SEISMIC DESIGN FOR REINFORCED CONCRETE HOSPITAL BUILDING INFLUENCED BY SOIL TYPE AND GRADE OF CONCRETE

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ABSTRAK

Reka bentuk seismik adalah sangat maju, kompleks dan dikawal ketat oleh kod dan piawaian. Kod seismik mempersembahkan kriteria untuk reka bentuk dan pembinaan struktur baru tertakluk kepada gerakan gempa bumi untuk meminimumkan kadar kehilangan nyawa dan meningkatkan keupayaan bangunan penting seperti bangunan hospital untuk berfungsi selepas gempa bumi. Kaedah semasa di Malaysia tidak mempraktikan reka bentuk seismik dalam merancang sesebuah bangunan. Kemudahan kesihatan terutamanya hospital terdedah kepada risiko kerosakan yang serius dan kehilangan nyawa semasa gempa bumi, jika tidak dibina dengan sewajarnya. Memandangkan bangunan hospital adalah salah satu struktur yang penting untuk keperluan awam sebagai institusi perubatan dan perlu menampung banyak orang, ia seharusnya dapat menahan beban seismik apabila berlaku gempa bumi dan ia berkait rapat dengan kekuatan struktur. Oleh itu, kajian ini menyiasat jumlah pengukuhan keluli bagi bangunan hospital konkrit bertetulang dengan reka bentuk seismik. Analisis dilakukan dengan menggunakan tiga jenis tanah yang berbeza dan dua jenis gred konkrit yang berbeza. Terdapat lapan model 8 tingkat bangunan hospital yang digunakan untuk analisis yang direka berdasarkan Eurocode 8 dan dijalankan dengan menggunakan perisian Tekla Structure Design. Berdasarkan keputusan, dapat disimpulkan bahawa berat gelang besi untuk elemen rasuk dan kolom meningkat sekitar 2.3% hingga 10.8% jika dibandingkan dengan reka bentuk bukan seismik.apabila bangunan itu dibina menggunakan gred konkrit G30. Sementara itu, untuk pengaruh gred konkrit, gred konkrit G30 memerlukan jumlah penguatan keluli yang lebih besar berbanding gred konkrit G40 iaitu sekitar 12.4% apabila strukturnya dibina di atas tanah jenis C. Oleh itu, jenis tanah dan gred konkrit perlu dipertimbangkan untuk bangunan yang menggunakan reka bentuk seismik.

ABSTRACT

Seismic design is highly developed, complex, and strictly regulated by codes and standards. Seismic codes present criteria for the design and construction of new structures subject to earthquake ground motions in order to minimize the hazard to life and to improve the capability of essential facilities such as hospital building to function after an earthquake. Current practice in Malaysia does not consider seismic design in designing buildings. Health facilities especially hospitals are exposed to risk, serious damage and loss of life during earthquakes, if not appropriately constructed. Since hospital building is one of significant structure for public necessity as a medical institution and need to accommodate lot of people, it must be able to resist seismic load whenever earthquake happen and it is strongly related with the strength of the structure. Hence, this research investigated the amount of steel reinforcement for reinforced concrete (RC) hospital building with seismic design. The analysis conducted by using three different Soil Type and two different Concrete Grade. There are total of eight models of 8 storey RC hospital building used for the analysis designed based on Eurocode 8 and conducted by using Tekla Structural Design software. Based on the result, it can be concluded that the weight of steel reinforcement for beam and column elements increase around 2.3% to 10.8% when compared to the non seismic design when built using Concrete Grade G30. As for the influenced of Concrete Grade, Concrete Grade G30 required larger amount of steel reinforcement compared to Concrete Grade G40 which is around 12.4% when the structure built on Soil Type C. Thus, Soil Type and Concrete Grade should be taken into consideration for seismic building design.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

α_{gR}	Peak Ground Acceleration
q	Behaviour factor
M_w	Magnitude of earthquake
F_b	Base shear force
$S_d(T)$	Design response spectrum
T_1	Fundamental period
λ	Correction factor
C_t	Coefficient
T_B	Lower limit of the period of the constant spectral acceleration branch
T_C	Upper limit of the period of the constant spectral acceleration branch
T_D	Beginning of the constant displacement response range of spectrum
S	Soil factor
α_g	Design ground acceleration
β	Lower bound factor for the horizontal design spectrum
γ_1	Importance factor
q_o	Basic value of behavior factor
K_w	Reflecting factor
M_{Ed}	Bending moment
V	Shear force
P	Axial force
$A_{s,req}$	Area of steel required

LIST OF ABBREVIATIONS

BS	British Standard
DCH	Ductility Class High
DCL	Ductility Class Low
DCM	Ductility Class Medium
JKR	Jabatan Kerja Raya
NS	Non Seismic
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
SPT	Standard Penetration Test

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake is one of the natural phenomenon that frequently happen around the world especially at the high seismic region. An earthquake refers to the shaking of the Earth’s surface which is resulting from the sudden release of energy in the lithosphere of earth that generates seismic waves. Earthquakes can range in size from those that are so weak that they cannot be felt to those violent enough to toss people around and destroy whole cities. The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

Fractures and movements within the earth’s crust generate earthquake ground motion by sending waves through the rocks and soil outward from the source (Tsai, 2014). These sources are known faults which defined as cracks or weakened planes in the earth’s crust most likely to “break” as a result of global tectonic movements. The propagation of the waves through the crust produces movement of the surface of earth. Any one location on the surface will move in every direction simultaneously, back and forth, side to side, and up and down, creating the shaking effect. The shaking effect, or seismic ground motion, is felt in all directions from the epicentre to the location where the fracture started.

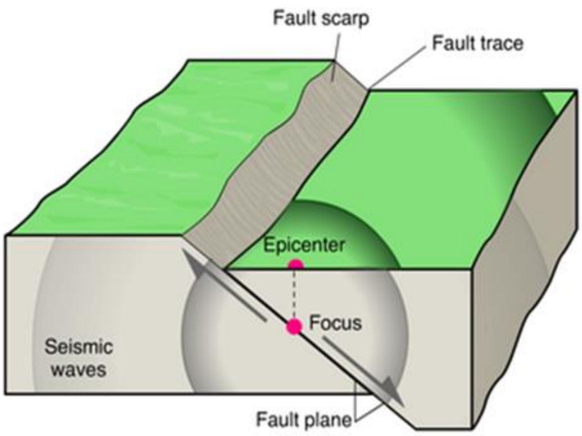

Figure 1.1 Slip of two block of earth during earthquake

(https://kcouse.weebly.com/earthquakes2.html)

According to Marto et al. (2013), Malaysia is considered to have the low seismicity profile and it is located on the Eurasian plate, and closer to the two interpolate boundaries which are the Australian Plates in the west and the Philippines Plate in the east. To date, more evidences are clearly showing that the early assumption Malaysia is free from earthquake is misleading. It is worth mentioning that one of the most significant regional earthquakes which brought catastrophic impacts is the 2004 Indian-Ocean Earthquake with the magnitude of M_w 9.1. This earthquake generated tsunami which devastated the shores of Indian Ocean which cause more than 200,000 people lost their lives (Satake, 2006). Not only this massive and extraordinary geological event had caused deaths and destructions, it had also disturbed the surrounding plate and deformed the core of the Sundaland.

The entire Peninsular has been displaced toward west southwest. The quake caused both co-seismic and post-seismic deformations for the whole of Southeast Asia. Observation of Omar and Jhonny (2009), has indicated that Peninsular Malaysia has experienced the worse deformation than others. Hence, Peninsular Malaysia is now closer to the epicenter and will experience greater impact in future quakes. Geologist have concluded that the initiation of local origin earthquake within Peninsular Malaysia is symptom of reactivation of inactive ancient faults caused by reformation of the Sundaland core as illustrated in Figure 1.2.

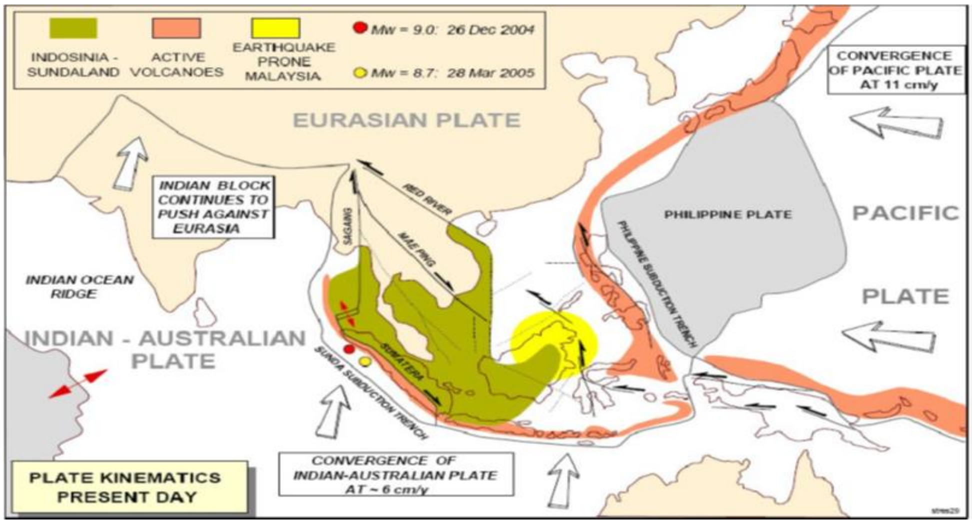

Figure 1.2 Earthquake-prone region of Malaysia (Tjia, 2008)

However, a different scenario has been observed in the East Malaysia. Since 1900 until 2014, at about 70 earthquake events between magnitude M_w 5.0 and above were recorded based on the local earthquakes within East Malaysia where seismic lineaments are not so well defined (Harith et al., 2017). The M_w 6.0 Mt. Kinabalu earthquake occurred at 23:15 UTC, June 4, 2015, within this ambiguous tectonic environment. It was the largest earthquake to strike Sabah province in the past century and came as a surprise to local communities (Wang, 2017).

Both Peninsular and Eastern part of Malaysia had been aware of the seismic hazard and necessities of applying seismic design on new buildings after having affected by the earthquakes. Although Peninsular Malaysia has a very low seismic risk, the damage potential could not be neglected as a large earthquake from neighbouring countries could create considerably ground motion over western part of Peninsular Malaysia. For instance, the earthquakes occurred on the 2nd November 2002, about 500km from Penang, have caused cracks to some buildings in Penang. The moment magnitude and the depth of this earthquake were 7.4 and 33km below the surface, respectively. Other earthquake with magnitude 7.3 occurred on the 25th July 2004 in South Sumatra had caused some cracks to one apartment in Gelang Patah, even though the location of epicenter and the depth of the earthquake were more than 400km from Johor Bahru and 576km below surface, respectively (Adnan, 2015). Based on these two cases, the effects of Sumatra earthquake have to be considered more seriously in Peninsular Malaysia.

A number of researches has been done related to the seismic activity that happen is effected by various factor. This study will focus on the effect of different type of soil and concrete grade to seismic design of reinforced concrete (RC) hospital building. Different type of soil will have different amplification factor by referring Eurocode 8 (2004). Other than that, having different grade of concrete used in RC design also give impact in seismic design. These are two important parameters in specifying earthquake actions for seismic design which will determine the total amount of steel required in seismic design. In overall, this study will be significant in reducing damages of element in a structure caused by earthquake as well as determining the influences of Soil Type and concrete grade to seismic design.

1.2 Problem Statement

According to Pappin et al. (2011), it is clear that Malaysia is surrounded to the west, south and east by areas of very high seismicity that are associated with major tectonic structures formed at the boundaries between the Asia tectonic plate and the India-Australia tectonic plate to the southwest and the Pacific tectonic plate to the east. 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. Yet, an instance whereby an earthquake had a devastating effect in Malaysia was the 9.2 M_w 2004 Sumatra Andaman mega earthquake which resulted in long-term post seismic deformation within the Sunda plate (Paul et al., 2012).

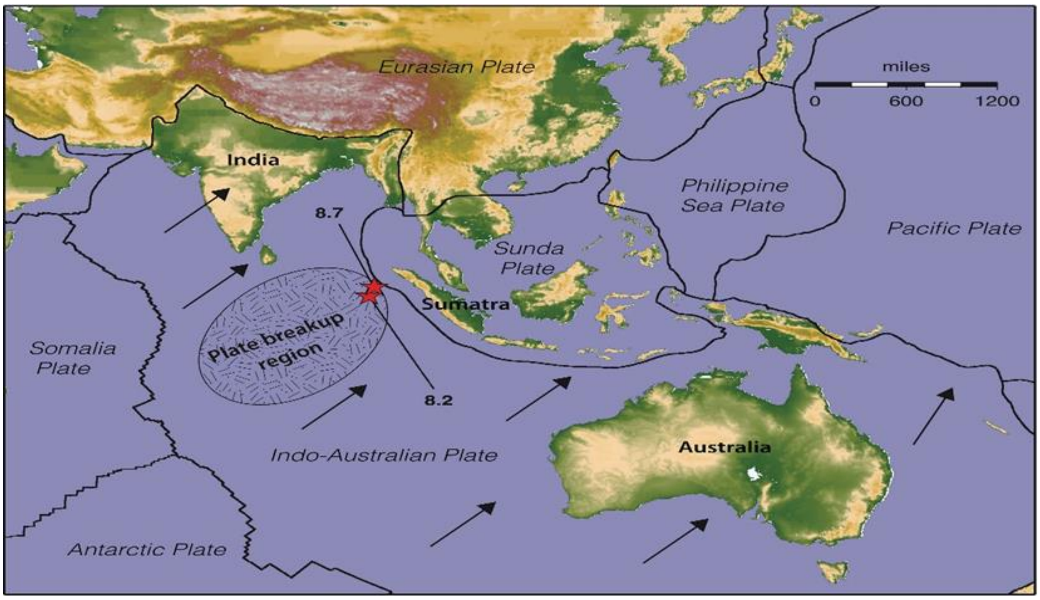

Figure 1.3 Map of the Indian Ocean region shows boundaries of Earth's tectonic plates in the area (https://phys.org)

The 2015 Sabah's earthquake struck Ranau with a moment magnitude of 6.0 on 5 June which lasted for 30 seconds. According to Adiyanto and Majid (2014), it is the strongest tremors which are recorded to be affect Malaysia since 1976. It also triggered extensive landslides along the steep slopes of Mt. Kinabalu, including rock falls that killed 18 people and injured at least 21 more along climbing trails on the steep mountain face (Wang, 2015). Sabah suffered nearly RM100mil in damage caused by this earthquake. The damage following the earthquake and more than 100 aftershocks affected 61 buildings such as schools, hospital and mosque, 22 roads and 22 slopes. This disaster raises questions among neither engineer nor public people about how far the existing buildings which were designed without seismic consideration can withstand the earthquake.

According to Tsai (2014), current buildings designed to modern codes are extremely unlikely to sustain serious structural damage or partial collapse in a design earthquake. Health facilities especially hospitals are exposed to risk, serious damage and loss of life during earthquakes, if not appropriately constructed. In times of disasters, hospitals must continue to provide medical service to those that were hospitalized before the disaster as well as those that require medical attention as a result of the event.

It is now well known that the essential buildings like RC hospital buildings are extremely important in maintaining post-earthquake functionality. Hospital building has its own properties and specification which need to follow properly along the process in designing the building, since hospital need to support high load from dead load and live load; hospital also has its own design criteria for certain areas such as emergency room. Every inch of the design has its own function. According to Ramli et al. (2017), seismic design for high-rise buildings, bridges and other structure has not been practiced in Malaysia, although Malaysia experiences minor to moderate earthquakes across the county.

Soil Type can influence the strength of soil which can be related directly to the structure destruction because soil is the bottom basic layer for whole structure that will rise until to the top of the building. One of the crucial but less controllable aspects is to know the real state of the local soil conditions. Failures and collapses can increase due to effect of soil with a complex and layered structure. Soil Type are ones of the main elements in performing a correct seismic design. This study is conducted to estimate how many steel need to be used for seismic design influenced by Soil Type.

Concrete is a construction material composed of cement, sand and coarse aggregates mixed with water which hardens with time. Concrete come with various grade according to their compressive strength. Grades of concrete refers to the strength and composition of the concrete, and the minimum strength the concrete should have following 28 days of initial construction. Normally, the grade of concrete used based on type of building constructed. Concrete grade also affected the amount of steel used for seismic design.

1.3 Objectives

The objective of the study is stated as follows:

i. To study the influence of Soil Type on the amount of steel reinforcement.

ii. To investigate the influence of grade of concrete on the amount of steel reinforcement.

1.4 Scope of Work

The following terms and conditions are applied and observed along this study:

i. An eight storey of RC hospital building has been used as the basic model.

ii. A total of 8 sets of eight storey RC hospital building has been designed based on different Soil Type (A, B, C) and concrete grade (G30 and G40).

iii. The Peak Ground Acceleration (PGA) value was fixed as $\alpha_{g\mathrm{R}}$ = 0.08g for all models to present the seismicity in Niah, Kota Marudu and Kuala Lumpur as proposed by National Annex (2017).

iv. All the model has been designed for ductility class medium (DCM).

v. The process of analysis and design of structural elements has been done by using Tekla Structure Design software and referring to Eurocode 8 (2004).

vi. The comparison has been made in term of amount of steel required as reinforcement for every model.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Earthquakes are the sudden shaking and vibrating of the Earth's crust as a result of a rapid release of energy when rocks break and move along faults. Earthquake-resistant design can be considered as the art of balancing the seismic capacity of structures with the expected seismic demand to which they may be subjected. In this sense, earthquake-resistant design is the mitigation of seismic risk, which may be defined as the possibility of losses (human, social or economic) due to the effects of future earthquakes. Seismic risk is often considered as the convolution of seismic hazard, exposure and vulnerability. Exposure refers to the people, buildings, infrastructure, commercial and industrial facilities located in an area where earthquake effects may be felt; exposure is usually determined by planners and investors, although in some cases avoidance of major geo-hazards may lead to relocation of new infrastructure. In this chapter, it will cover literature review from previous study that related and relevant with this current study.

2.2 Earthquake Disaster

Achour (2005) has studied about the earthquake induced structural and non-structural damage in hospitals around the world. In his studies, he stated that earthquakes have always been a threat to human life and a major cause for damage to infrastructure. The objectives of his studies are to explore the significance and performance of healthcare facilities in disasters and compare healthcare facilities response to earthquakes. As a result, he declared that previous earthquakes resulted in physical damage, threatened lives and damaged healthcare facilities, whose main function is to save lives and reduce the impact of disasters.

Zhao et al. (2009) carried out a studied about field investigation on the performance of building structures during the 12 May 2008 Wenchuan earthquake in China. According to the researches, the devastating earthquake that struck the south western Chinese province of Sichuan leaving 69,227 dead and 374,643 injured, with 17,923 people still missing five months after the main event. The epicentre of the earthquake was located in Wenchuan County, which triggered a fault rupture length of about 300km, stretching northeast through Beichuan County and reaching Qingchuan County. Many towns on both sides of the fault were severely damaged and a few of the town is destroyed. Three of the towns that suffered the largest levels of devastation which is Yingxiu Town of Wenchuan County, Beichuan Town of Beichuan County, and Hanwang Town of Shifang Citymodels are used in this research. The works also focus on the description of building performance during and after the disaster, in particular of reinforced concrete (RC) frame, RC confined masonry, unreinforced and unconfined masonry, industrial, local vernacular and historical buildings.

Figure 2.1 Damages of residential building because of the earthquake disaster (https://ourplnt.com)

From the information gathered during the field mission it is possible to conclude that the poor performance of building structures is the result of the combination of several factor which is the wide use of solid clay bricks for the construction of infill walls and non-structural elements, which due to their large weight, result in an increase of the forces induced by the earthquake. Other than that, the poor construction quality of most building structures, both in terms of materials and seismic design, even in structures of recent construction which did not conform to the current Chinese seismic design code is also one of the factor.

2.3 Sumatran Fault

The Peninsula Malaysia is one of zone that located within the stable core of the Sunda plate and have low seismicity and strain rate characters. According to Rangin et al. (1999), geodetic data also indicate that strains measured within the Stable Sunda zone are low. This is the main reason of why earthquake is not become one of main attention to be consider in Malaysian practice.

Balendra and Li (2008) had conducted a research regarding the Seismic Hazard of Singapore and Malaysia. Balendra stated that although Peninsula Malaysia and Singapore are located on a stable part of the Eurasian Plate, buildings on soft soil are occasionally subjected to tremors due to far-field effects of earthquakes in Sumatra. In the last few years, tremors were felt several times in tall buildings in Kuala Lumpur, the capital of Malaysia, due to large earthquakes in Sumatra. The mechanism for such tremors is illustrated in Figure 2.1. The seismic waves, generated from an earthquake in Sumatra, travel long distance before they reach Singapore bedrock. The high frequency earthquake waves damped out rapidly in the propagation while the low frequency or long period waves are more robust to energy dissipation and as a result they travel long distances. Thus the seismic waves reaching the bedrock of Singapore or Malay Peninsula are rich in long period waves, and are significantly amplified due to resonance when they propagate upward through the soft soil sites with a period close to the predominant period of the seismic waves. The amplified waves cause resonance in buildings with a natural period close to the period of the site, and the resulting motions of buildings are large enough to be felt by the residence.

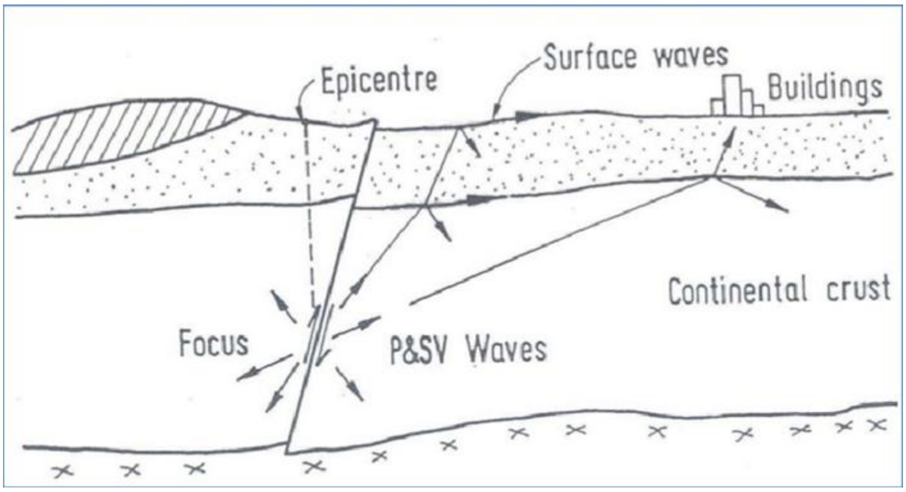

Figure 2.1 Schematic diagram for far-field effects of earthquakes (Balendra et al., 2001)

The Sumatran subduction zone is formed by subduction of the India-Australian plate beneath the Eurasian plate at a rate of about 67mm per year. The nearest location of this subduction zone is about 600km to Singapore. Most of the earthquakes generated in this zone are shallow to intermediate with very unusual deep events. As a result, they concluded that according to the historical records, the earthquakes that influence Singapore and Malay Peninsula are originated from two earthquake faults which is Sumatran subduction zone and Sumatran fault.

