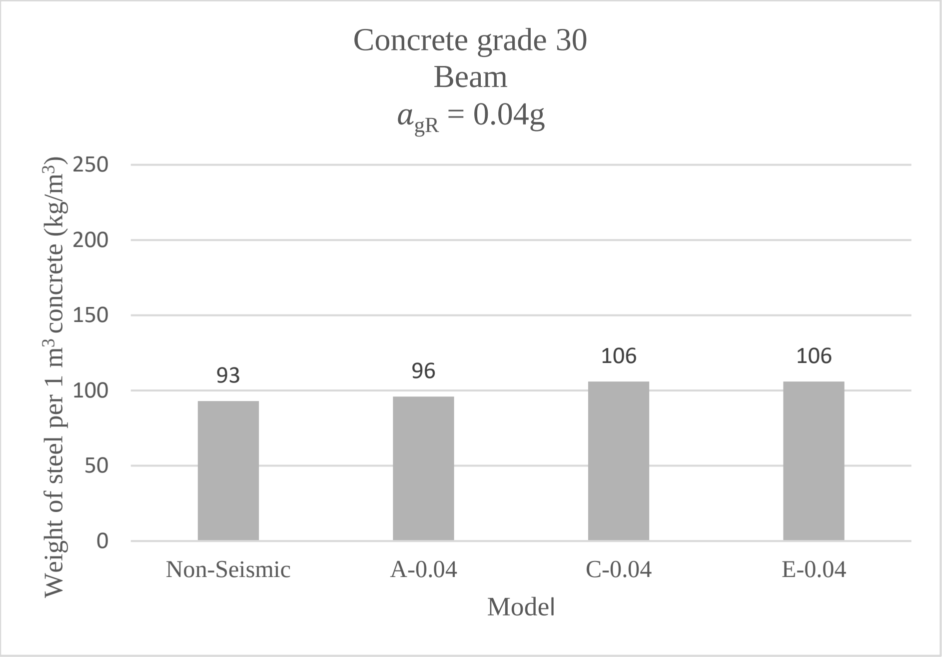

Figure D1a Total amount of steel required for 1m^3 of concrete of beam for a_{gR} = 0.04g

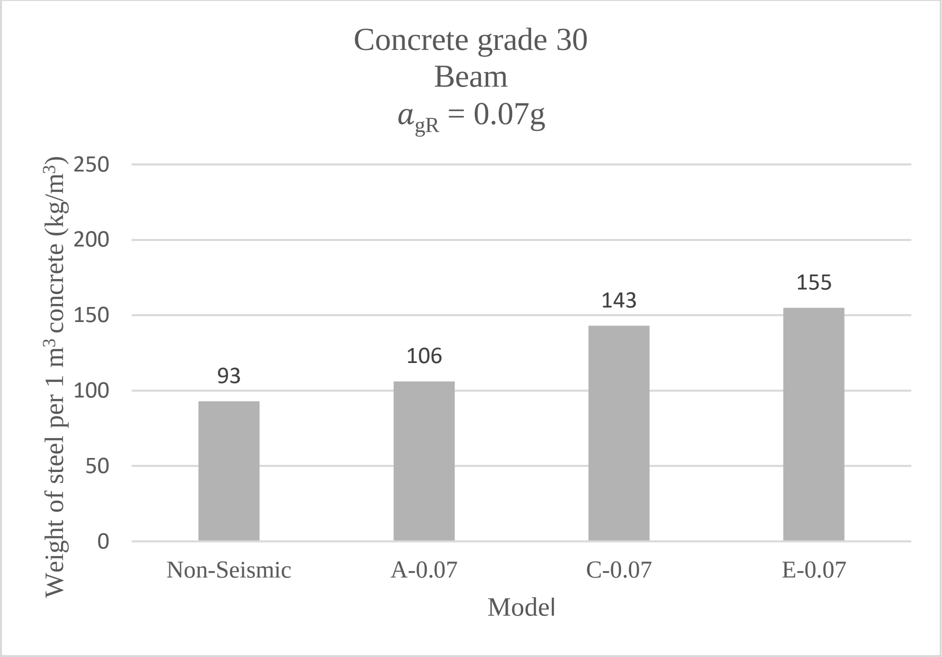

Figure D1b Total amount of steel required for 1m^3 of concrete of beam for a_{gR} = 0.07g