Figure 2.2 Sumatran fault and subduction of the Indian-Australian Plate into Eurasian Plate (Balendra et al., 2001)

2.4 Seismic Design

An investigation about the analysis and design of 3-storey Hospital structure subjected to seismic load using STAAD PRO has been conducted by Adiyanto et al. (2008). In this study, three different analytical reactions which is bending moment, shear force, and inter storey drift of 3-storey hospital building is analysed when subjected to various intensity of seismic load. One beam is selected from the 3-storey hospital building and it is designed to hold seismic load with different intensity. From the analysis, the value of bending moment and shear forces are increase from gravity load to low, medium, and high seismic load applied. It can be concluded that higher load will produce higher bending moment and shear force. In term of inter-storey drift checking, the value of inter-storey drift is increase start from gravity load, low seismic load, medium seismic load, and followed by the high seismic load at the same level.

Saka (2018) has conducted a study about the effect of Soil Type and grade of concrete on amount of steel reinforcement for RC Hospital building with seismic design. The author used a 6 storey RC hospital building by using Tekla Structure Software as model for her research. 10 sets of 6 storey RC hospital building have been use as the models to achieve the objective of the research. The building was assumed 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 (PGA) of 0.10g, ductility class medium (DCM), behaviour factor, q of 3.9 and designed based on Eurocode 8 (2004).

From the research, the author concluded that the amount of steel reinforcement for RC hospital building with seismic design when built on Soil Type D is higher compared to the other models built on other Soil Type and non-seismic design model. For the effect of grade of concrete, for overall beam and column element of the whole building, 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. It proves that when the higher of grade of concrete, the compressive strength also become more strong and it do not require 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.

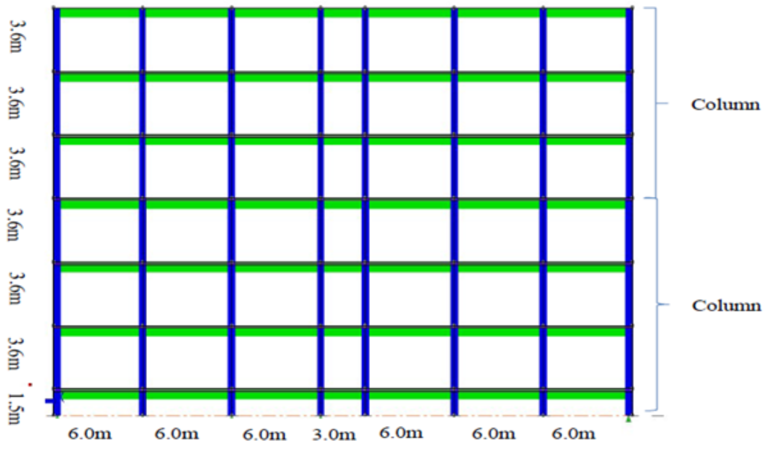

Figure 2.3 Front view of RC hospital building that is used by the author (Saka, 2018)

A study about the seismic design for RC hospital building influenced by level of PGA and class of ductility has been conducted by Ahmad Jani (2018) in order to study the influences of PGA and class of ductility on the amount of steel reinforcement required. To achieve the objectives of the study, 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. To compare the percentage increment of steel reinforcement required, 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 ductility class low (DCL). From the study, it can be concluded that the total amount of reinforcement required in a building is higher when it is subjected to higher magnitude of PGA. This is because higher magnitude of PGA resulted in higher value of response spectrum, $S_d(T)$ which will increase the value of base shear force, F_b. When the value of F_b increase, the total amount of steel reinforcement required will increase. The other conclusion from this study is the total amount of reinforcement required in a building is higher when it is subjected to low class of ductility. This is because the lower class of ductility, or lower the value of q resulted in higher value $S_d(T)$ which will increase the value of F_b. When the value of F_b increase, the amount of steel required also will increase.

Safie (2018) has studied the seismic design for RC hospital building affected by soil type and class of ductility. The objectives of this study is to determine the effect of soil type and class of ductility on the amount of steel reinforcement. The two storey RC school building is designed based on Eurocode 8 (2004) to represent the existing RC school building and assumed to experience 0.065g of PGA. The analysis is done repeatedly with different type of soil which is Soil Type B and Soil Type D and ductility class which is DCM and ductility class high (DCH) by using Tekla Structural Designer. The conclusion of this study is the RC school building built on Soil Type D (soft soil) resulted in higher weight of steel reinforcement required compared to when the school building is built on Soil Type B (stiff soil).

The study on influenced of Concrete Grade and level of seismicity on seismic design of RC school building designed to Eurocode 8 (2004) conducted by Yaakup (2018) with the objectives of to determine the effect of magnitude of PGA and effect of grade concrete of two storey RC school building on the amount of steel reinforcement required. The model is assumed to be built on Soil Type B and the ductility assumed is DCM. The analysis is done by using Tekla Structural Designer software used the values of PGA of 0.08g and 0.16g on three different grade of concrete which are G25, G30 and G35. From the study, it can be concluded that the higher the magnitude of PGA subjected to the RC school building, the higher total amount of reinforcement required. This is because the higher the value of $S_d(T)$ resulted in higher magnitude of PGA which also will increase the value of F_b. As the shear force increase, total amount of steel reinforcement required will also increase. Other than that, the total amount of steel reinforcement required for RC school building with higher concrete grade is lower is also the conclusion of this study. This is because as the concrete grade higher, it possessed higher compressive strength which resulted in lower amount of steel reinforcement required.

2.5 Ground Motion

Continuous effort has been aimed towards increasing the recognition of the potential seismic hazard of earthquakes and the resulting liability of constructions, in general and RC buildings, in particular. Seismic performance of RC structures under earthquake motion are directly associated with the level of structural damage attained.

Ground motion is the movement of the earth's surface from earthquakes. The Earth shakes with the passage of earthquake waves, which radiate energy that had been "stored" in stressed rocks, and were released when a fault broke and the rocks slipped to relieve the pent-up stress. The strength of ground shaking is measured in the velocity of ground motion, the acceleration of ground motion, the frequency content of the shaking and how long the shaking continues. Ground motion sequences can create significant damage in structures due to the accumulation of the inelastic deformation from the repeated sequences before any structural repair is possible. Damage status of RC buildings is greatly influenced by the characteristics of the imposed ground motion. (Elassaly, 2015).

2.6 Summary

In summary, seismic design approach for future constructions of the buildings in Malaysia is worthwhile to be considered. From the literature review, the selection of the characteristic of seismic design is noted to be very important in analysis and design which includes the Soil Type and concrete grade. This is because difference value of them will cause an influence to the cost of a project. Therefore, this study will be conducted to understand on the effect of different Soil Type and concrete grade in seismic design along with its building cost referring to Eurocode 8 as seismic provision.

CHAPTER 3

METHODOLOGY

3.1 Background

Summary of methodology used along this research to evaluate the influence of Soil Type and grade of concrete on amount of steel needed for reinforced concrete (RC) hospital building is explained in this chapter. In this chapter, it also included the sequence of steps from model setup until taking off phase. In the design stage, Eurocode 8 (2004) has been used as the main reference. Tekla Structure Software has been used in modelling and analysis phase. There are few parameters that has been used in this study and some of them use various value or class for the model. The summary of the research methodology is shown in Figure 3.1.

3.2 Flow Chart of Research Methodology

There are four stages that is included in this research. The first one is the model setup which including the setup for material, height, level and dimension for model. The second stage included two process which is structural analysis and seismic design process which is conducted using same software used in model setup stage. The third stage is to carry out the taking off process which shows the comparison of concrete volume and steel weight per $1m^3$ concrete for each model. The last stage is to calculate the estimated cost of materials used for RC hospital building according to the current market prices.

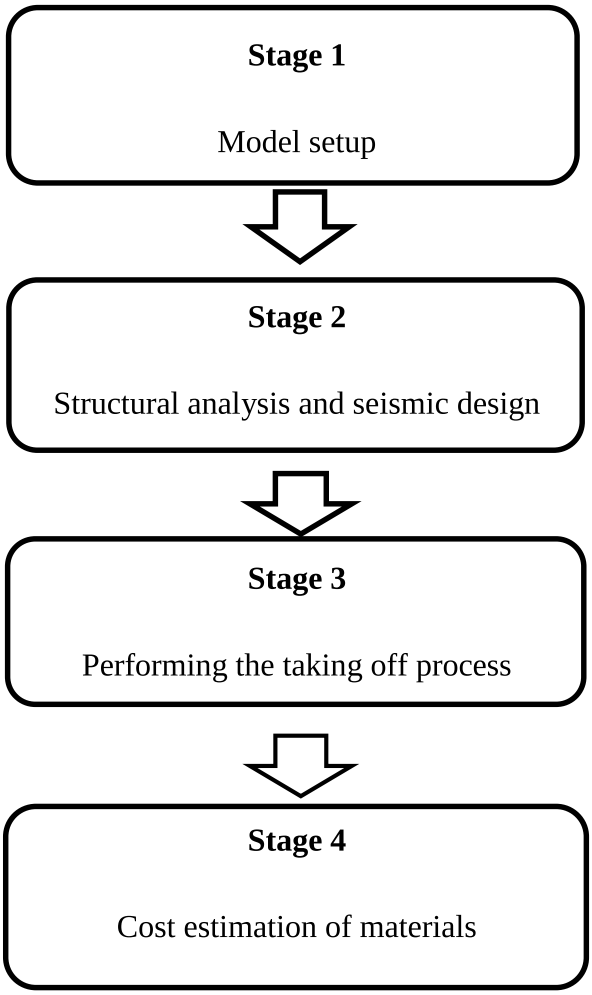

Figure 3.1 Flow chart of research methodology

3.3 Stage 1: Model setup

In this study, an 8 storey RC moment resisting frame hospital building is used as the model. According to National Bureau (2001), 8 storey RC building is categorize in medium-rise RC building. Table 3.1 explain about the number of storey of a building and its class of rise. High-rise building is not recommended for hospital building due to its ineffectiveness evacuation process if any emergency happened.

Table 3.1 Number of storey and its class of rise (National Bureau, 2001)

Number of Storey	Class of Rise
1-6 stories	Low-rise
7-12 stories	Medium-rise
> 13 stories	High-rise

The 8 storey RC hospital building is model by using the Tekla Structure Software and AutoCAD in this stage. This 8 storey RC hospital building has 28.8m height up from ground level and 1.5 meter down from ground level and the area for each level is 960 square meter. The front view of the RC hospital building shown in Figure 3.2. Figure 3.3 show the layout for each level.

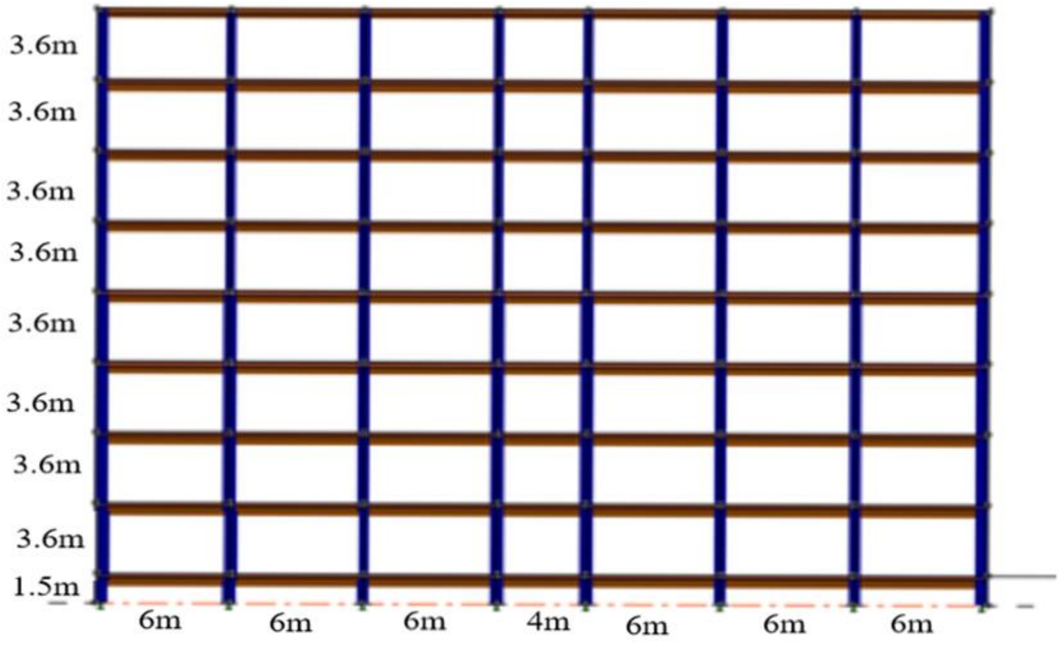

Figure 3.2 Front view of RC hospital building generated in Tekla Structure software

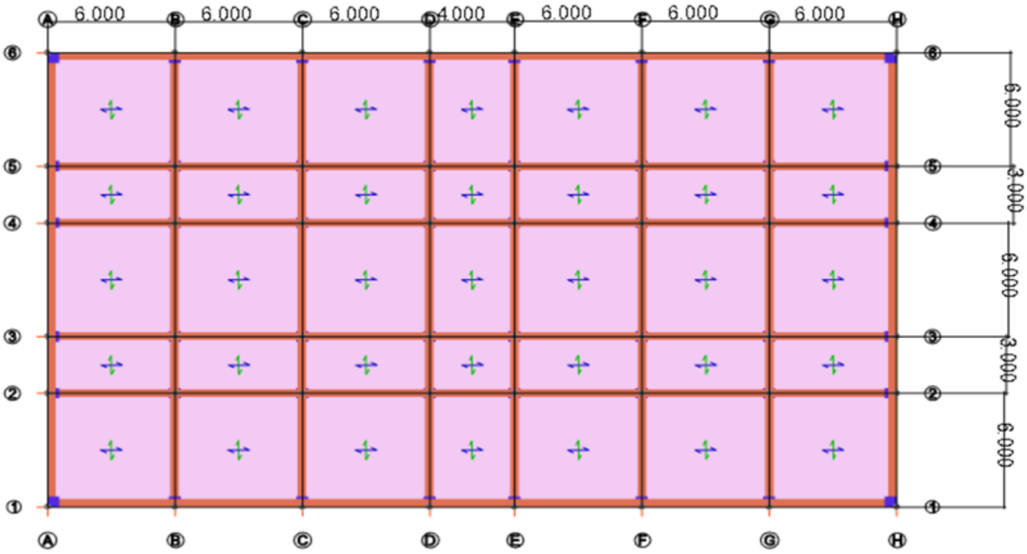

Figure 3.3 Layout of RC hospital building

There are three different dimension of beam used for the building model which is 400mm x 650mm for the beam on ground floor until floor 3, 300mm x 600mm for the beam on floor 4 until floor 7 and 250mm x 500mm for roof beam. The material of beam used is concrete. While for the column size, this building is designed with two sizes of column which is the first column labelled as Column A for foundation level until third level, it uses 550mm x 550mm column size. For fourth level until roof level, it is labelled as Column B which is used 500mm x 500mm as the column size. Concrete is used as the column's material. For the thickness of slab, the design used 250mm for all floor.

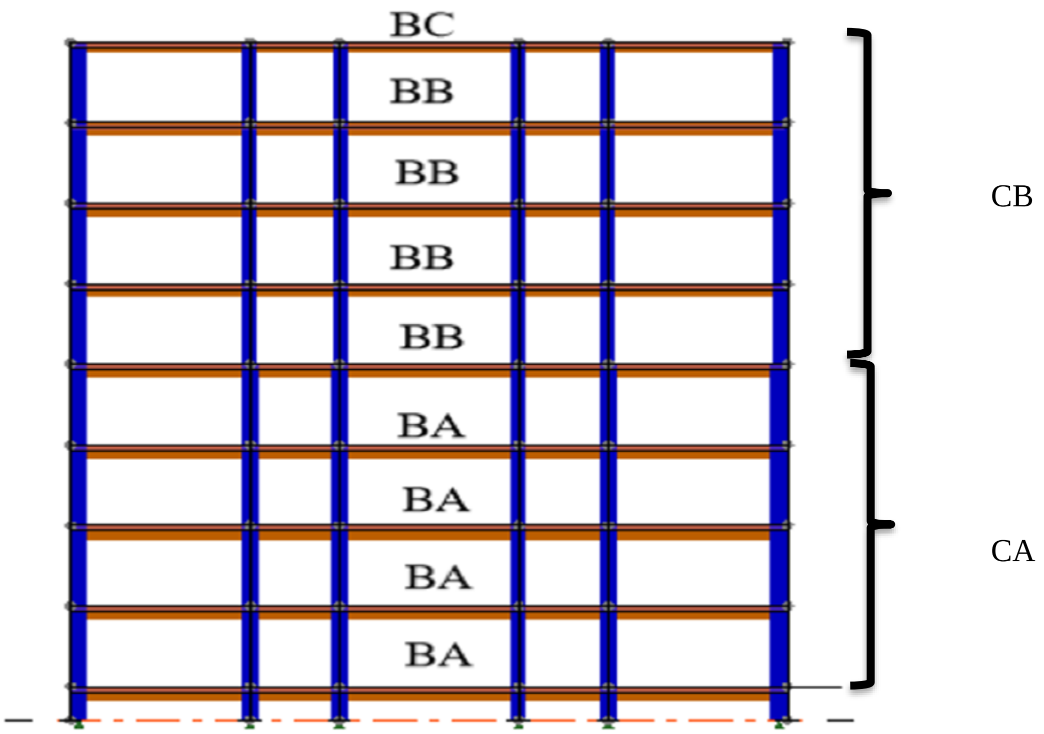

Figure 3.4 Side view of 8 storey RC hospital building

Table 3.2 Dimension of the structural members of the frame

BEAM	DIMENSION (mm)
BA	400 x 650
BB	300 x 600
BC	250 x 500
COLUMN	DIMENSION (mm)
CA	550 x 550
CB	500 x 500

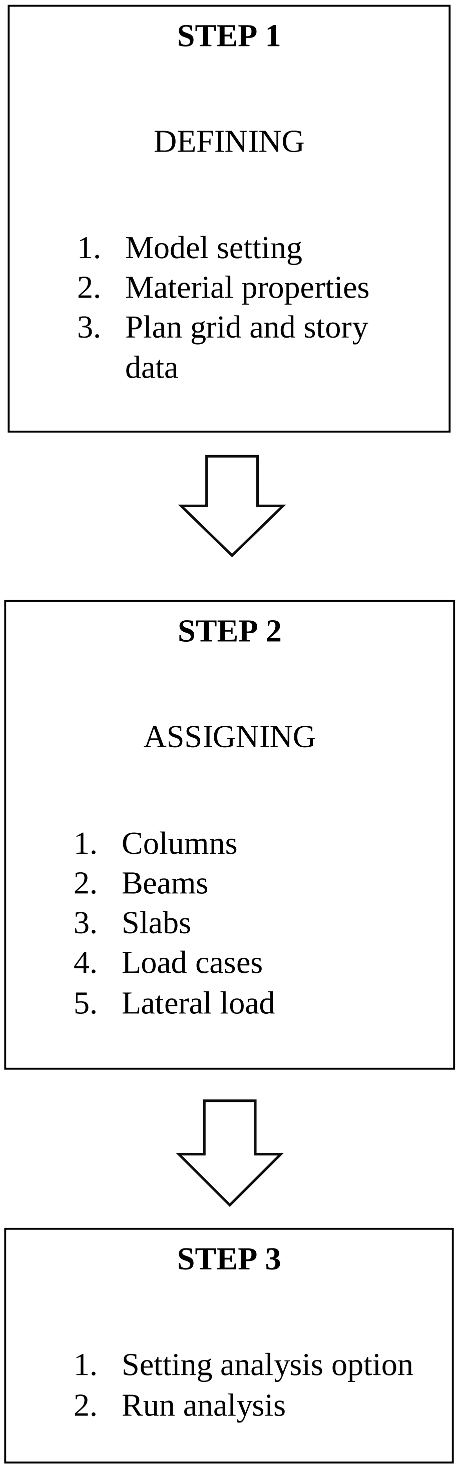

Figure 3.5 Steps involved in building modelling using Tekla Structure software

3.3.1 Load cases

In phase 2, the hospital building is designed based on Eurocode 8 using by Tekla software. Beams and columns is design in order to get the total reinforcement required. The various parameter that is used are complying with the current condition of our country. The material properties for the hospital building is shown in Table 3.3 in accordance to Mc Kenzie (2004).

Table 3.3 Weight of material (Mc Kenzie, 2004)

Materials	Weight	Units
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
Brickwall	3.0	kN/m^2/m height

Hospital building that is used in this study and is categorized in Category A and Category C3 for load distribution as stated in Eurocode 1 (2002) shown in Table 3.4. Therefore, the live load, qk imposed on the floor, corridor and roof of this category equal to 2.0 kN/m^2, 4.0 kN/m^2 and 0.4 kN/m^2, respectively. Table 3.5, Table 3.6, and Table 3.7 show the imposed load on floor, roof categorization and imposed load on roof, respectively, as stated in Eurocode 1 (2002).

Table 3.4 Categories of use (Eurocode 1, 2002)

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.
B	Office	
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, cafes, 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, sport 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 of floors, stairs, and balconies in the building (Eurocode 1, 2002)

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

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.
K	Roofs accessible with occupancy according to categories A to D.
I	Roofs accessible for special services, such as helicopter lading areas.

Table 3.7 Imposed loads on roofs of category H (Eurocode 1, 2002)

Roof	qk, [kN/m^2]	Qk [kN]
Category H	qk	Qk

NOTE 1: For category H qk may be selected within the range 0,00 kN/m2 to 1,0 kN/m2 and Qk 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:

$$qk = 0,4\ kN/m^2\ .\ Qk = 1,0\ kN$$

NOTE 2: qk may be varied by the National Annex dependent upon the roof slope.

NOTE 3: qk may be assumed to set on an area A which may be set by the National Annex. The recommended value for A is 10 m2, within the range of zero to the whole area of the roof.

NOTE 4 Sec. also 3.3.2 (1)

3.4 Stage 2: Structural analysis and Seismic design

Tekla Structure Software is used to run analysis of this research same as software used in model setup. During setting up before start analysis, it involved few type of parameters to insert in the setting option. Soil Type and grade of concrete also involve in the parameters that need to be insert in the setting analysis option by using various value or condition of that parameters. Some parameter was fixed value due to it is not the main parameters that need to be study such as peak ground acceleration (PGA), class of ductility, behaviour factor, *q* and importance factor, λ.