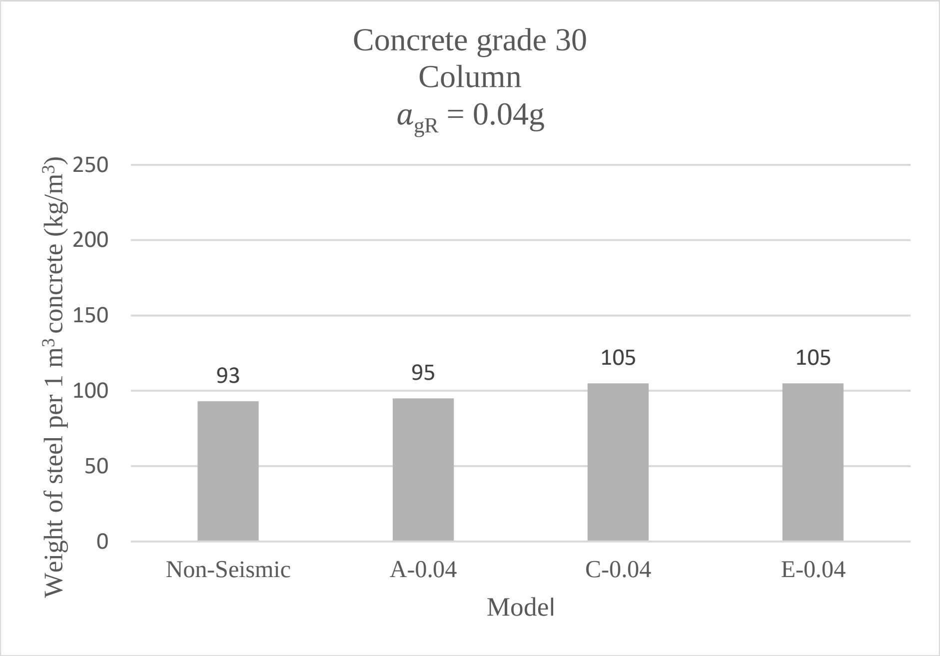

Figure D2a Total amount of steel required for $1m^3$ of concrete of column for a_{gR} = 0.04g

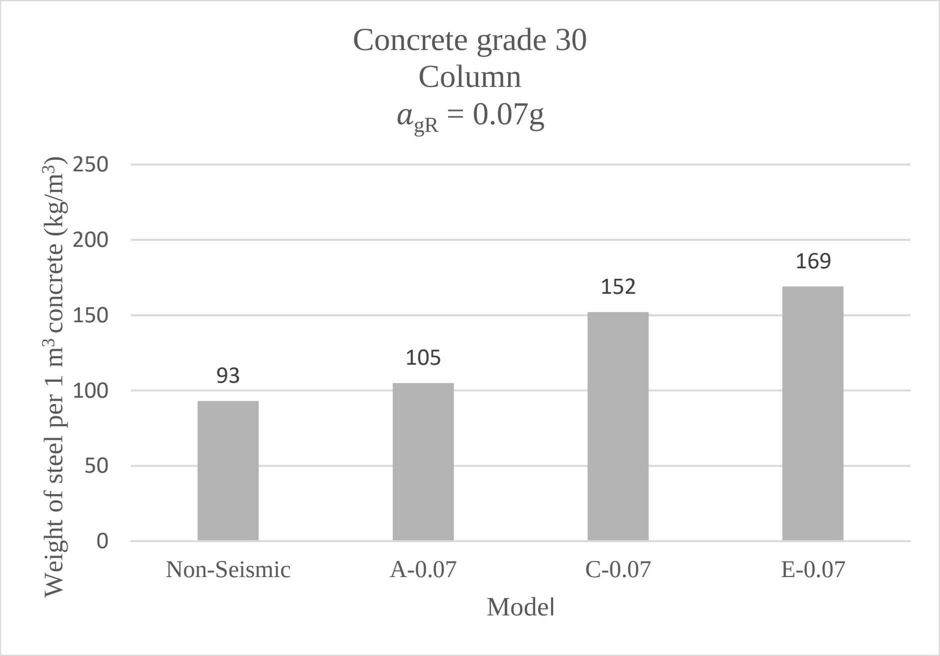

Figure D2b Total amount of steel required for $1m^3$ of concrete of column for a_{gR} = 0.07g

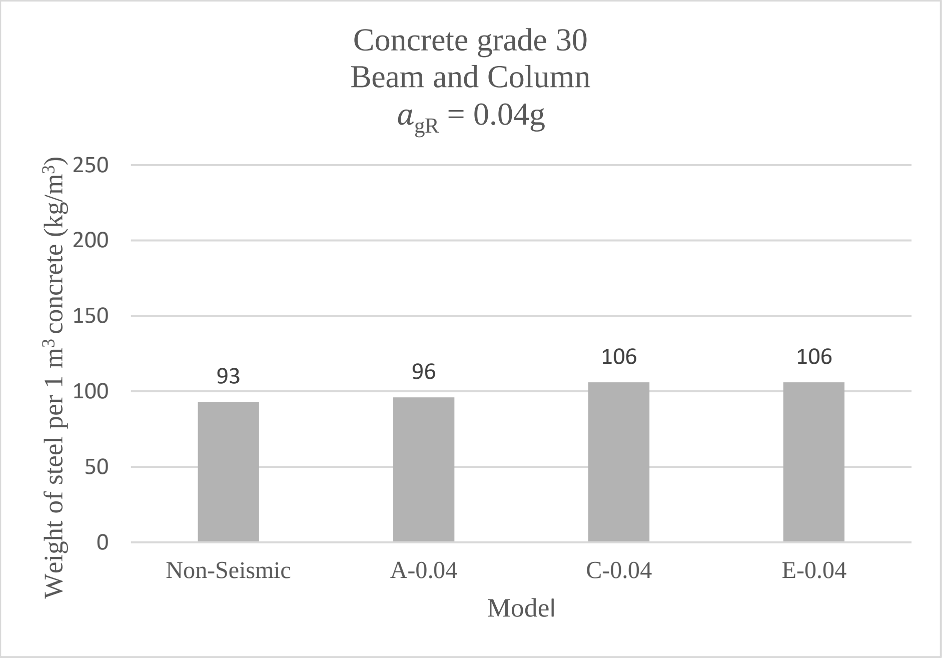

Figure D3a Total amount of steel reinforcement for 1m^3 of concrete of Beam and Column (Overall) for a_{gR} = 0.04g

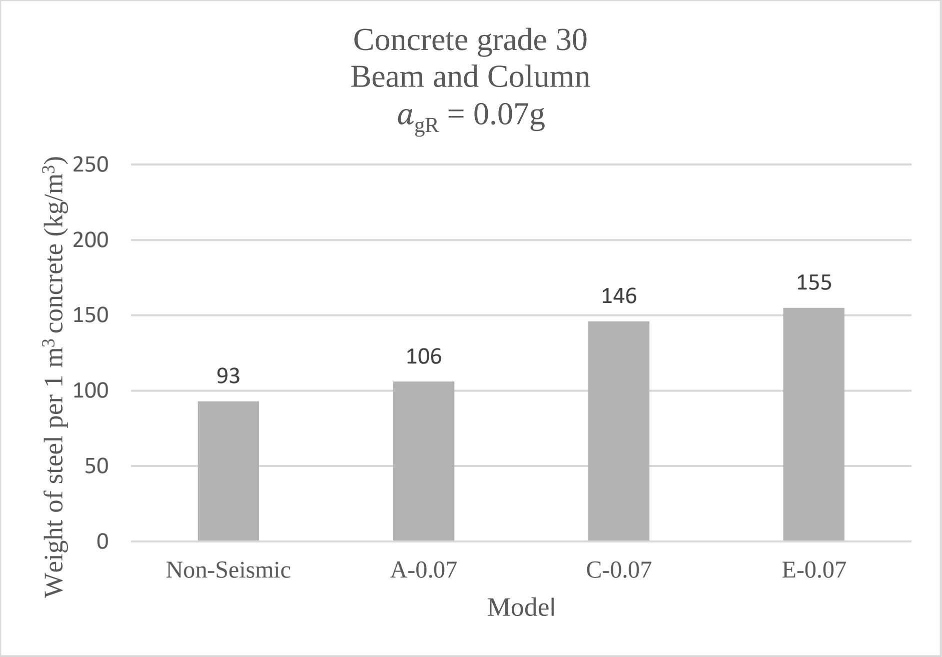

Figure D3b Total amount of steel reinforcement for 1m^3 of concrete of Beam and Column (Overall) for a_{gR} = 0.07g