3.4.1 Soil Type in seismic design

Soil has its own classes and comes from various of type. Type of soil is determined by undergone soil investigation that involve boring process to determine the soil type and Standard Penetration Test (SPT) to determine its strength. Soil Type is one of parameter that influence the seismic design on the amount of steel needed for the RC hospital building.

Soil Type has been classified into few categories based on its behaviour according to Eurocode 8 (2004). It shown in Table 3.8, three type of is inserted in the analysis option which is Soil Type A, Soil Type B and Soil Type C repeatedly using same model but change the Soil Type. This Soil Type also play a role in design response spectrum where parameter type of soil related in its calculation equation.

Different type of soil has different strength to hold anything on it. The softer the soil texture, the weaker it will be. Soil Type A soil texture that contain or mix with gravel or rock will make the soil become stronger. The rock and gravel element help it to become cohesion, the soil hard to slide each surface and as the support agent of the soil. This aspect explained in 3.3.4.

Table 3.8 Ground type (Eurocode 8, 2004)

Ground type and description	$V_{s,30}$	N_{STP}	c_u
A: Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	>800	-	-
B: Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	360 - 800	>50	>250
C: Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.	180 – 360	15 - 50	70 - 250

3.4.2 Grade of concrete

Concrete come from various type and grade. The grade of concrete differentiates the concrete strength to be use in building construction and at the same time it also influences the quantity of steel needed to support the load of the building. In this study, the grade of concrete used is G30 and G40. This concrete grade inserted in material setup before and during modelling and also inserted in analysis option.

3.4.3 Base Shear Force

Base shear force can be defined as estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure. In determining the lateral load act on each level of the building, the magnitude of F_b acting on the building is one of important parameter has to be calculate. According to Clause 4.3.3.2.2 in Eurocode 8 (2004), the value of F_b that act on each level in horizontal direction can be determine by using following expression;

$$F_b = S_d(T_1).m.\lambda \tag{3.1}$$

Where; $S_d(T_1)$ = The ordinate of the design spectrum at period T_1;

T_1 = The fundamental period of vibration of the building for lateral motion in the direction considered;

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

λ = The correction factor, the value of which is equal to: λ=0,85 if $T_1 \leq 2\ T_c$ and the building has more than two storey, or λ=1.0

$S_d(T_1)$, m, λ and correspond to the ordinate of the design spectrum at period T_1, the total mass of the building above the foundation or above the top of a rigid basement, and the correction factor, respectively. The value of T_1 can be defined by using following equation.

$$T_1 = C_t\ .\ H^{3/4} \tag{3.2}$$

Where; C_t = 0.085 for moment resistant space steel frames, 0.075 for moment resistant space concrete frames and for eccentrically braced steel frames and 0.050 for all other structures;

H = The height of the building in m, from the foundation or from the top of a rigid basement

3.4.4 Design response spectrum

From equation 3.1 stated in section 3.3.3 above, the ordinate of the design spectrum at period, T_1, in $S_d(T_1)$ is required to determine the value of F_b acting on the building. For this purpose, Clause 3.2.2.5 in Eurocode 8 (2004) developed a series of design response spectrum. This study conducted the series by considering the Type 1 response spectrum which compatible for Soil Type A, Soil Type B and Soil Type C. Equation (3.3) to (3.6) had been referred to develop the design response spectrum.

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

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

$$T_C \leq T \leq T_D : S_d(T) = \alpha_g . S . \frac{2.5}{q} . [\frac{T_C}{T}] \geq \beta . \alpha_g \tag{3.5}$$

$$T_D \leq T : S_d(T) = \alpha_g . S . \frac{2.5}{q} . [\frac{T_C T_D}{T^2}] \geq \beta . \alpha_g \tag{3.6}$$

Where;

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

α_g = design ground acceleration on Type A ground ($\alpha_g = \gamma_1 . \alpha_{gR}$)

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

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

T_D = beginning of the constant displacement response range of the spectrum

S = soil factor

q = behaviour factor

$S_d(T_1)$ = design spectrum

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

By referring the Eurocode 8 (2004), the value of soil factor, S, value of lower limit of the period of the constant spectral acceleration branch, T_B, the value of upper limit of the period of the constant spectral acceleration branch, T_C, and the value of beginning of the constant displacement response range of the spectrum, T_D, is given in Table 3.9 based on soil type.

Table 3.9 Main parameters to Develop Type 1 Design Response Spectrum (Eurocode 8, 2004)

Ground type	S	T_B	T_C	T_D
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0

3.4.4.1 Design ground acceleration, α_g

The value of design ground acceleration can be determined by referring Clause 3.2.1 (3) in Eurocode 8 (2004) as below;

$$\alpha_g = \gamma_1 . \alpha_{gR} \tag{3.7}$$

Where; γ_1 = Importance factor

α_{gR}= Reference peak ground acceleration

The value of γ_1 is depends on the importance classes of building where in Clause 4.2.5, Eurocode 8 (2004) classify the building into four importance classes where consider on the consequences of collapse for human life, importance for public safety, and civil protection as shown in Table 3.10. For this study, the importance factor value used is 1.4 due to the model used is RC hospital building which classified in importance class IV. According to Fardis et al. (2015), the recommended value of γ_1 is to offer better protection of life for such buildings due to its importance after disaster.

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

Important class	Buildings	Important factor, γ_1
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 institution 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

While the value of α_{gR} is based on magnitude of PGA for Malaysia as proposed by Adnan et al. (2008) and also published by MOSTI (2009) illustrated in map format. Figure 3.7 and Figure 3.8 shown the seismic hazard map in Malaysia with the PGA value. The PGA value stated is in unit gal which is 1 gal = 0.001g. For example, the PGA value for Peninsular Malaysia and Eastern Malaysia in range of 20 gals to 120 gals where in 'g' terms, it in range 0.02g to 0.12g. The PGA value used in this study is fixed which is 0.08g to present the seismicity in Niah, Kota Marudu and Kuala Lumpur. The latest seismic hazard map for Malaysia is shown in Appendix A as proposed by National Annex (2017).

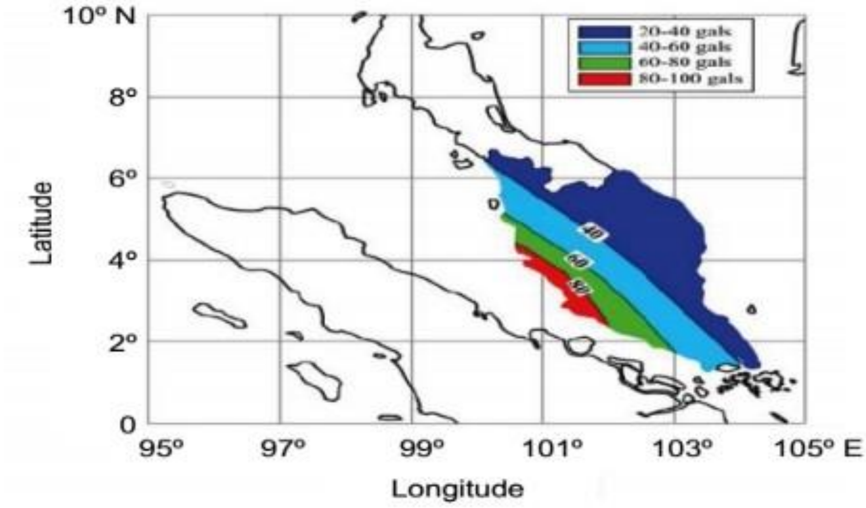

Figure 3.6 Seismic hazard map on Peninsular Malaysia (MOSTI, 2009)

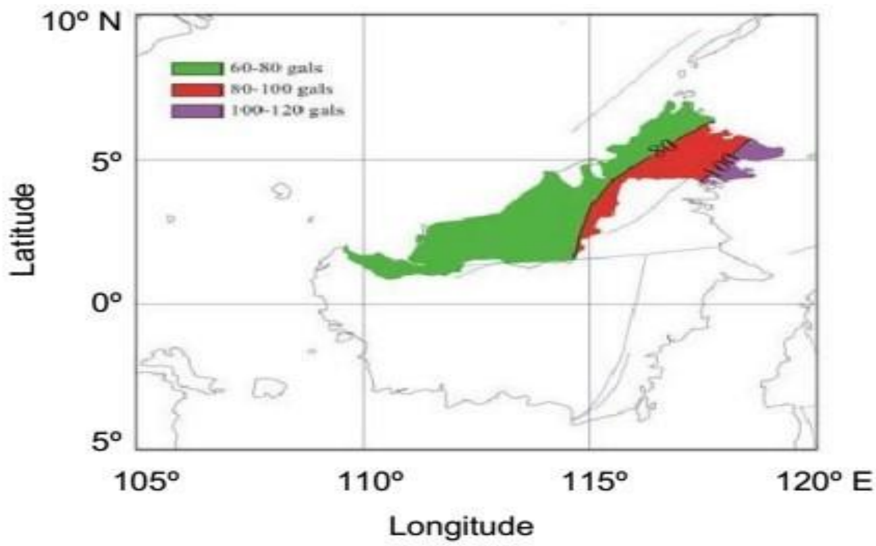

Figure 3.7 Seismic hazard map on Eastern Malaysia (Adnan et al., 2008)

3.4.4.2 Behaviour factor

Behaviour factor, q is one of the important parameter in seismic design. The force is obtained from a linear analysis reduced by the behaviour factor in order to take into account for non-linear response of a structure according to Eurocode 8 (2004). Amount of materials needed especially steel reinforcement for the RC structure building will increase and at the same time will result increase in cost without using this concept. Base shear force reduced by the behaviour factor by scaling down the design response spectrum to decrease the ordinate of the design spectrum at period, T_1.

The value of q is strongly related to the level of ductility where ductility design corresponds to high value of q and vice versa (Adiyanto, 2016). According to Clause 5.3.3 in Eurocode 8 (2004), the value of the behaviour factor up to 1.5 for RC moment resisting frame with ductility class low (DCL) may be used in deriving the seismic actions, regardless of the structural system and the regularity in elevation. While for ductility class medium (DCM) and ductility class high (DCH) structure, according to Eurocode 8, the behaviour factor in design can be derived as equation (3.8) below;

$$q = q_0 . K_w \geq 1.5 \qquad (3.8)$$

Where; q_0= Basic value of behaviour factor

K_w= Reflecting factor

Where q_0 is depart of structural type and its regularity in elevation. K_w represents the factor reflecting the prevailing failure mode in structural system with wall. The value K_w is equal to 1.0 for frame and frame-equivalent dual system but for other systems, clauses 5.2.2.2 (111) P in Eurocode 8 (2004) stated the derivation of K_w. Table 3.11 shown the basic value of behaviour factor, q_0.

Table 3.11 Basic value of behaviour factor, q_0 (Eurocode 8, 2004)

Structural Type	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_U / \alpha_I$	$4.5\alpha_U / \alpha_I$
Uncoupled wall system	3.0	$4.0\alpha_U / \alpha_I$
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

The multiplication factor, α_U / α_I can be approximated as follow (Eurocode 8, 2004):

i. One-storey buildings: $\alpha_U / \alpha_I = 1.1$
ii. Multi-storey, one-bay frames: $\alpha_U / \alpha_I = 1.2$
iii. Multi-storey, multi-bay frames or frame equivalent dual structure: $\alpha_U / \alpha_I = 1.3$

Since this research is focused on the multi-storey and multi-bay RC frame, the value of α_U / α_I is equal to 1.3. The proposed value of behaviour factor in Eurocode 8 (2004) is shown in Table 3.12 and since the ductility class is fixed as DCM, the value of behaviour factor is equal to 3.9.

Table 3.12 Proposed value for behaviour factor, q for multi-storey and multi-bay RC frame (Eurocode 8, 2004)

Ductility	DCL	DCM	DCH
Range of behaviour factor, q	$1.0 \le q \le 1.5$	$1.5 < q < 5.85$	$q \ge 5.85$
Proposed value (Eurocode 8, 2004)	1.5	3.9	5.85

3.4.5 Structural analysis

After the magnitude of base shear force has been determined and proportionally distributed along the height of the frame as lateral load, bending moment, *M*, shear force, *V*, and axial force, *P*, determined by undergone the structural analysis which will be used as input for design.

3.4.5.1 Seismic design of beam

This subsection explains the flow of seismic design of beam. Figure 3.8 show the flow of beam seismic design.

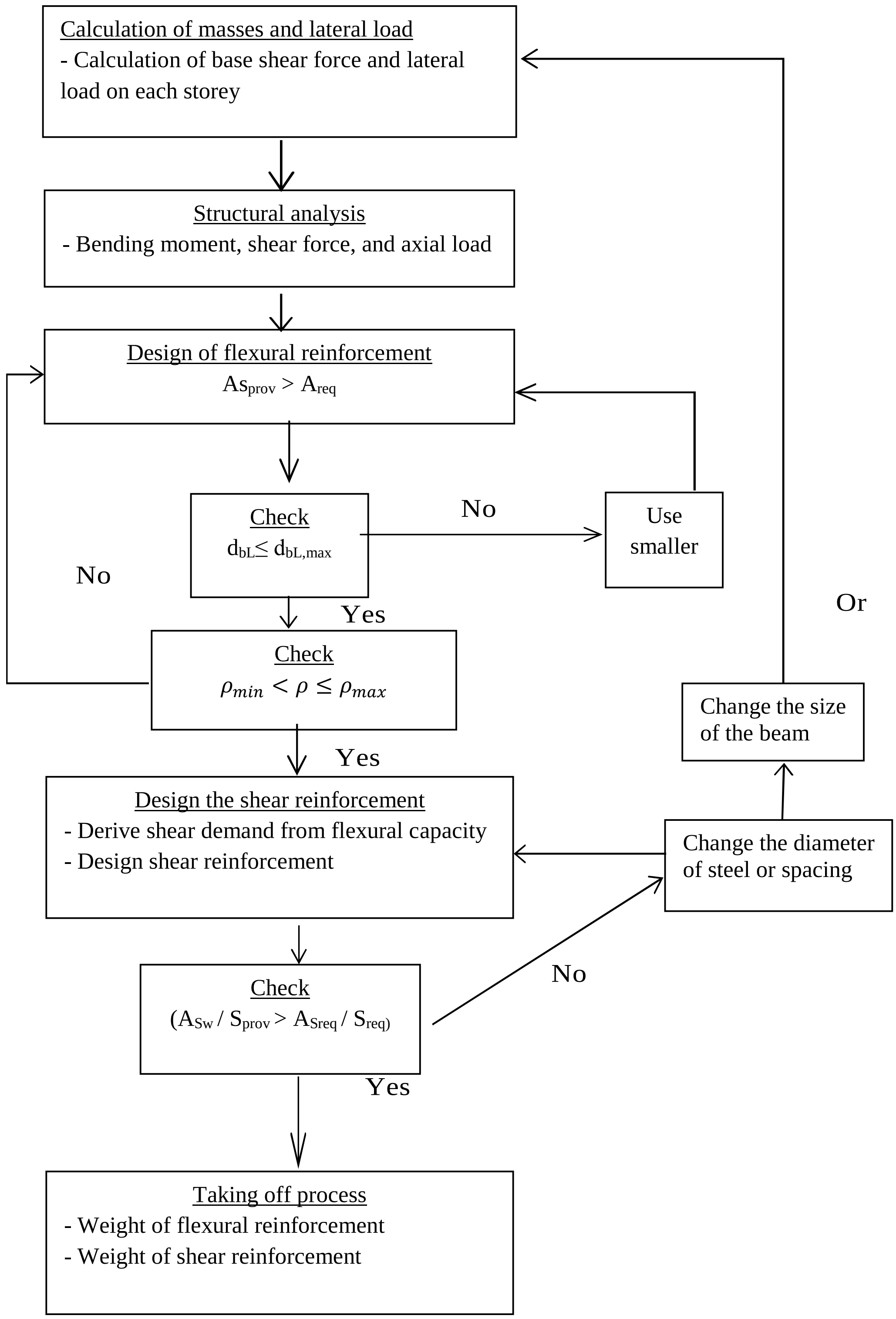

Figure 3.8 Beam seismic design flow based on Eurocode 8 (Adiyanto, 2016)

3.4.5.2 Seismic design of column

Column design is carried out according to Eurocode 8. Maximum bending moment was used to determine the column size and amount of steel reinforcement needed. Figure 3.9 shows the flow chart of column design based on Eurocode 8 (2004.)

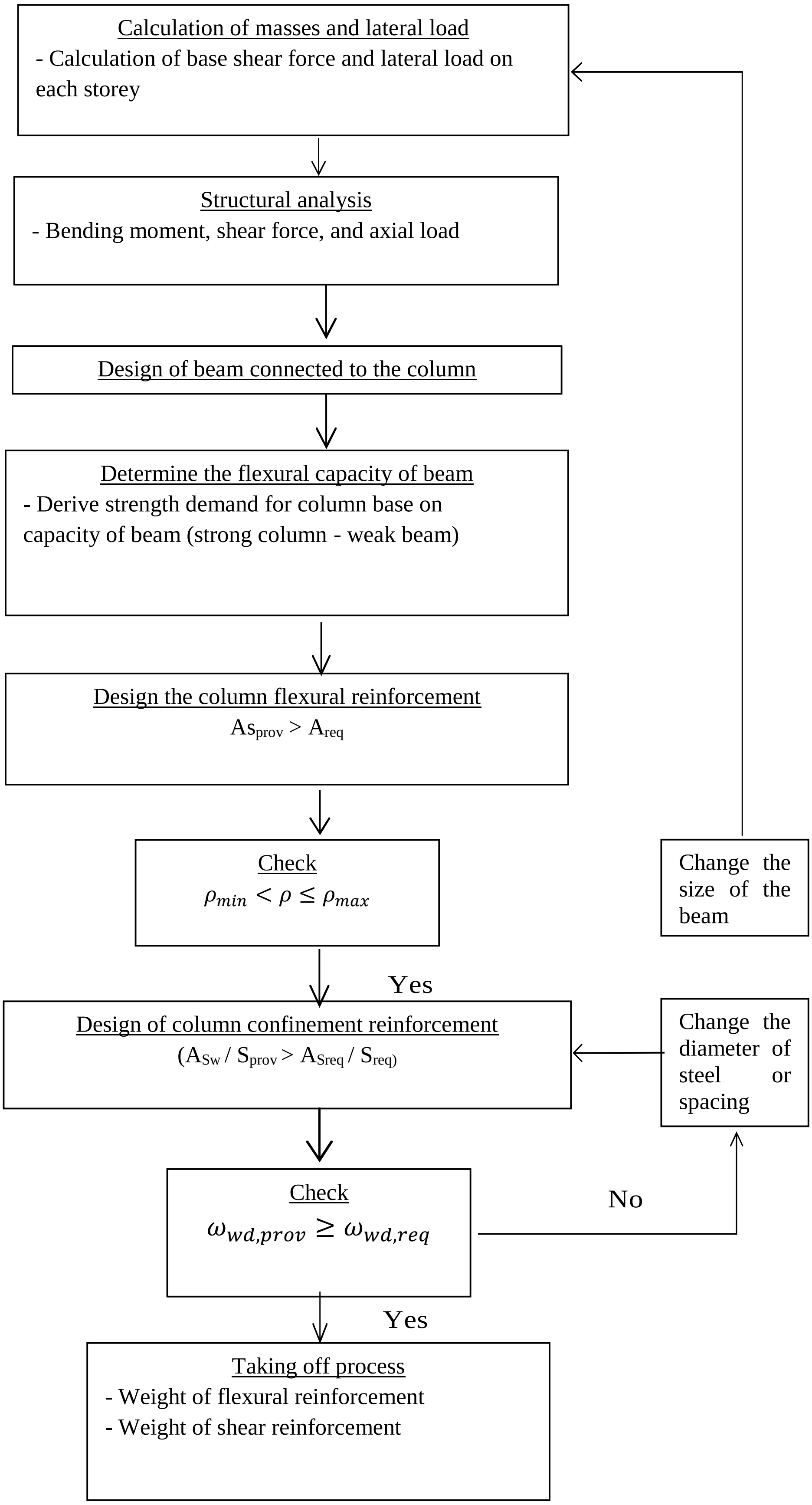

Figure 3.9 Column seismic design flow based on Eurocode 8 (Adiyanto, 2016)

3.5 Stage 3: Performing taking off

Taking off process is performed to determine the amount of steel required for the seismic design models of 8 storey RC hospital building based on the structural elements of the building which is beam and column. The comparison of taking off is made based on result of each model differ by two main parameters used in this study which is Soil Type and grade of concrete. The comparison of normalise of steel weight per $1m^3$ concrete also is made for each model.

3.6 Stage 4: Cost estimation of materials used

In this stages, the cost estimation of materials used for the RC hospital based on the structural elements of the building which is beam and column is calculated according to current market prices. The comparison of the cost is based on result of each model differ by the weight of steel reinforcement needed for the RC hospital.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the discussion of result based on analysis and design performed is presented. The results are obtained as the model is analysed and designed using different values of Soil Type and grade of concrete. The comparison has been made based on the required amount of steel reinforcement for the reinforced concrete (RC) hospital building. Furthermore, the comparison also includes the design response spectrum, $S_d(T)$, of the model. The results obtained will be discussed based on lateral force method as proposed in Eurocode 8 (2004) where the earthquake action on building can be represented by the base shear force, F_b, which will then affect the amount of steel required for the building.

4.2 Design Response Spectrum and Base Shear Force

In order to producing the design response spectrum, there are few value taken based on the variables used. The design response spectrum used in this research is design response spectrum for inelastic analysis constructed based on equation proposed by Eurocode 8 (2004) as previously discussed in Chapter 3, equation 3.3 to 3.6.

The value of $S_d(T)$ is parameter which play the main role in this analysis and design result. There are few fixed value used for the expression. The first one is importance factor, γ_1, which the value of importance factor taken base on the important class. The important class selected based on the type of the constructed building. Since the proposed building for this research is hospital building, it classified in important class IV and bring the γ_1 is equal to 1.4. The classification table can be referred to Table 3.10 in Chapter 3 of Eurocode 8 (2004).

Behaviour factor, q, is also one of variable used in this expression. Since the ductility class this study used is constant which is ductility class medium (DCM), the value of q used equal to 3.9. The peak ground acceleration (PGA), α_{gR}, is 0.08g constantly and it bring the value for design ground acceleration, α_g, is equal to 0.112g where produced form the expression as previously discussed in Chapter 3, equation 3.7.

The range of the time, T_1, for the design spectrum used is 1.0 second. The various value of soil factor, S, value of lower limit of the period of the constant spectral acceleration branch, T_B, the value of upper limit of the period of the constant spectral acceleration branch, T_C, and the value of beginning of the constant displacement response range of the spectrum, T_D used is based on the various of Soil Type that is used in this study which is Soil Type A, Soil Type B, and Soil Type C. The values taken as in Table 3.9 in Chapter 3 which recommended by Eurocode 8 (2004). Figure 4.1 shows the design response spectrum for all Soil Type A, Soil Type B and Soil Type C.