APPENDIX E

INFLUENCE OF LEVEL OF SEISMICITY

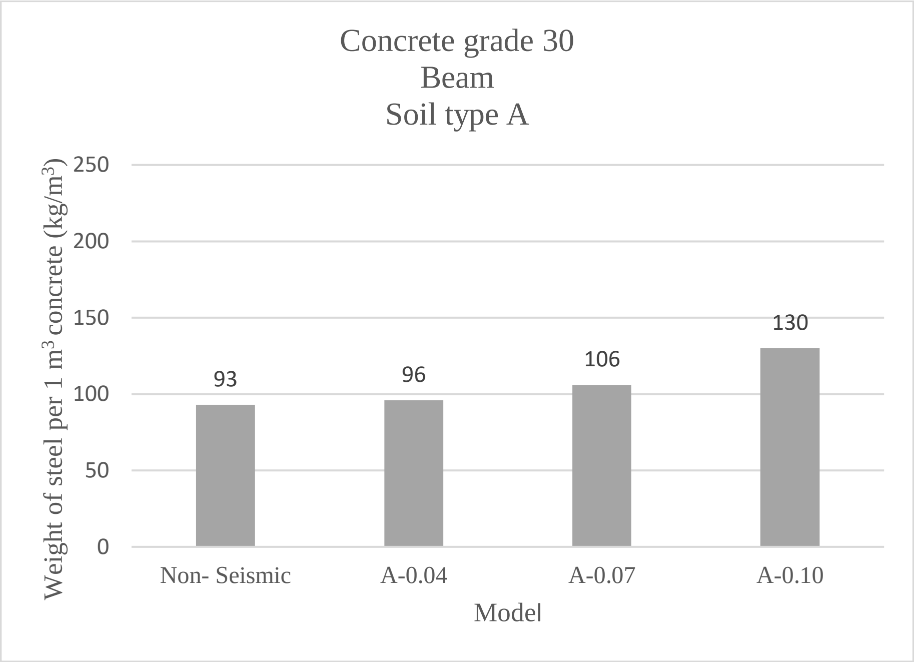

Figure E1a Total amount of steel required for 1m^3 of concrete of beam for Soil Type A

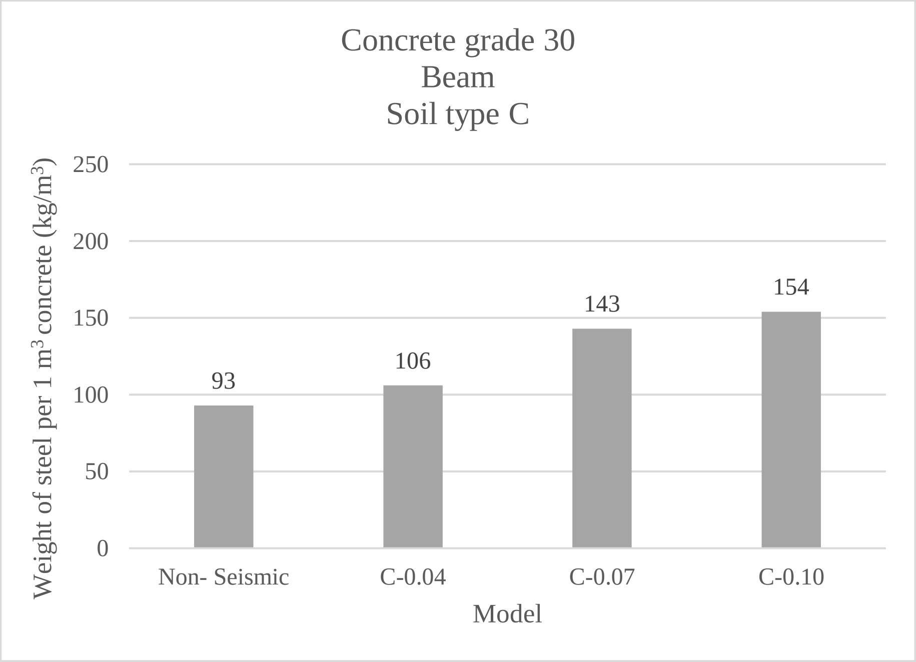

Figure E1b Total amount of steel required for 1m^3 of concrete of beam for Soil Type C