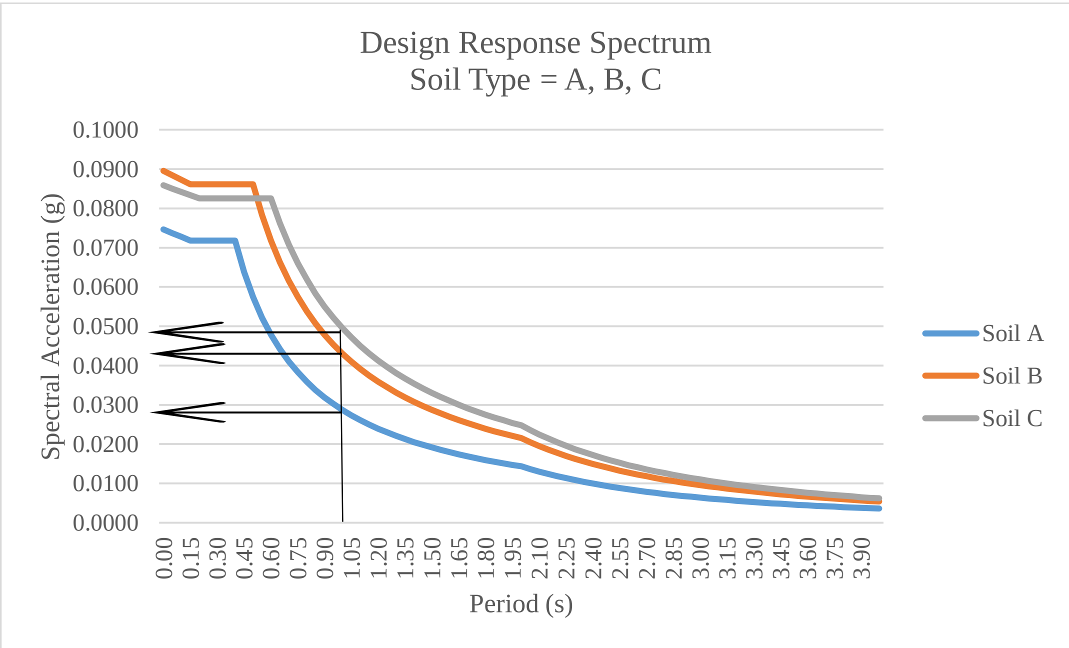

Figure 4.1 Design response spectrum for Soil Type A, Soil Type B and Soil Type C

Figure 4.1 shows the combination of design response spectrum for three different Soil Type which presented three different values of $S_d(T)$. The lowest $S_d(T)$ value is from Soil Type A and the highest one is from Soil Type C. The $S_d(T)$ value is 0.029g, 0.043g and 0.049g when defined by using Soil Type A, Soil Type B and Soil Type C respectively.

The value of $S_d(T)$ can be defined by determine the value of T_1 by using equation as previously discussed in Chapter 3, equation 3.2. The value of T_1 defined is equal to 1.0s and it makes the value of $S_d(T)$ is equal to 0.049g which is on Soil Type C. The value of design spectrum is strongly related with the value of F_b as mentioned on equation 3.4 in Chapter 3 where when the mass of the element, m, and correction factor, λ, is constant, F_b related directly to $S_d(T)$ which means the value of F_b increase as the value of $S_d(T)$ increase. This result shows the similar pattern with previous study by Adiyanto et al. (2019). Table 4.1 below shows the value of base shear force for all model.

Table 4.1 Design Response Spectrum and Base Shear Force

Model	Soil Type	Concrete Grade	$S_d(T_1)$ (m/s^2)	Mass	F_b (kN)
A-30	A	30	0.029	7800.46	2268
B-30	B	30	0.043	7800.46	2891.8
C-30	C	30	0.049	7800.46	3325.5
A-40	A	40	0.029	7800.46	2268
B-40	B	40	0.043	7800.46	2891.8
C-40	C	40	0.049	7800.46	3325.5

4.2 Influenced of Soil Type and Concrete Grade on Concrete Volume

This study investigated the influenced of Soil Type and Concrete Grade on the amount of concrete volume used for beams and columns element of the RC hospital building. The result of concrete volume used for beam and column is obtained and discuss as below.

4.3.1 Influenced of Soil Type and Concrete Grade on Concrete Volume for Beam

Figure 4.2 shows the comparison of total amount of concrete volume used for beam for all model. The figure shows the value of concrete volume used for all model is similar because of the sizes that is used for beam element for all model in this study is same which is 400x650mm, 300x500mm and 250x500mm for BA, BB and BC respectively. The location of the beam is shown in Appendix B.

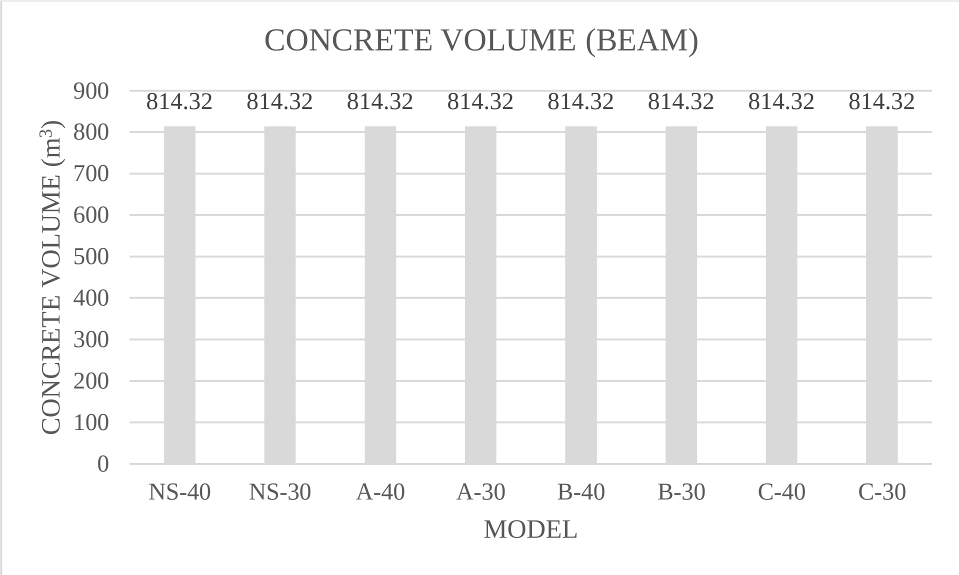

Figure 4.2 Total amount of concrete volume of beam for all model

4.3.2 Influenced of Soil Type and Concrete Grade on Concrete Volume for Column

Figure 4.3 shows the comparison of total amount of concrete volume used for column for all model. The figure shows the value of concrete volume used for all model is similar because of the sizes that is used for column element for all model in this study is same which is 550x550mm and 500x500mm for CA and CB respectively. The location of the beam is shown in Appendix B.

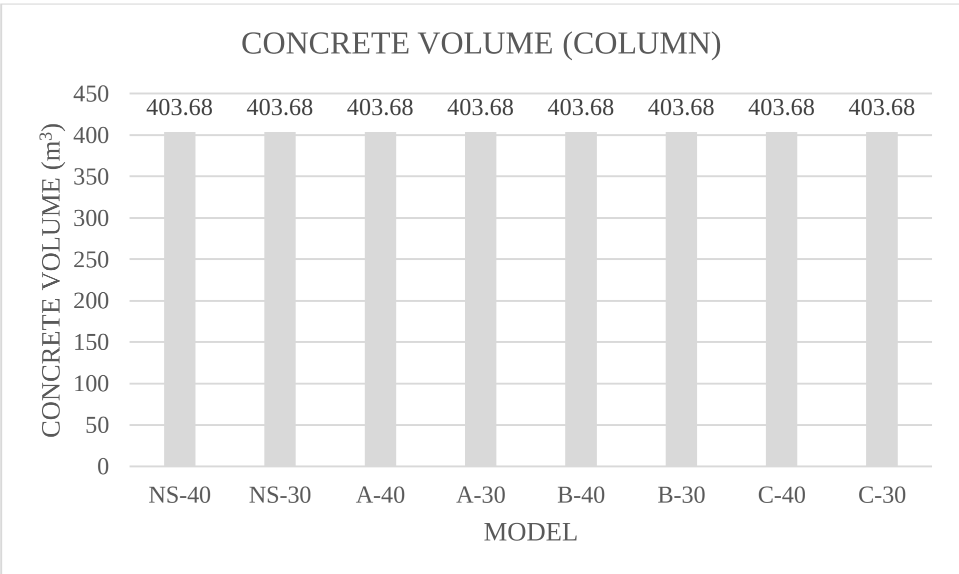

Figure 4.3 Total amount of concrete volume of column for all model

4.3.2 Influenced of Soil Type and Concrete Grade on Concrete Volume for Beam and Column

Figure 4.4 shows the comparison of total amount of concrete volume used for beam and column for all model. The figure shows the value of concrete volume used for all model is similar because of the sizes that is used for beam and column element for all model in this study is same. There are no changes in size of beam and column element has been made during the analysis of the model due to there are no failure of beam and column element occurred during the process.

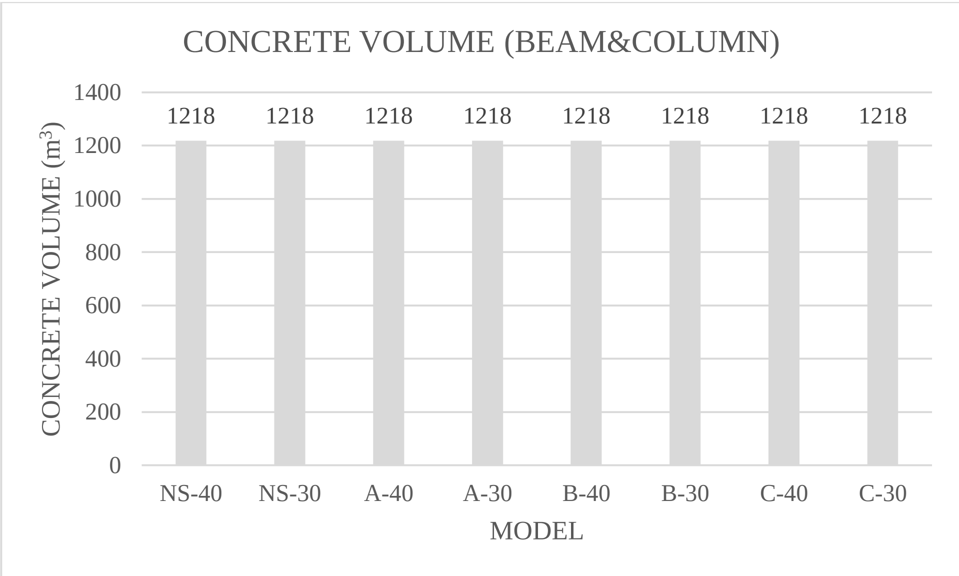

Figure 4.4 Total amount of concrete volume of Beam and Column for all model

4.4 Influenced of Soil Type on Amount of Steel Reinforcement

This study is conducted by using three different types of soil which is Soil Type A, Soil Type B and Soil Type C. Each Soil Type produced its own effect on the amount of steel reinforcement for the RC hospital building. The weight of steel reinforcement for each Soil Type are compared to the non-seismic model. The result shows the comparison of steel required for all beam and column reinforcement for both Concrete Grade G30 and G40. All others detail of influenced of Soil Type on amount of steel used for each beam and column element can be find in Appendix C.

4.4.1 Influenced of Soil Type on Amount of Steel Used for Beam Reinforcement

In order to discuss on the influenced of Soil Type on amount of steel used for beam reinforcement, the comparison on the total amount of steel weight graph has been developed with building model of non seismic design, Soil Type A, Soil Type B and Soil Type C. Figure 4.5 and Figure 4.6 show the weight of steel of Beam for both Concrete Grade G30 and G40, respectively.

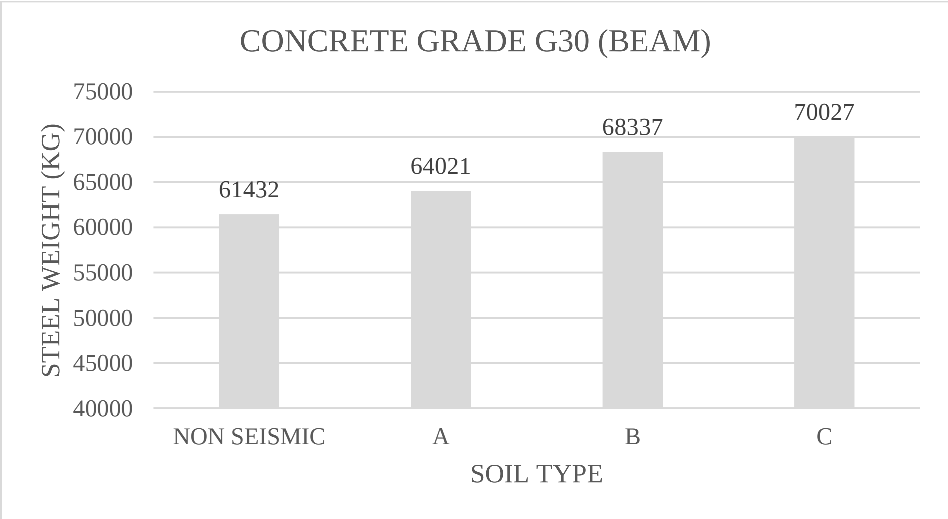

Figure 4.5 Total weight of steel of Beam for Concrete Grade G30 influenced by Soil Type

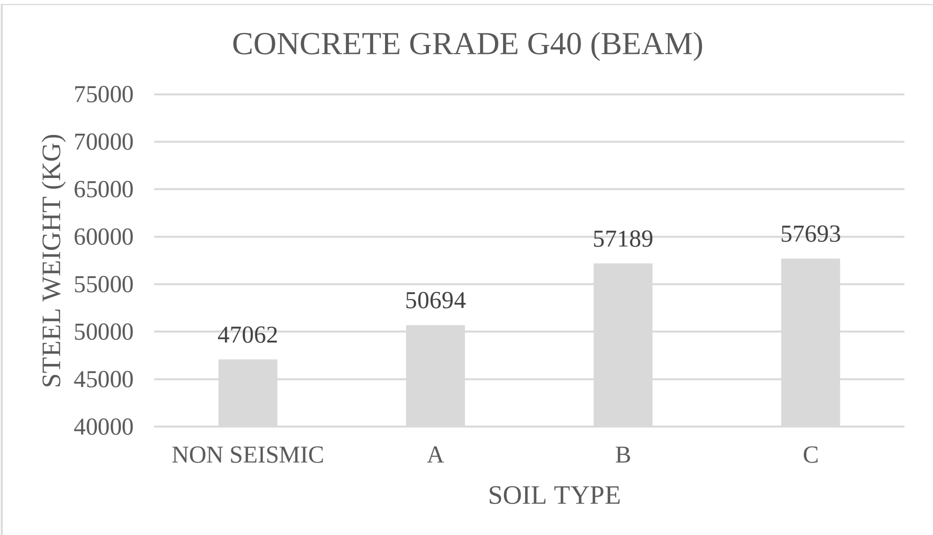

Figure 4.6 Total weight of steel of Beam for Concrete Grade G40 influenced by Soil Type

From above figures, the graphs show the similar pattern for comparison of total weight of steel of beam for both Concrete Grade G30 and G40 influenced by Soil Type. The consistencies of the graph show that the effect of different Soil Type gives significant effect to the amount of steel reinforcement required for beam. Figure 4.5 shows a cumuliform pattern of graph where the building model with the lowest amount of steel weight is non seismic design with 61432 kg and the highest is Soil Type C which is 70027 kg for Beam with Concrete Grade G30. Figure 4.6 also shows the cumuliform pattern of graph where the building model with lowest amount of steel weight is non seismic design with 47062 kg and the highest one is Soil Type C which is 57693 kg for Beam with Concrete Grade G40.

The weight 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 higher the bending moment of the element, the higher the weight of steel reinforcement required. Table 4.1 shows the bending moment, M_{Ed}, and area of steel, $A_{s,req}$, of steel reinforcement of Beam B1 when built on non seismic design, Soil Type A, Soil Type B and Soil Type C. Soil Type C has the highest value of M_{Ed} and $A_{s,req}$ for steel reinforcement compared to others as shown in Table 4.2 below.

Table 4.2 Steel reinforcement of Beam B1 influenced by Soil Type

Soil Type	Concrete Grade	M_{ed} (kNm)	K/K’	As,req (mm^2)	As,min (mm^2)	As,prov (mm^2)
Non seismic	30	99.5	0.27	420	407	603
A	30	105	0.29	444	407	603
B	30	119	0.32	503	532	942
C	30	257	0.67	1086	532	1437

4.4.2 Influenced of Soil Type on Amount of Steel Used for Column Reinforcement

In order to discuss on the influenced of Soil Type on amount of steel used for column reinforcement, the comparison on the total amount of steel weight graph has been developed with building model of non seismic design, Soil Type A, Soil Type B and Soil Type C. Figure 4.7 and Figure 4.8 show the weight of steel of Column for both Concrete Grade G30 and G40, respectively.

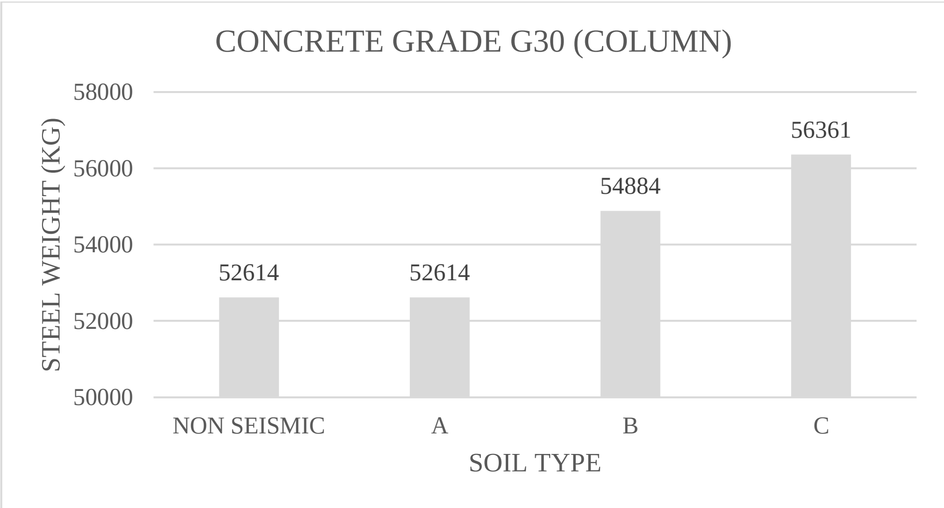

Figure 4.7 Total weight of steel of Column for Concrete Grade G30 influenced by Soil Type

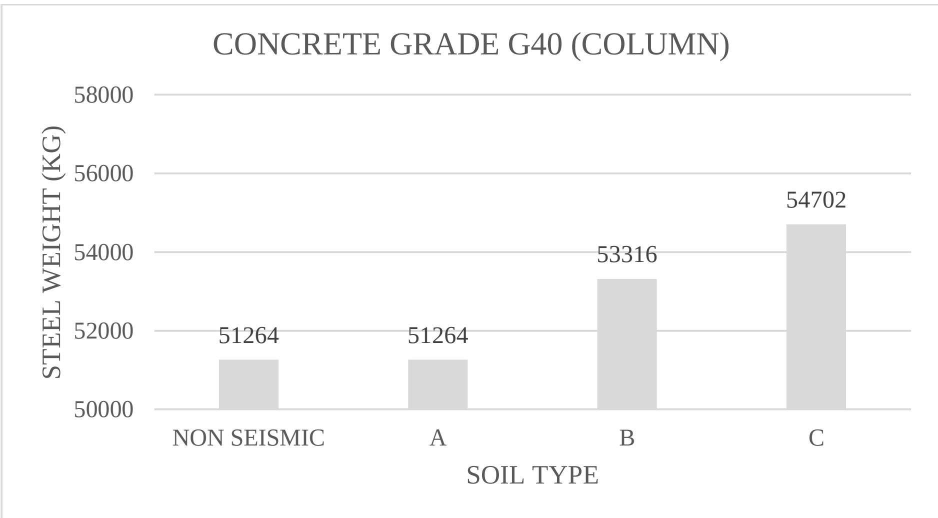

Figure 4.8 Total weight of steel of Column for Concrete Grade G40 influenced by Soil Type

From above figures, the graphs show the similar pattern for comparison of total weight of steel of column for both Concrete Grade G30 and G40 influenced by Soil Type. The consistencies of the graph show that the effect of different Soil Type gives significant effect to the amount of steel reinforcement required for column. Figure 4.7 shows a varies pattern of graph where the building model with the lowest amount of steel weight is non seismic design and Soil Type A with 52614 kg and the highest is Soil Type C which is 56316 kg for column with Concrete Grade G30. Figure 4.8 also shows them varies pattern of graph where the building model with lowest amount of steel weight is non seismic design and Soil Type A with 51264 kg and the highest one is Soil Type C which is 54702 kg for Column with Concrete Grade G40.

The weight 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 higher the bending moment of the element, the higher the weight of steel reinforcement required. Table 4.2 shows the bending moment, M_{Ed}, and area of steel, $A_{s,req}$, of steel reinforcement of Column when built on non seismic design, Soil Type A, Soil Type B and Soil Type C. Soil Type C has the highest value of M_{Ed} and $A_{s,req}$ for steel reinforcement compared to others as shown in Table 4.3 below.

Table 4.3 Steel reinforcement of Column C1 influenced by Soil Type

Soil Type	Concrete Grade	Med (kNm)	Mres (kNm)	As,min (mm^2)	As,max (mm^2)	As,l (mm^2)
Non seismic	30	58.7	351.7	1361	12100	3770
A	30	60.2	350.6	1361	12100	3770
B	30	65.7	388.2	1361	12100	3770
C	30	65.7	388.2	1361	12100	3770

4.4.3 Influenced of Soil Type on Amount of Steel Used for Beam and Column Reinforcement

Figure 4.9 and Figure 4.10 below show the weight of steel for all beam and column element in the whole RC hospital building for both Concrete Grade G30 and G40 respectively, when constructed on non seismic design, Soil Type A, Soil Type B and Soil Type C.