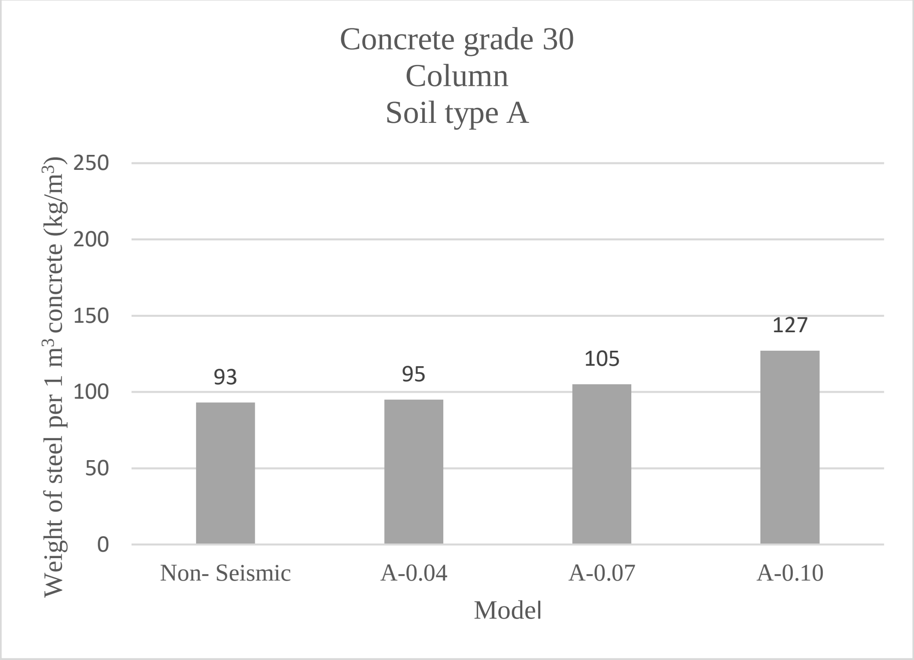

Figure E2a Total amount of steel required for 1m3 of concrete of column for Soil Type A

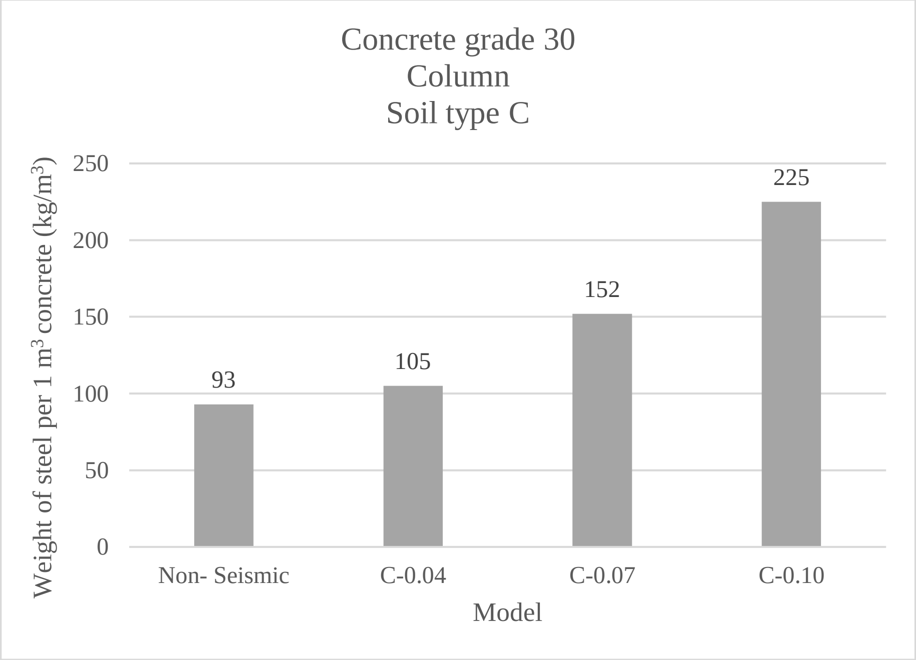

Figure E2b Total amount of steel required for 1m^3 of concrete of column for Soil Type C

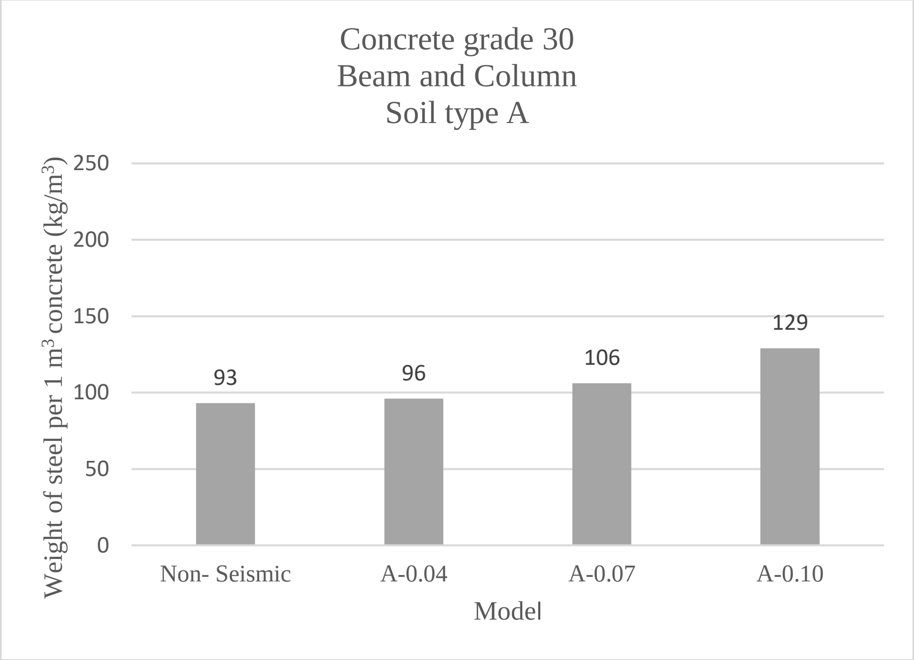

Figure E3a Total amount of steel required for 1m^3 of concrete of beam and column (overall) for Soil Type A

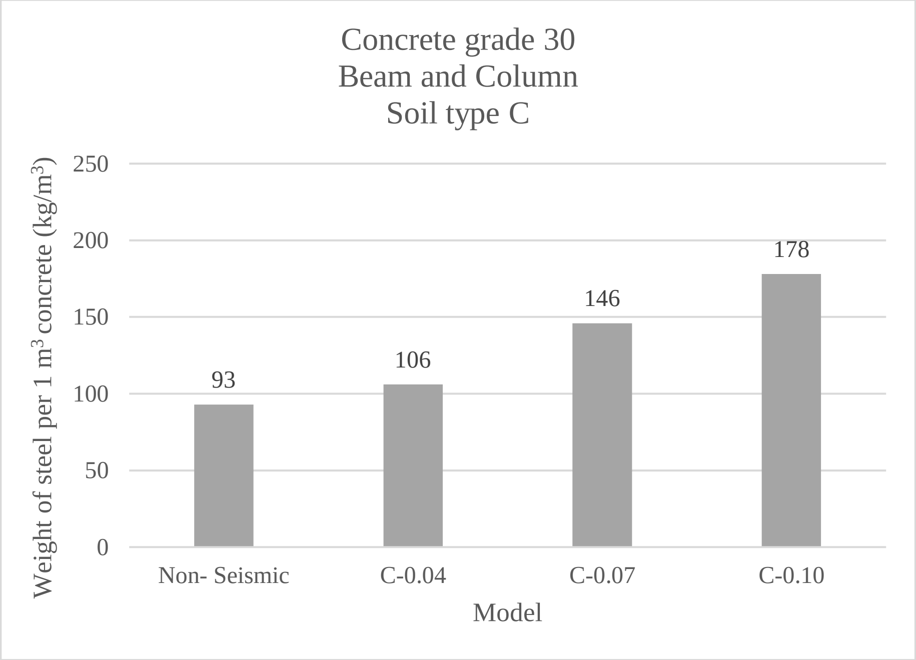

Figure E3b Total amount of steel required for 1m^3 of concrete of beam and column (overall) for Soil Type C