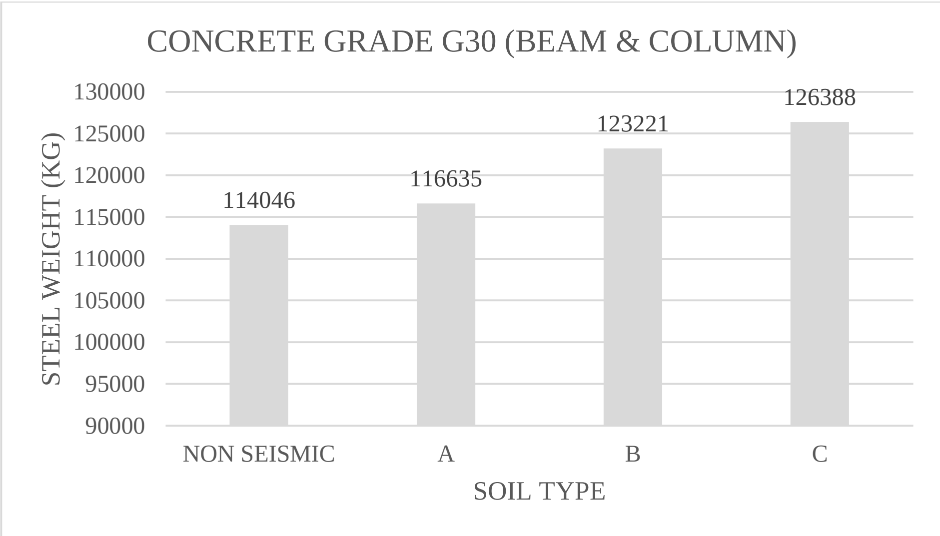

Figure 4.9 Total weight of steel of Beam and Column for Concrete Grade G30 influenced by Soil Type

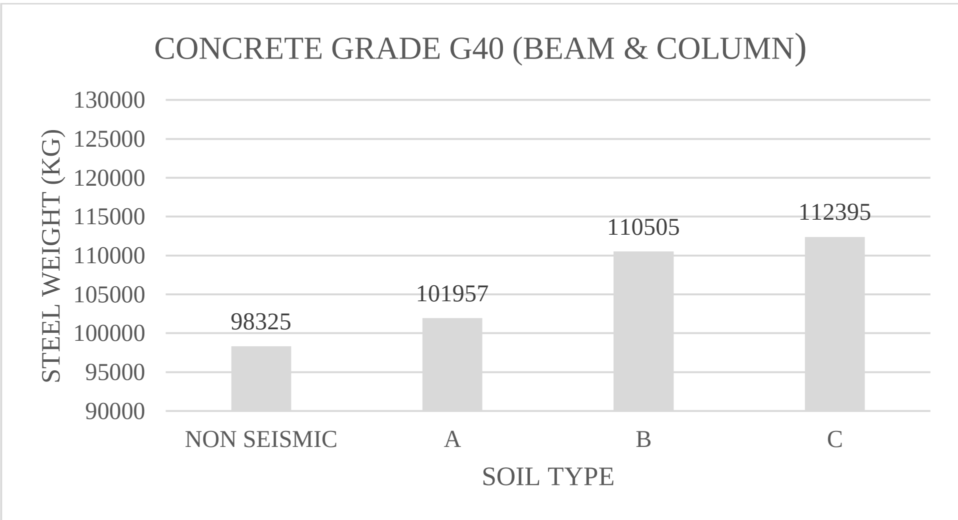

Figure 4.10 Total weight of steel of Beam and Column for Concrete Grade G40 influenced by Soil Type

From Figure 4.9 and Figure 4.10, it can be concluded that the graph is increase linearly. As in the Figure 4.9, the weight of steel reinforcement for beam and column increase around 2.3% to 10.8% when compared to the non seismic design. For more detail, the increment is equal to 2.3%, 8.0% and 10.8% when built on Soil Type A, Soil Type B and Soil Type C, respectively. Non seismic design has the lowest amount of steel required while Soil Type C is the highest one. While as in the Figure 4.10, the weight of steel reinforcement for beam and column increase around 3.7% to 14.3% when compared to the non seismic design. For more detail, the increment is equal to 3.7%, 12.4% and 14.3% when built on Soil Type A, Soil Type B and Soil Type C, respectively. Non seismic design has the lowest amount of steel required while Soil Type C is the highest one which shows the same pattern as for the Concrete Grade G30.

The result is strongly related to the value of $S_d(T)$, on various of Soil Type. Based on the previous $S_d(T)$ on Figure 4.1, Soil Type C has the highest $S_d(T)$ value. It is affect the value of F_b of the design where the F_b value increase perpendicularly with the $S_d(T)$ value. When the F_b value increase, the bending moment of the element also increase indirectly, thus, the value of $A_{s,req}$ also become larger and automatically the amount of steel required to cover up the area will be increase. From the analysis, it proves that Soil Type C can be classified as the critical Soil Type since it has the softer soil texture which did not strong enough to hold the concrete without large amount of steel reinforcement used and has the highest amount of M_{Ed} and $A_{s,req.}$ This result is in good agreement with previous study by Saka (2018).

4.5 Influenced of Concrete Grade on Amount of Steel Reinforcement

This study is conducted by using two different types of grade of concrete which is concrete grade G30 and concrete grade G40. Each grade of concrete gives its own effect on the amount of steel reinforcement for the building based on its compressive strength. The weight of steel reinforcement for each Concrete Grade are compared to the non-seismic model. The result shows the comparison of steel required for all beam and column reinforcement for all Soil Type which is Soil Type A, Soil Type B, and Soil Type C. All others detail of influenced of Concrete Grade on amount of steel used for each beam and column element can be find in Appendix D.

4.5.1 Influenced of Concrete Grade on Amount of Steel Used for Beam Reinforcement

In order to discuss on the influenced of Concrete Grade on amount of steel used for beam reinforcement, the comparison on the total amount of steel weight graph has been developed with both Concrete Grade of G30 and G40. Figure 4.11, Figure 4.12 and Figure 4.13 show the weight of steel of beam for Soil Type A, Soil Type B and Soil Type C respectively.

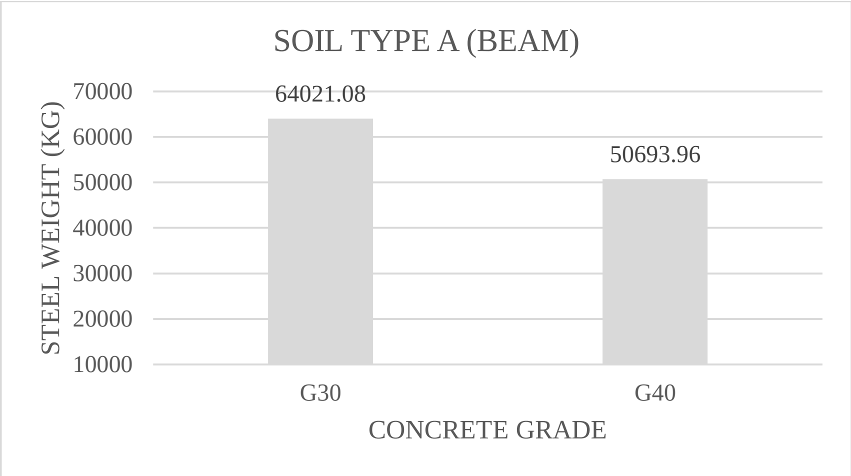

Figure 4.11 Total weight of steel of Beam for Soil Type A influenced by Concrete Grade

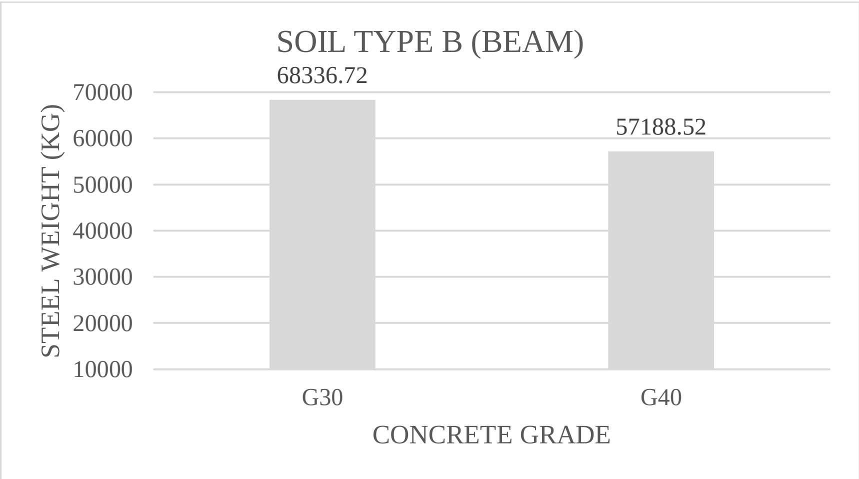

Figure 4.12 Total weight of steel of Beam for Soil Type B influenced by Concrete Grade

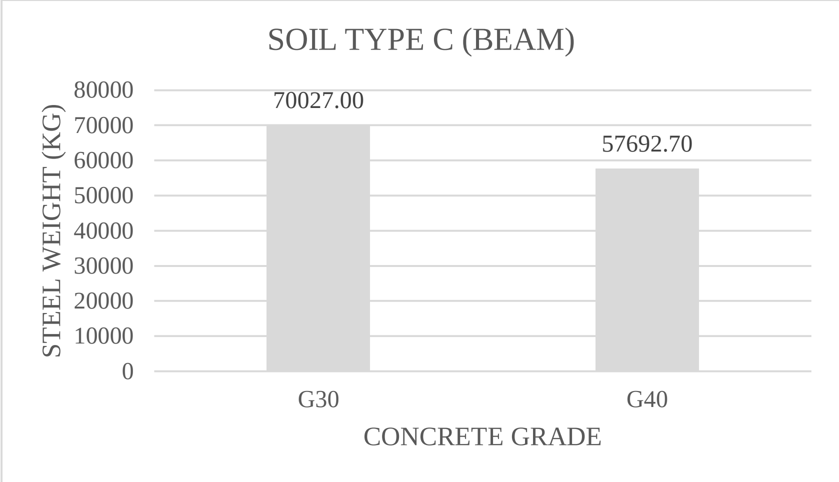

Figure 4.13 Total weight of steel of Beam for Soil Type C influenced by Concrete Grade

Figure 4.11 shows that the weight of steel reinforcement of beam for Soil Type A for concrete grade G30 is higher than concrete grade G40 which is 64021.08 kg while for concrete grade G40 is 50693.96 kg. The difference between the two grades of concrete is about 26.3%. Figure 4.12 shows that the weight of steel reinforcement of beam for Soil Type B for concrete grade G30 is higher than concrete grade G40 which is 68336.72 kg while for concrete grade G40 is 57188.52 kg. The difference between the two grades of concrete is about 19.5%. Figure 4.13 shows that the weight of steel reinforcement of beam for Soil Type C for concrete grade G30 is higher than concrete grade G40 which is 70027.00 kg while for concrete grade G40 is 57692.70 kg. The difference between the two grades of concrete is about 21.4%. From the above graphs, it can be concluded that the graphs show the same pattern which the weight of steel of beam for Concrete Grade G30 is higher than the weight of steel for Concrete Grade G40.

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 shear force. The higher the bending moment of the element, the weight of steel reinforcement required increase, respectively. Table 4.3 shows the value of M_{Ed}, and $A_{s,req}$, of steel reinforcement of beam when built on Soil Type C by using two different grade of concrete which are grade of concrete G30 and grade of concrete G40. Grade of concrete G30 has the highest value of M_{Ed} and $A_{s,req}$ for steel reinforcement of beam compared to grade of concrete G40 as shown in Table 4.3 below.

Table 4.3 Steel reinforcement of Beam B1 influenced by Concrete Grade

Soil Type	Concrete Grade	Med (kNm)	K/K’	As,req (mm^2)	As,min (mm^2)	As,prov (mm^2)
C	30	257	0.67	1086	532	1437
	40	248	0.51	1048	532	1340

4.5.2 Influenced of Concrete Grade on Amount of Steel Used for Column Reinforcement

In order to discuss on the influenced of Concrete Grade on amount of steel used for column reinforcement, the comparison on the total amount of steel weight graph has been developed with both Concrete Grade of G30 and G40. Figure 4.14, Figure 4.15 and Figure 4.16 show the weight of steel of beam for Soil Type A, Soil Type B and Soil Type C respectively.

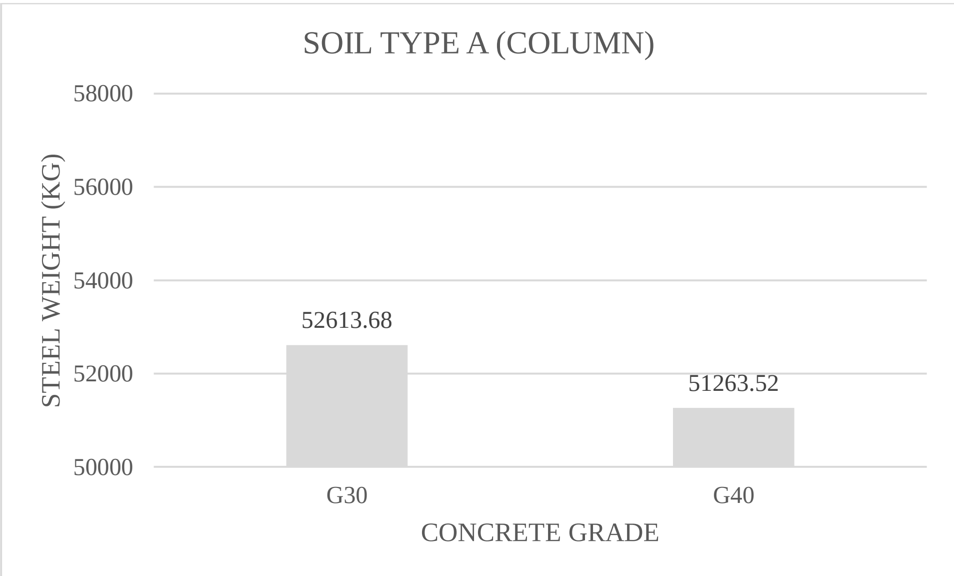

Figure 4.14 Total weight of steel of Column for Soil Type A influenced by Concrete Grade

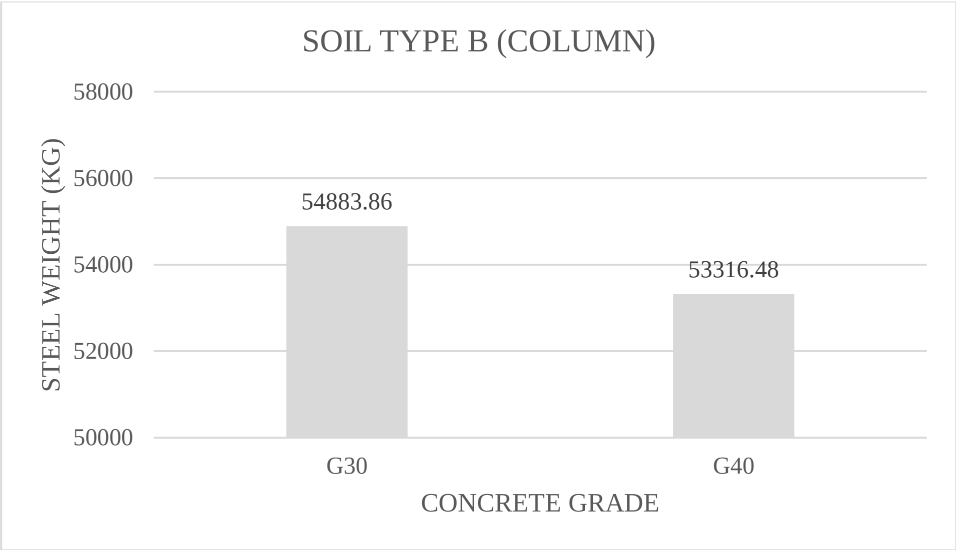

Figure 4.15 Total weight of steel of Column for Soil Type B influenced by Concrete Grade

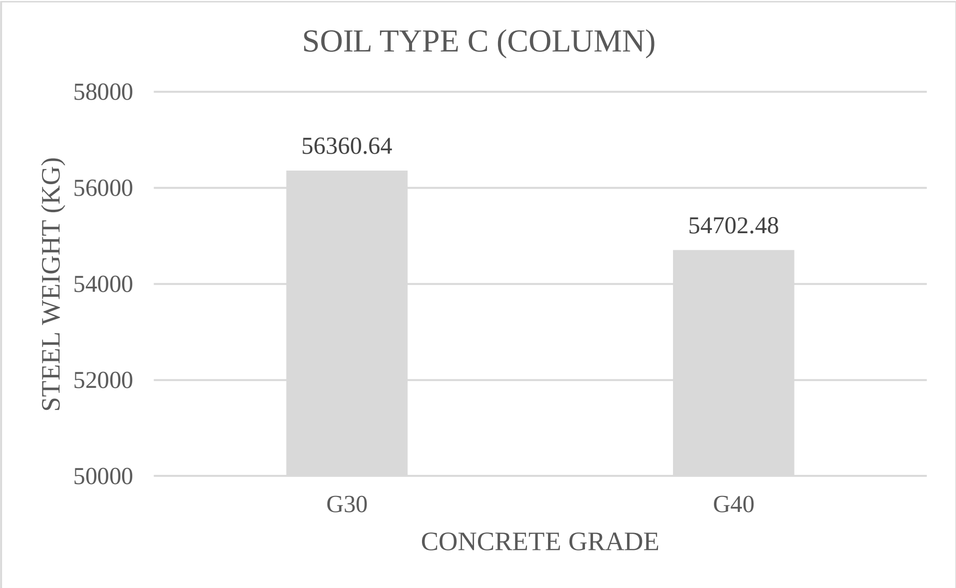

Figure 4.16 Total weight of steel of Column for Soil Type C influenced by Concrete Grade

Figure 4.14 shows that the weight of steel reinforcement of column for Soil Type A for concrete grade G30 is higher than concrete grade G40 which is 52613.68 kg while for concrete grade G40 is 51263.52 kg. The difference between the two grades of concrete is about 2.6%. Figure 4.15 shows that the weight of steel reinforcement of column for Soil Type B for concrete grade G30 is higher than concrete grade G40 which is 54883.86 kg while for concrete grade G40 is 53316.48 kg. The difference between the two grades of concrete is about 2.9%. Figure 4.16 shows that the weight of steel reinforcement of column for Soil Type C for concrete grade G30 is higher than concrete grade G40 which is 56360.64 kg while for concrete grade G40 is 54702.48 kg. The difference between the two grades of concrete is about 3.0%. From the above graphs, it can be concluded that the graphs show the same pattern which the weight of steel of beam for Concrete Grade G30 is higher than the weight of steel for Concrete Grade G40.

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 shear force. The higher the bending moment of the element, the weight of steel reinforcement required increase, respectively. Table 4.4 shows the value of M_{Ed}, and $A_{s,req}$ of steel reinforcement of beam when built on Soil Type C by using two different grade of concrete which are grade of concrete G30 and grade of concrete G40. Grade of concrete G30 has the highest M_{Ed} and $A_{s,req}$ for steel reinforcement of column compared to grade of concrete G40 as shown in Table 4.4 below.

Table 4.4 Steel reinforcement of Column C1 influenced by Concrete Grade

Soil Type	Concrete Grade	Med (kNm)	Mres (kNm)	As,min (mm^2)	As,max (mm^2)	As,l (mm^2)
C	30	65.7	388.2	1361	12100	3770
	40	58.6	361.3	1361	12100	3650

4.5.3 Influenced of Concrete Grade on Amount of Steel Used for Beam and Column Reinforcement

Figure 4.17, Figure 4.18 and Figure 4.19 below show the weight of steel for all beam and column element in the whole RC hospital building Soil Type A, Soil Type B and Soil Type C respectively, when constructed using Concrete Grade G30 and G40.

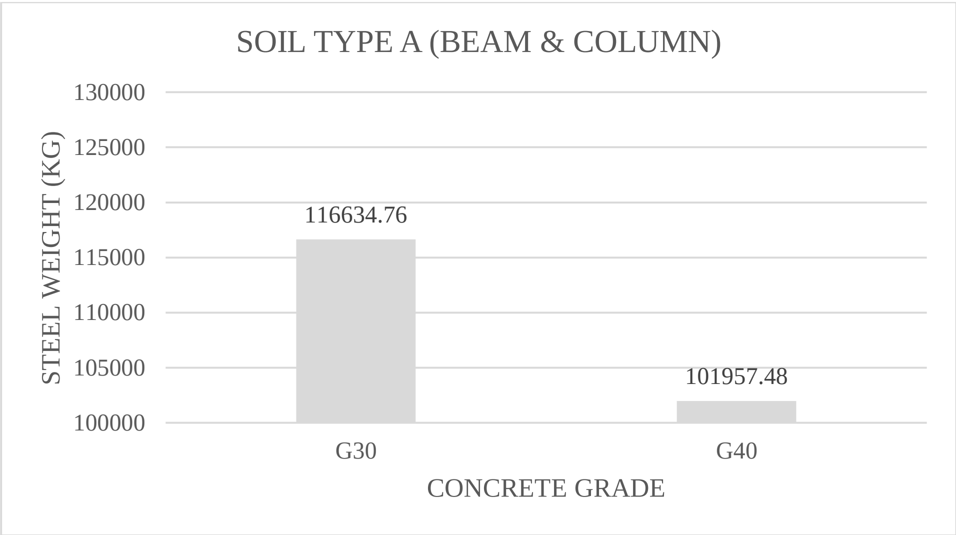

Figure 4.17 Total weight of steel of Beam and Column for Soil Type A influenced by Concrete Grade

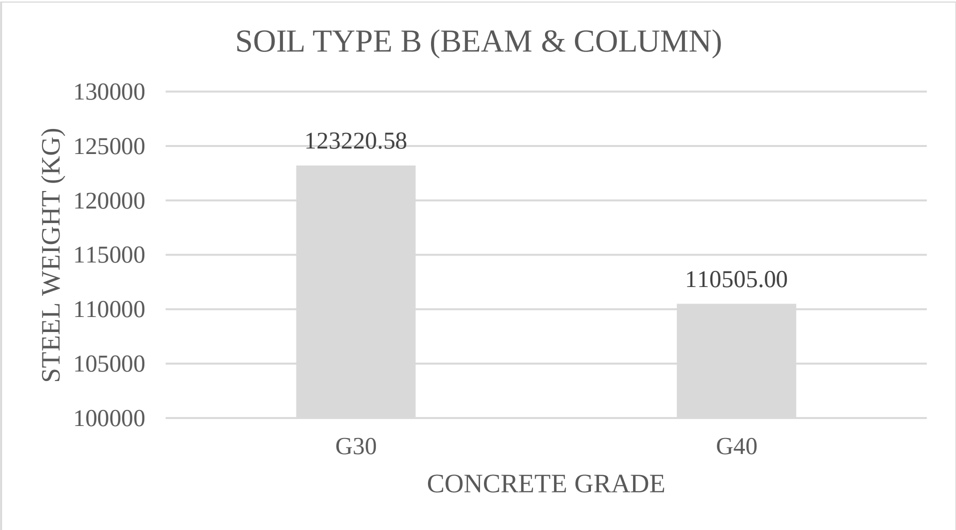

Figure 4.18 Total weight of steel of Beam and Column for Soil Type B influenced by Concrete Grade

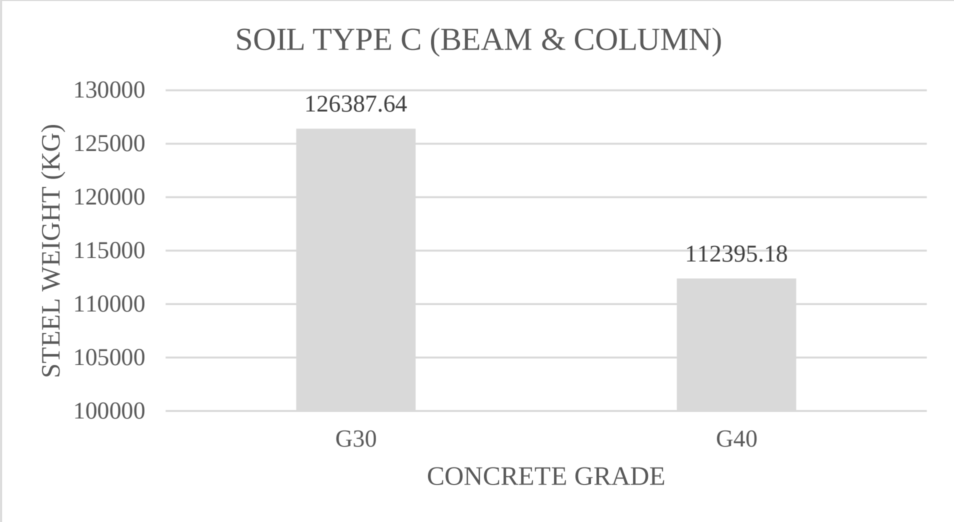

Figure 4.19 Total weight of steel of Beam and Column for Soil Type C influenced by Concrete Grade

As in the Figure 4.17, the difference of amount of weight of steel reinforcement for beam and column of concrete grade G30 and concrete grade G40 is about 11.1% where the grand total of weight of steel reinforcement for concrete grade G30 is 116634.76 kg and 104957.48 kg for concrete grade G40. While for Figure 4.18, the difference of amount of weight of steel reinforcement for beam and column of concrete grade G30 and concrete grade G40 is about 11.5% where the grand total of weight of steel reinforcement for concrete grade G30 is 123220.58 kg and 110505.00 kg for concrete grade G40. Lastly, as in the Figure 4.19, the difference of amount of weight of steel reinforcement for beam and column of concrete grade G30 and concrete grade G40 is about 12.4% where the grand total of amount of steel reinforcement for concrete grade G30 is 126387.64 kg and 112395.18 kg for concrete grade G40. From Figure 4.17, Figure 4.18 and Figure 4.19, it can be concluded that the concrete grade G30 required high amount of steel reinforcement compared to concrete grade G40.

The result is strongly related to the strength of concrete or more specific, it called as compressive strength of the concrete. As the grade concrete increase, the compressive strength also increases and make it become stronger to hold the building without using large amount of steel reinforcement. When the concrete grade decrease, the value of M_{Ed}, of an element increase, thus cause the value of $A_{s,req}$ become larger. Hence, the amount of steel reinforcement for the building also increase. Since concrete grade G30 has compressive strength of 30 MPa while concrete grade G40 is 40 MPa, it proves that grade of concrete G30 can be classified as the critical concrete grade and required more steel reinforcement compared to grade of concrete G40. This result shows the similar pattern with previous study by Saka (2018).

4.6 Total Weight of Steel Reinforcement per 1m^3 Concrete Normalised to Gravity Load Model

Total weight of steel reinforcement per 1m^3 concrete normalised to gravity load model is the ratio of non seismic model to seismic model. Figures below show the result for all model.

4.6.1 Total Weight of Steel Reinforcement per 1m^3 Concrete Grade G30 Normalised to Gravity Load Model for Beam and Column

Figure 4.20 shows the total weight of steel reinforcement per 1m^3 Concrete Grade G30 normalised to gravity load model for beam and column elements.

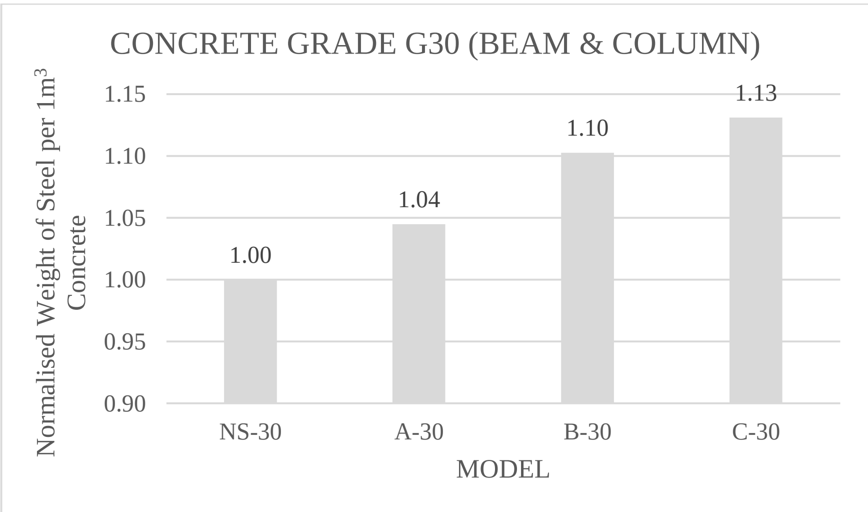

Figure 4.20 Total Weight of Steel Reinforcement per 1m^3 Concrete Grade G30 Normalised to Gravity Load Model for Beam and Column

From Figure 4.20, it can be concluded that the graph is increase linearly. Obviously the increment of the ratio is strongly influenced by the steel weight per $1m^3$ concrete. Figure 4.20 shows that model C-30 has the highest ratio among other Soil Type and non seismic design model. This is because the amount of steel reinforcement per $1m^3$ concrete for RC hospital building with seismic design when built on Soil Type C is higher compared to the other models built on other Soil Type and non seismic design model. From Figure 4.20, the ratio increase around 4% to 13% when compared to the non-seismic model. For further detail, the increment is equal to 4%, 10% and 13% for model A-30, B-30 and C-30, respectively.

4.6.2 Total Weight of Steel Reinforcement per $1m^3$ Concrete Grade G40 Normalised to Gravity Load Model for Beam and Column

Figure 4.20 shows the total weight of steel reinforcement per $1m^3$ Concrete Grade G40 normalised to gravity load model for beam and column elements.

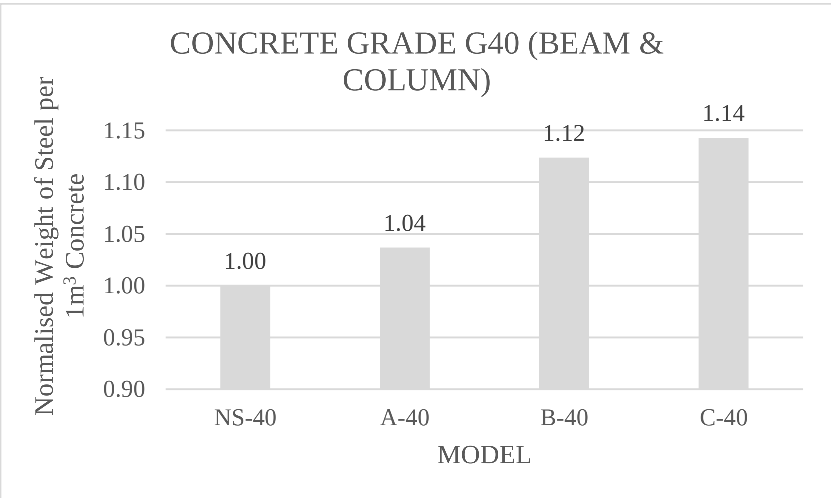

Figure 4.21 Total Weight of Steel Reinforcement per $1m^3$ Concrete Grade G40 Normalised to Gravity Load Model for Beam and Column

From Figure 4.21, it can be concluded that the graph is increase linearly. Obviously the increment of the ratio is strongly influenced by the steel weight per $1m^3$ concrete. Figure 4.21 shows that model C-40 has the highest ratio among other Soil Type and non seismic design model. This is because the amount of steel reinforcement per $1m^3$ concrete for RC hospital building with seismic design when built on Soil Type C is higher compared to the other models built on other Soil Type and non seismic design model. From Figure 4.21, the ratio increase around 4% to 14% when compared to the non-seismic model. For further detail, the increment is equal to 4%, 12% and 14% for model A-40, B-40 and C-40, respectively.

4.7 Estimation of Total Cost of Materials

This research estimated the total cost of materials of RC hospital building for beams and column elements. In this research, two different of Concrete Grade which is Concrete Grade G30 and Concrete Grade G40 is used. According to Jabatan Kerja Raya (2017), the market price of ready mix concrete for Concrete Grade G30 and Concrete Grade G40 is RM 372.10 per $1m^3$ and RM 416.60 per $1m^3$, respectively.

4.7.1 Estimation of Total Cost of Materials for Concrete Grade G30

Figure 4.22, Figure 4.23 and Figure 4.24 below show cost of concrete used, cost of steel reinforcement used and total cost of materials of beams and columns for RC hospital building when the building is built using Concrete Grade G30, respectively.

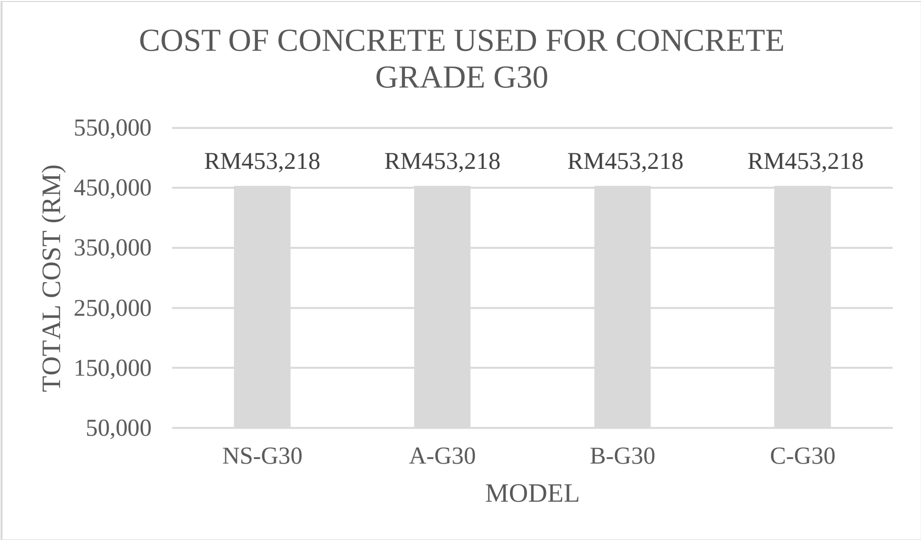

Figure 4.22 Cost of Concrete Used for Beams and Columns for Concrete Grade G30

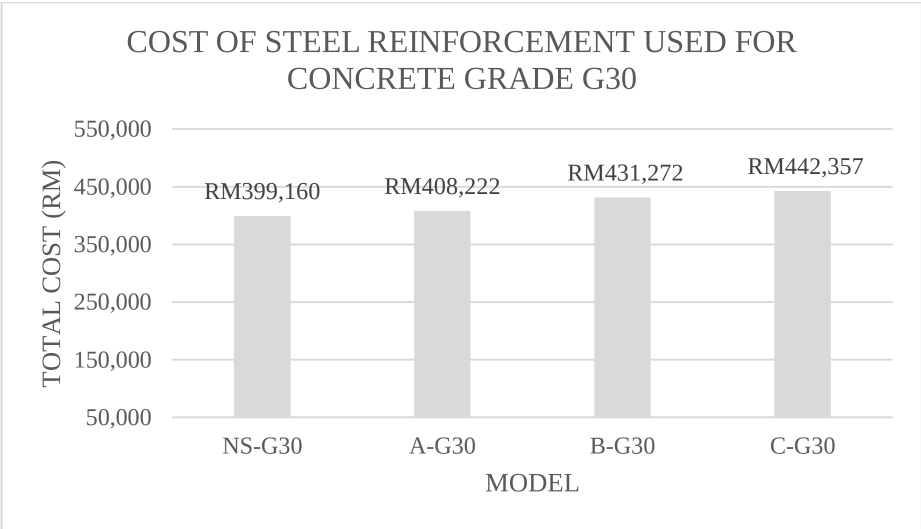

Figure 4.23 Cost of Steel Reinforcement Used for Beams and Columns for Concrete Grade G30

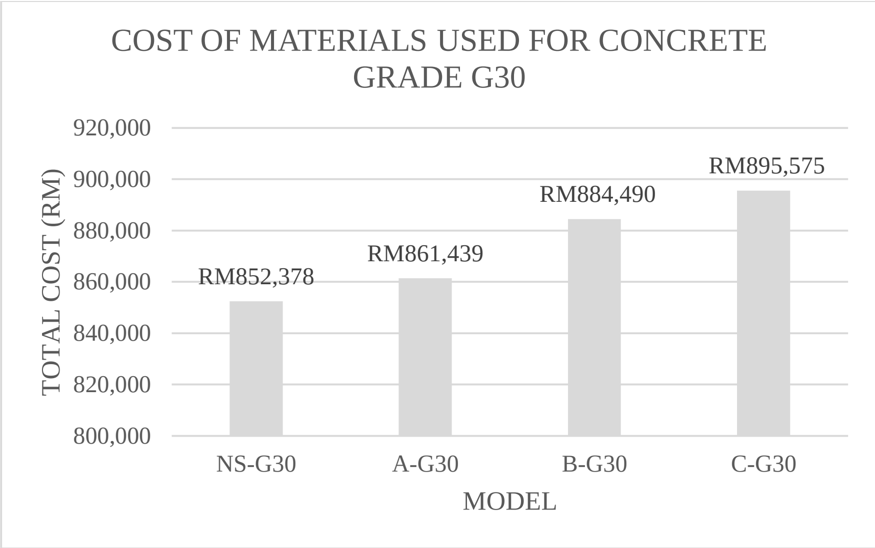

Figure 4.24 Total Cost of Materials Used for Beams and Columns of RC Hospital Building for Concrete Grade G30

As in the Figure 4.22, the cost of concrete used for beams and columns is similar for all model because of the same size of beams and columns used in all model. From Figure 4.23, it can be concluded that the graph is increase linearly. Obviously the increment of estimated cost for steel reinforcement used for beams and columns is strongly influenced by the steel weight. From Figure 4.24, the cost of steel reinforcement used for beam and column increase around 2.3% to 10.8% when compared to the non-seismic design. For further detail, the increment is equal to 2.3%, 8.0% and 10.8% when built on Soil Type A, Soil Type B and Soil Type C, respectively. As in the Figure 4.24, the total cost of materials used for beam and column increase around 1.1% to 5.1% when compared to the non-seismic design. For more detail, the increment is equal to 1.1%, 3.8% and 5.1% when built on Soil Type A, Soil Type B and Soil Type C, respectively. It can be concluded that non seismic model has the lowest amount of total cost of materials used for RC hospital building when it built using Concrete Grade G30 while Soil Type C is the highest amount of total cost of materials used for RC hospital building when the building is built using Concrete Grade G30.

4.7.2 Estimation of Total Cost of Materials for Concrete Grade G40

Figure 4.25, Figure 4.26 and Figure 4.27 below show cost of concrete used, cost of steel reinforcement used and total cost of materials of beams and columns for RC hospital building when the building is built using Concrete Grade G40, respectively.

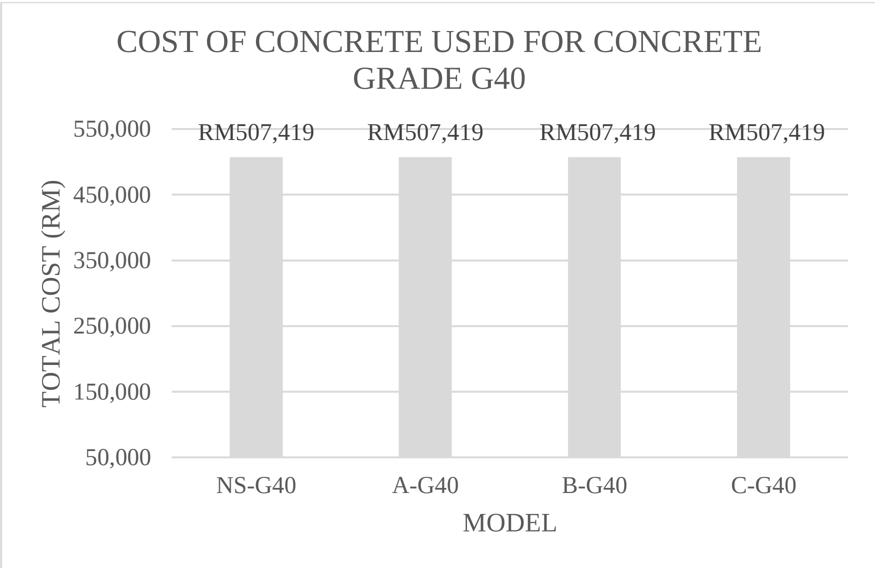

Figure 4.25 Cost of Concrete Used for Beams and Columns for Concrete Grade G40

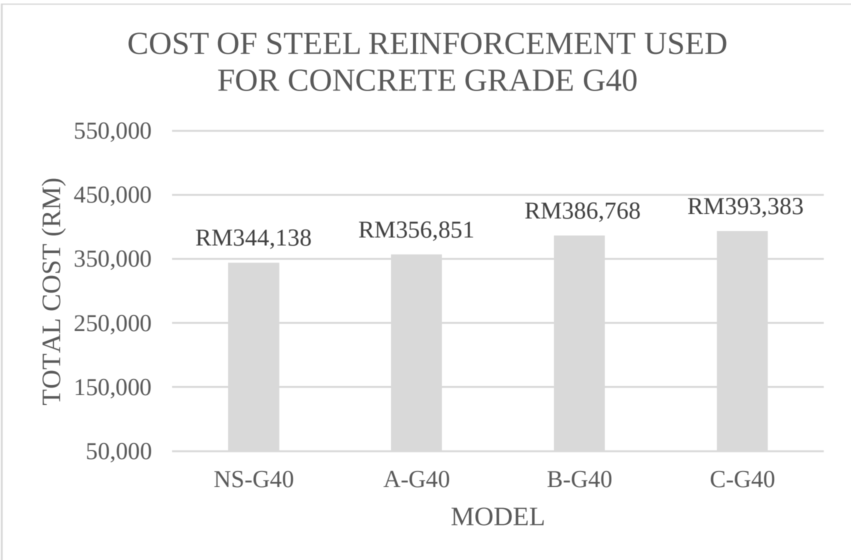

Figure 4.26 Cost of Steel Reinforcement Used for Beams and Columns for Concrete Grade G40

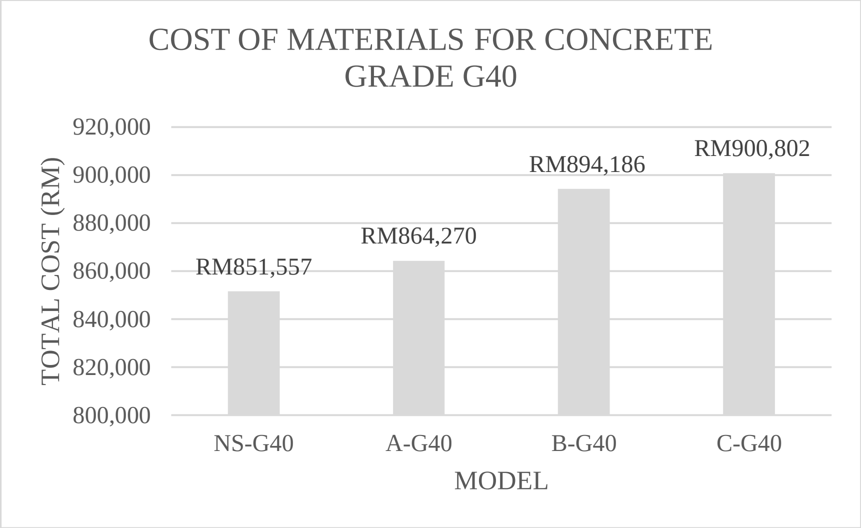

Figure 4.27 Total Cost of Materials Used for Beams and Columns of RC Hospital Building for Concrete Grade G40

As in the Figure 4.25, the cost of concrete used for beams and columns is similar for all model because of the same size of beams and columns used in all model. From Figure 4.23, it can be concluded that the graph is increase linearly. Obviously the increment of estimated cost for steel reinforcement used for beams and columns is strongly influenced by the steel weight. From Figure 4.26, the cost of steel reinforcement used for beam and column increase around 3.7% to 14.3% when compared to the non-seismic design. For further detail, the increment is equal to 3.7%, 12.4% and 14.3% when built on Soil Type A, Soil Type B and Soil Type C, respectively. As in the Figure 4.24, the total cost of materials used for beam and column increase around 1.5% to 5.6% when compared to the non-seismic design. For more detail, the increment is equal to 1.5%, 5.0% and 5.6% when built on Soil Type A, Soil Type B and Soil Type C, respectively. It can be concluded that non seismic model has the lowest amount of total cost of materials used for RC hospital building when it built using Concrete Grade G30 while Soil Type C is the highest amount of total cost of materials used for RC hospital building when the building is built using Concrete Grade G30.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This research studies about the influenced of Soil Type and Concrete Grade on amount of steel reinforcement used for reinforced concrete (RC) hospital building with seismic design. The non-seismic design was also carried out as the comparison to the seismic design. The total of eight sets of 8 storey RC hospital building have been used as the models in order to achieve the objective of this research. The building was assumed constructed on three different types of soil which are Soil Type A, Soil Type B and Soil Type C by using two different grade of concrete which are concrete grade G30 and concrete grade G40. The models also designed with peak ground acceleration (PGA) of 0.08g, ductility class medium (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. The conclusion reached from this research are listed as follows.

1) The amount of steel reinforcement for RC hospital building with seismic design when built on Soil Type C is higher compared to the other models built on other Soil Type and non seismic design model. Based on the overall beam and column element for the whole building, it shows the total amount of steel reinforcement for the beam and column element for Soil Type C is about 10.8% higher compared to the non seismic design which need about 126388 kg of steel reinforcement when constructed by using grade of concrete G30. While for concrete grade G40, it 14.3% higher and need about 112395 kg of steel reinforcement. Thus, it proves that Soil Type C with seismic design consideration required large amount of steel reinforcement since its soil texture is the softer compared others and according to

Ground Type of Eurocode 8 (2004), it can be considered as deep deposits of dense or medium dense sand, gravel or stiff clay. In addition, the total cost of materials for RC hospital building built in Soil Type C is higher compared to other model built on other Soil Type and non seismic model.

2) As for the influenced of grade of concrete, for beam and column element of the whole building, the amount of steel reinforcement for RC hospital building for G40 required about 12.4% lower than grade of concrete G30 when built on Soil Type C with seismic design consideration. Grade of concrete G30 and grade of concrete G40 required about 126387.64 kg and 112395.18 kg of steel reinforcement, respectively. While for non seismic design building which considered no seismic design consideration, the concrete grade G30 is 16.0% higher than concrete grade G40. Thus, the building required more amount of steel reinforcement when constructed by using concrete grade G30 either with or without seismic design consideration. Concrete Grade G30 required more steel reinforcement since its compressive strength is lower than grade of concrete G40 which is 30 MPa while for Concrete Grade G40 is 40 MPa, respectively. It proves that when Concrete Grade is higher, the compressive strength also become more strong and it do not require a large amount of steel reinforcement to support it since its compressive strength of the concrete itself can cover up the strength to hold the building structure.

5.2 Recommendation for further research

There are several recommendations can be considered in order to improve the study of seismic design. This research can be further enhanced by the following recommendations:

1. This research could be conducted by using others Soil Type based on Eurocode 8 (2004) which is Soil Type D and Soil Type E by using same model.
2. Different values of Concrete Grade also should be considered.
3. Since this research only is focus on beam and column element, further study for other elements such as slab and foundation should be carried out.

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APPENDIX A
SEISMIC HAZARD MAP OF MALAYSIA

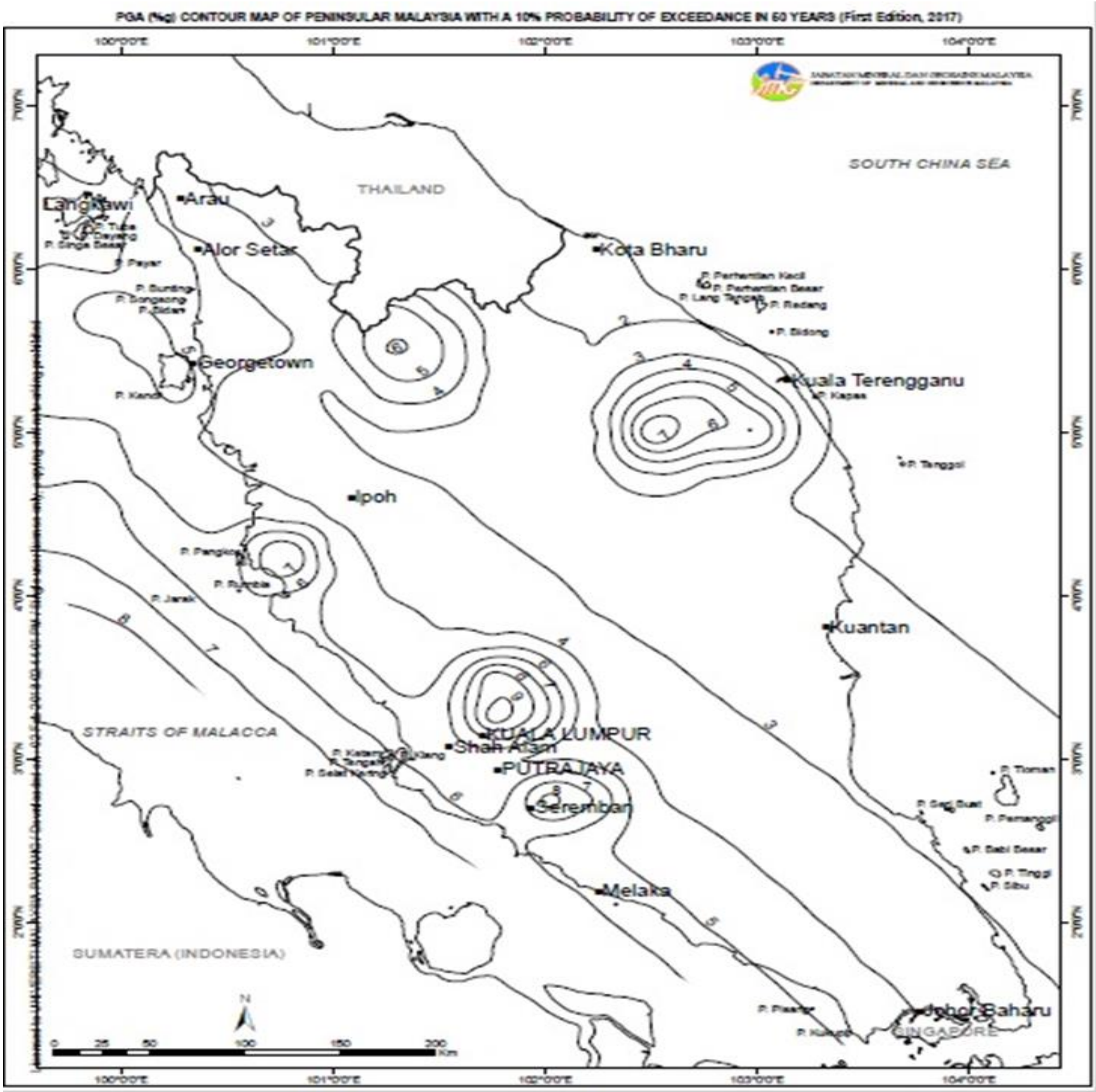

Figure A1 Seismic Hazard Map of Peninsular Malaysia

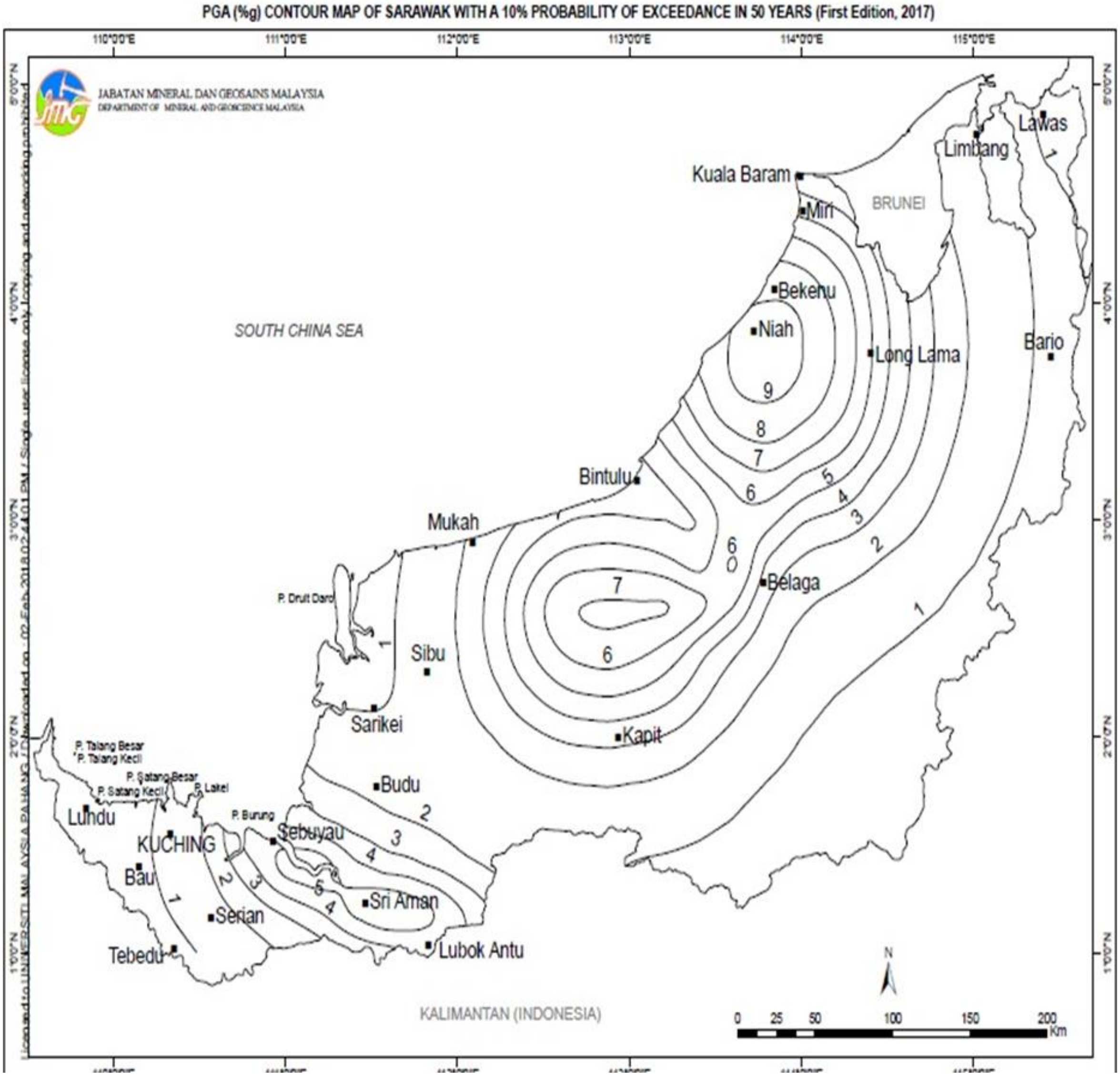

Figure A2 Seismic Hazard Map of Sarawak

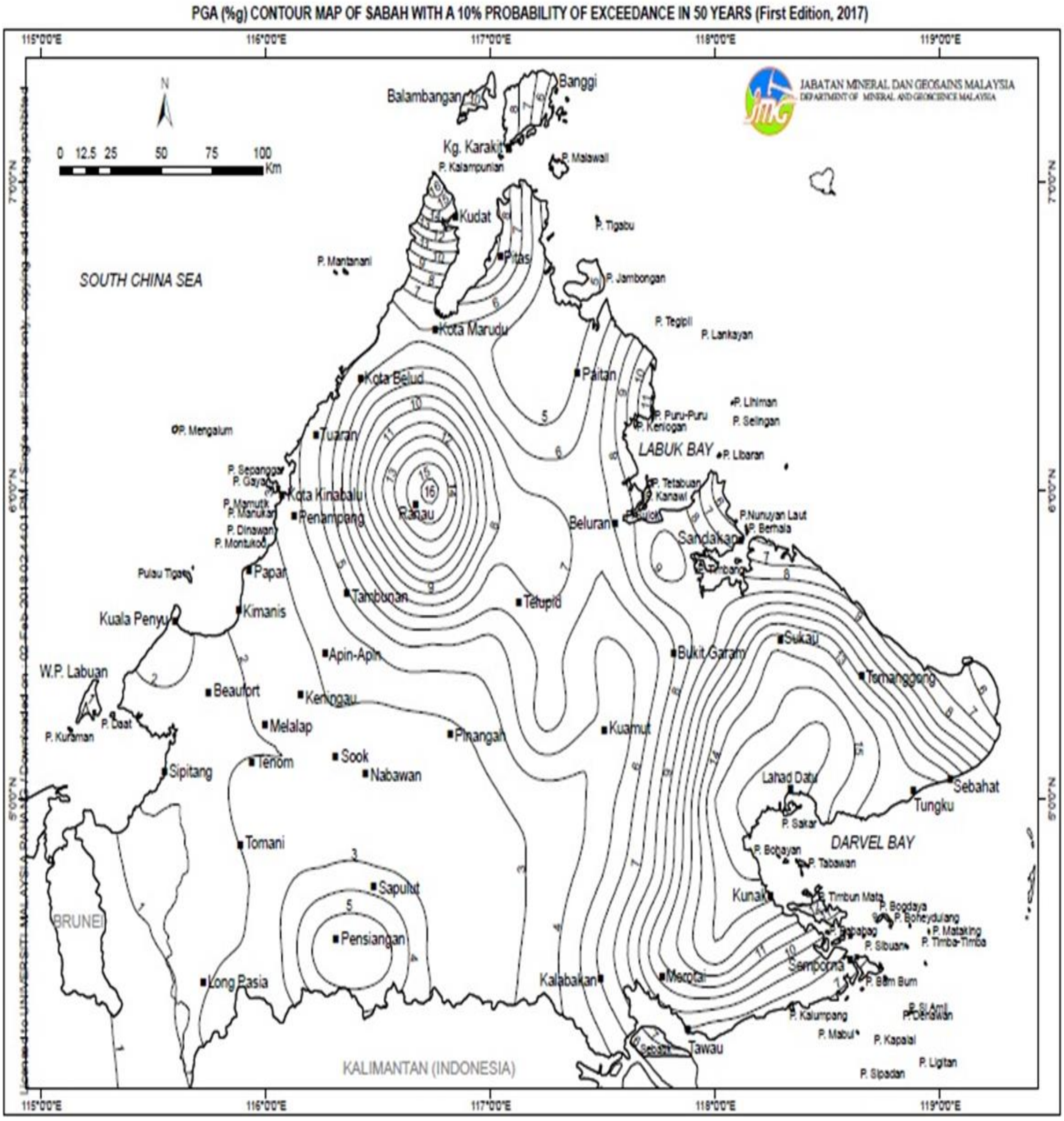

Figure A3 Seismic Hazard Map of Sabah

APPENDIX B

LOCATION OF BEAM AND COLUMN

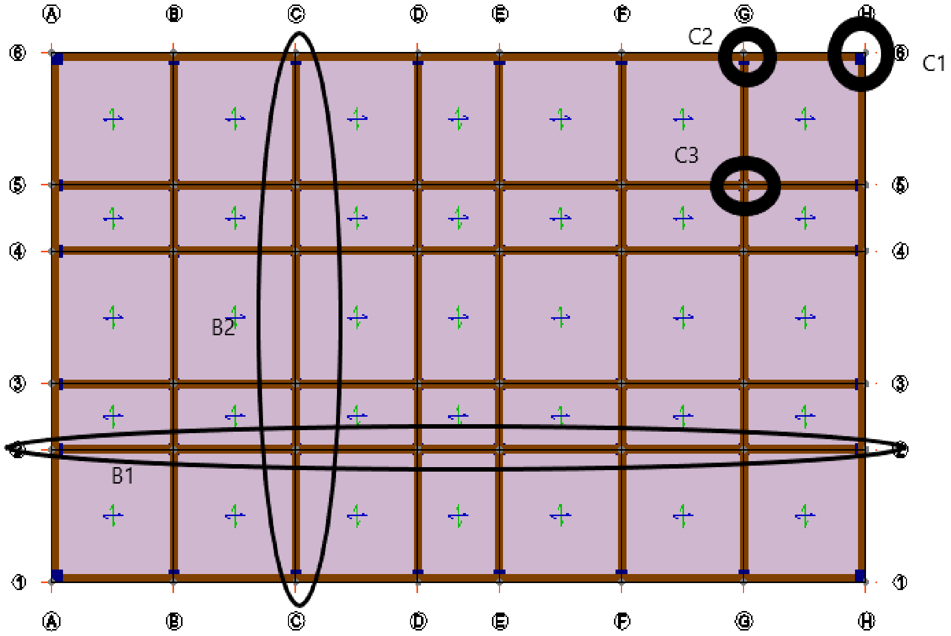

Figure B1 Location of Beam B1, Beam B2, Column C1, Column C2 and Column C3

APPENDIX C

EFFECT OF SOIL TYPE ON AMOUNT OF STEEL REINFORCEMENT

GRADE OF CONCRETE G30

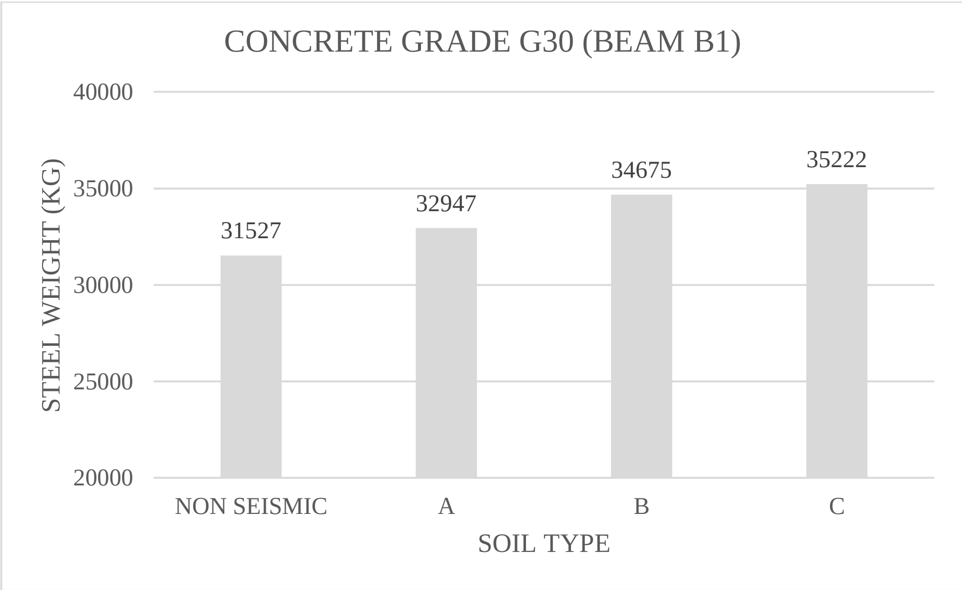

Figure C1a Total amount of steel reinforcement of Beam B1 influenced by Soil Type

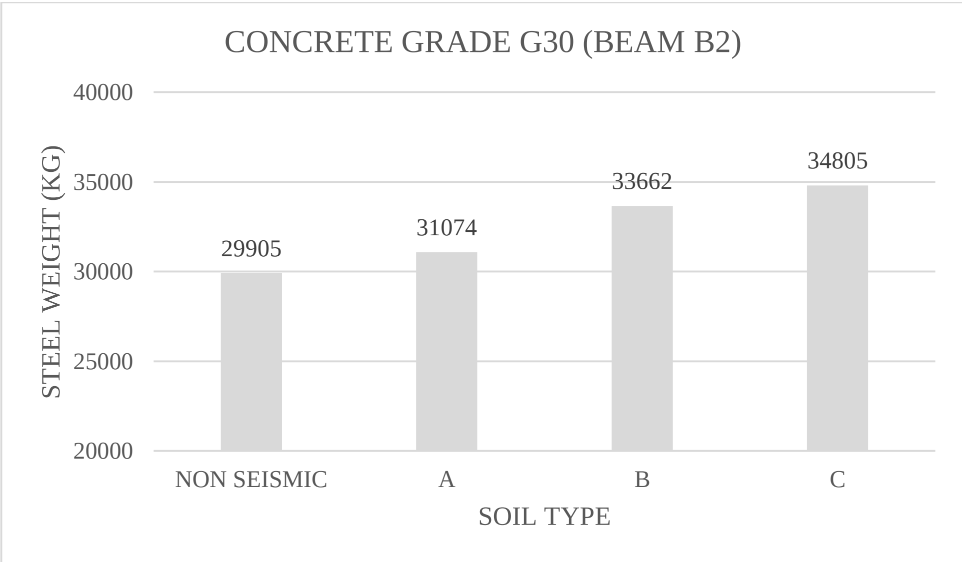

Figure C1b Total amount of steel reinforcement of Beam B2 influenced by Soil Type

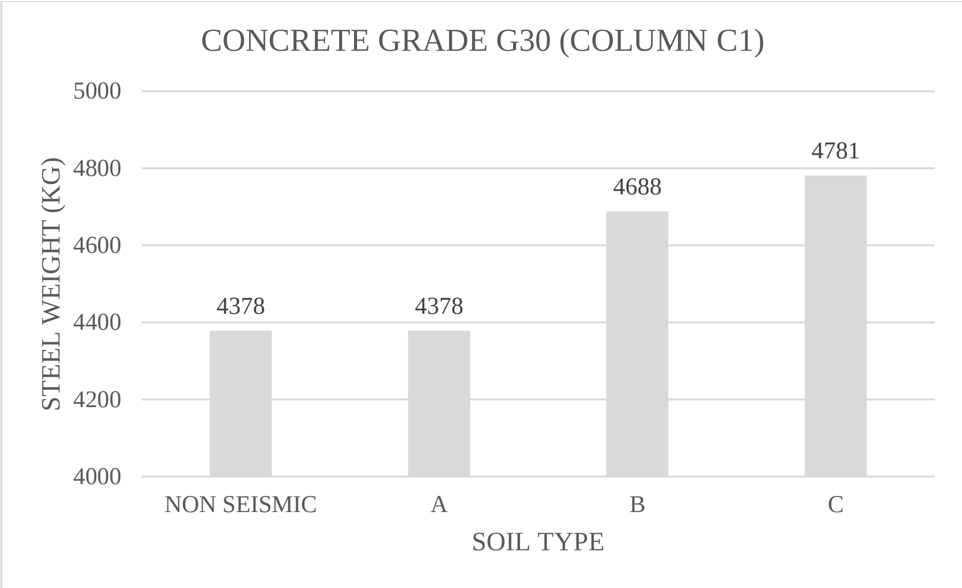

Figure C1c Total amount of steel reinforcement of Column C1 influenced by Soil Type

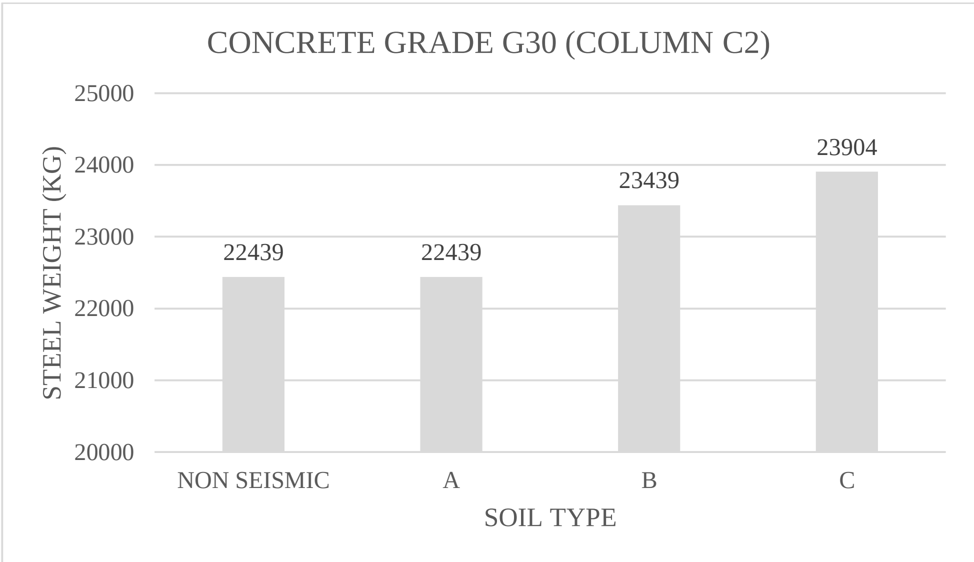

Figure C1d Total amount of steel reinforcement of Column C2 influenced by Soil Type

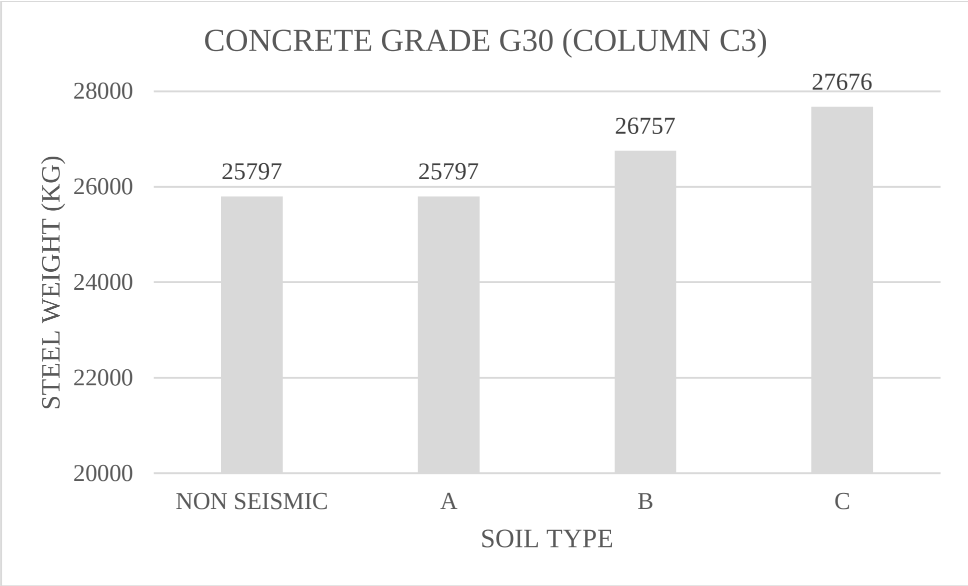

Figure C1e Total amount of steel reinforcement of Column C3 influenced by Soil Type

GRADE OF CONCRETE G40

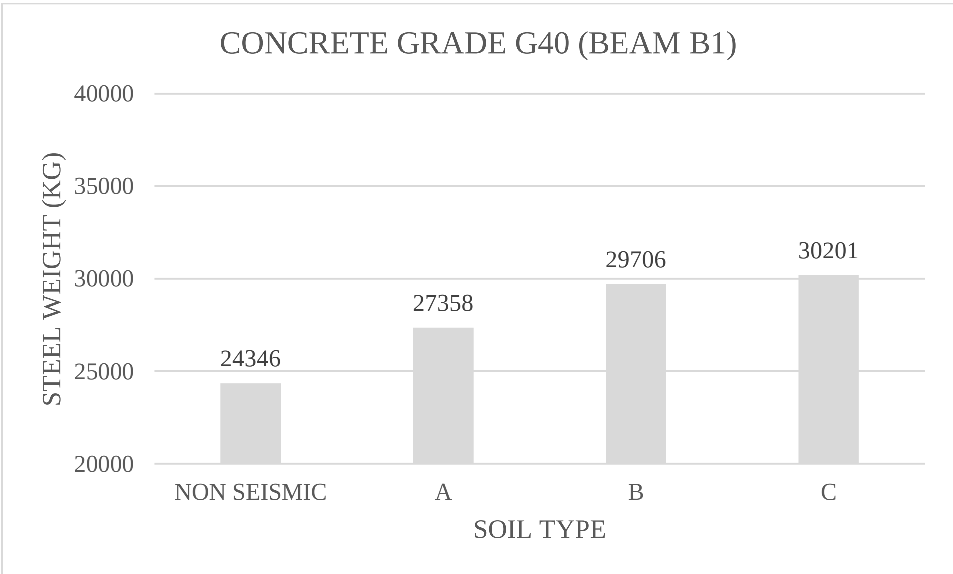

Figure C2a Total amount of steel reinforcement of Beam B1 influenced by Soil Type

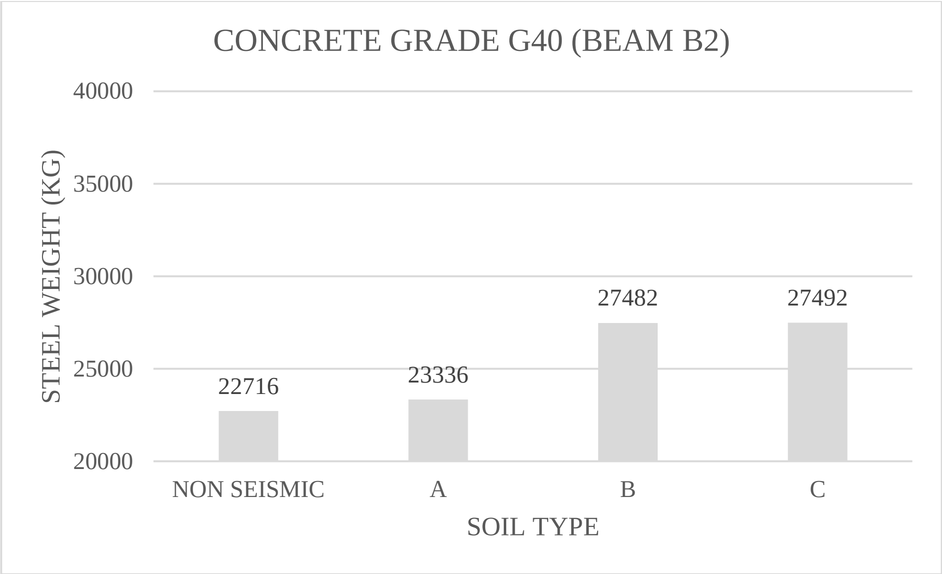

Figure C2b Total amount of steel reinforcement of Beam B2 influenced by Soil Type

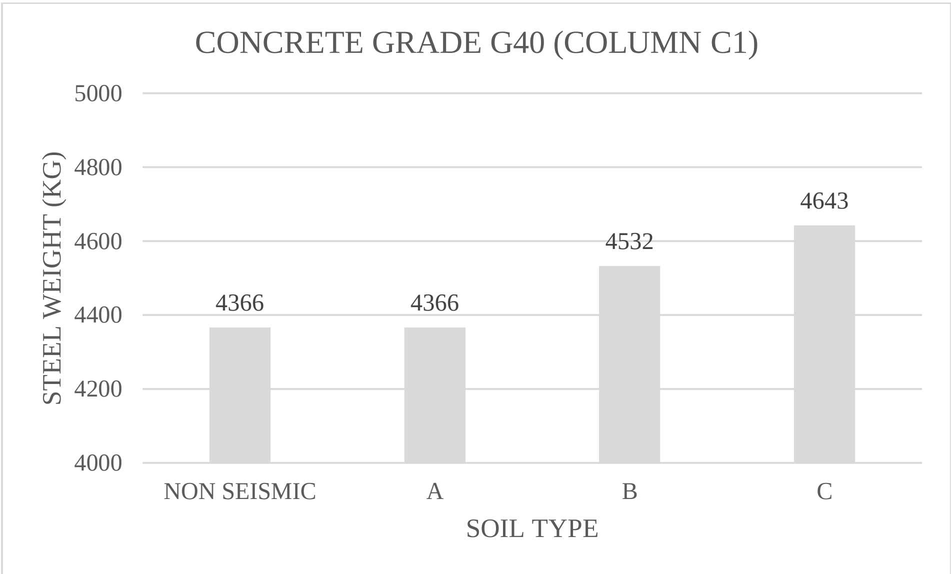

Figure C2c Total amount of steel reinforcement of Column C1 influenced by Soil Type

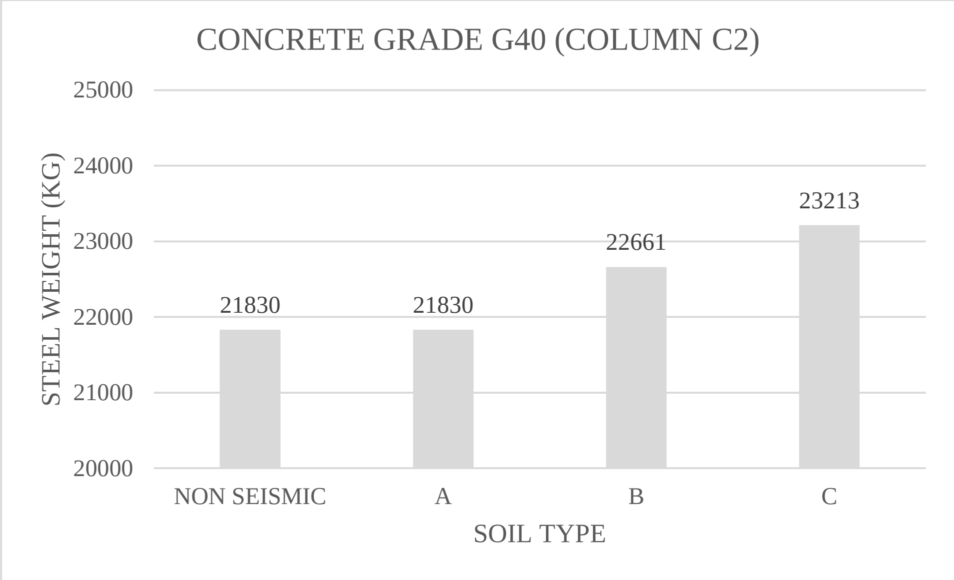

Figure C2d Total amount of steel reinforcement of Column C2 influenced by Soil Type

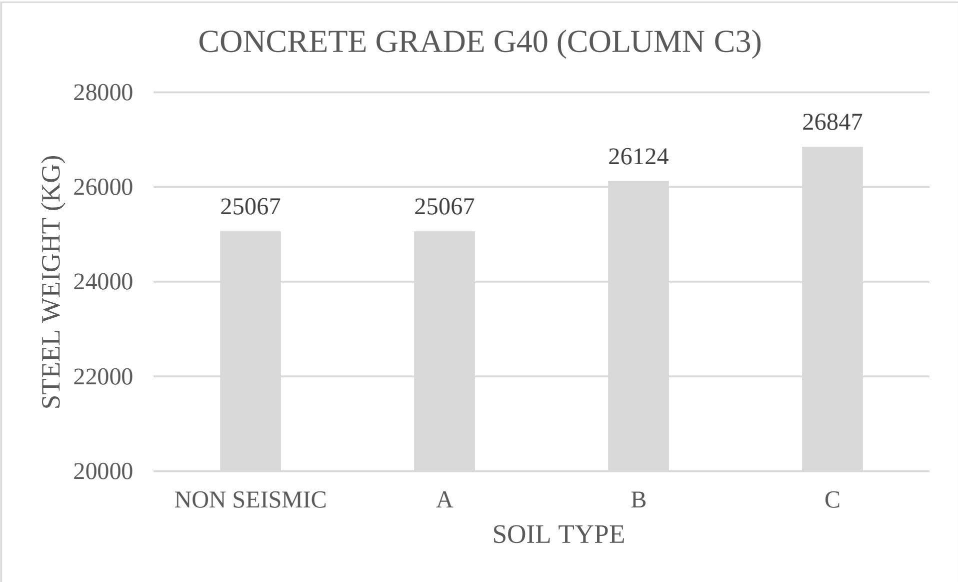

Figure C2e Total amount of steel reinforcement of Column C3 influenced by Soil Type

APPENDIX D

EFFECT OF CONCRETE GRADE ON AMOUNT OF STEEL REINFORCEMENT

SOIL TYPE A

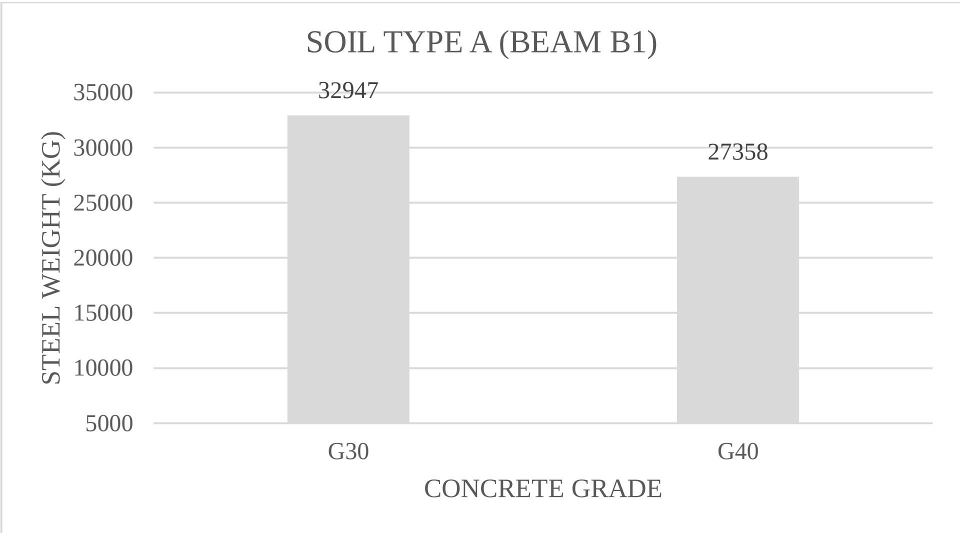

Figure D1a Total amount of steel reinforcement of Beam B1 influenced by Concrete Grade

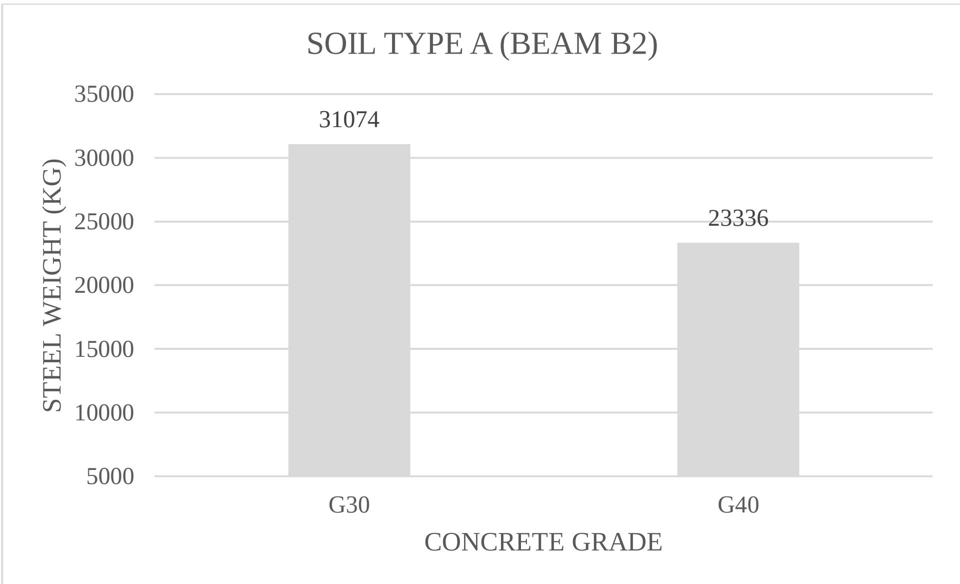

Figure D1b Total amount of steel reinforcement of Beam B2 influenced by Concrete Grade

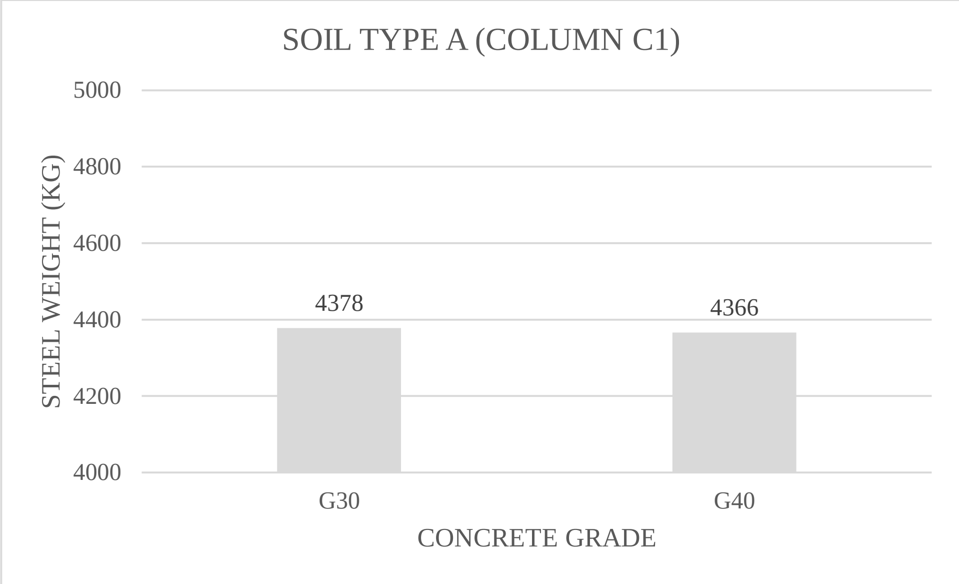

Figure D1c Total amount of steel reinforcement of Column C1 influenced by Concrete Grade

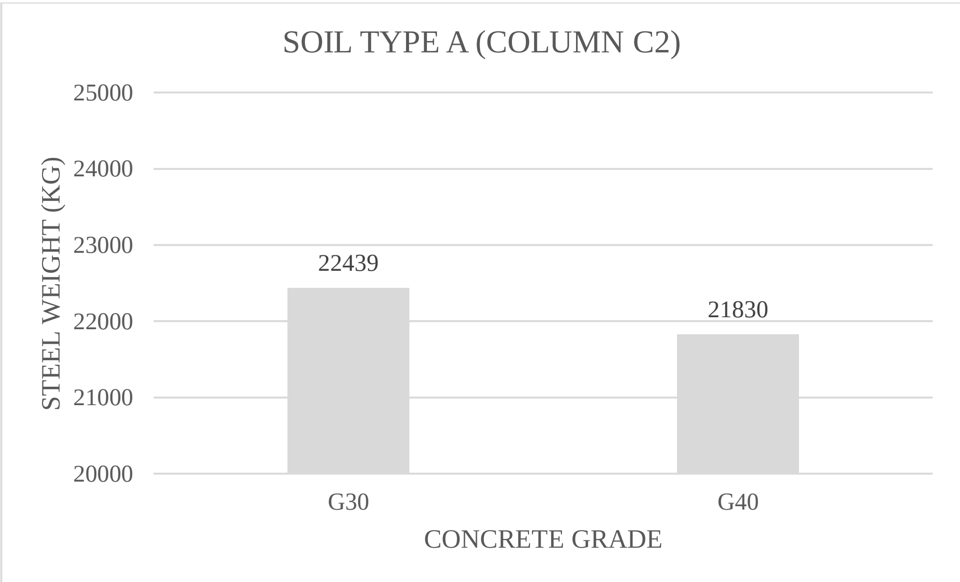

Figure D1d Total amount of steel reinforcement of Column C2 influenced by Concrete Grade

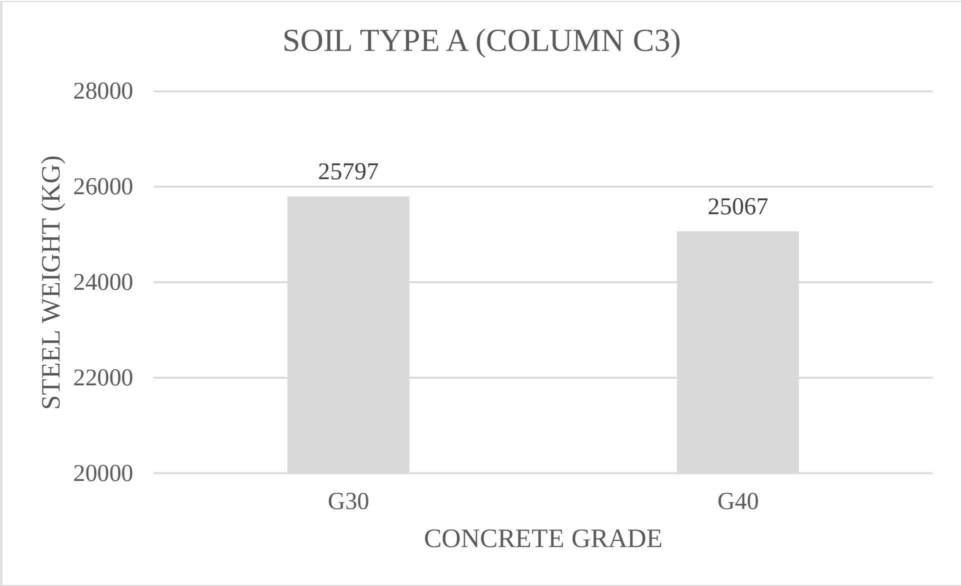

Figure D1e Total amount of steel reinforcement of Column C3 influenced by Concrete Grade

SOIL TYPE B

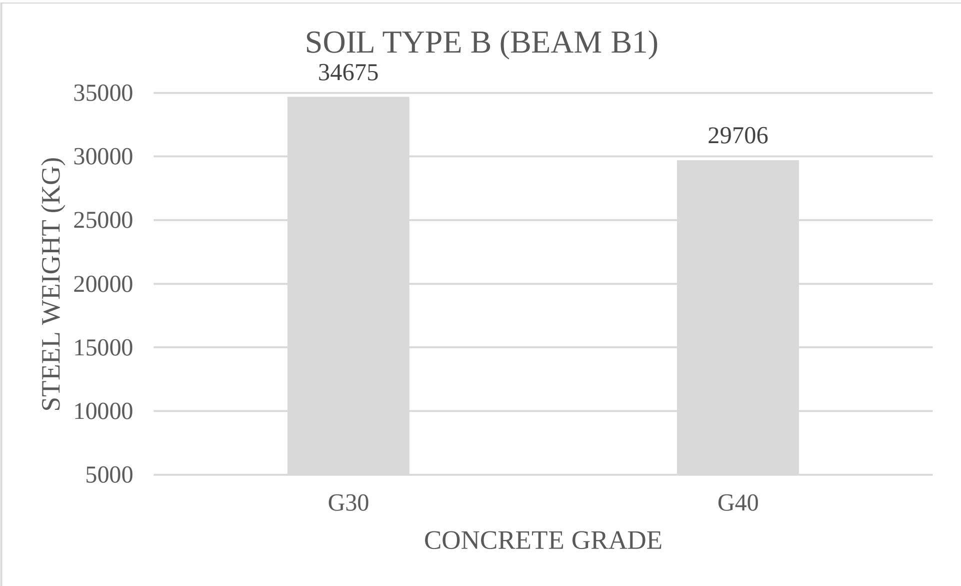

Figure D2a Total amount of steel reinforcement of Beam B1 influenced by Concrete Grade

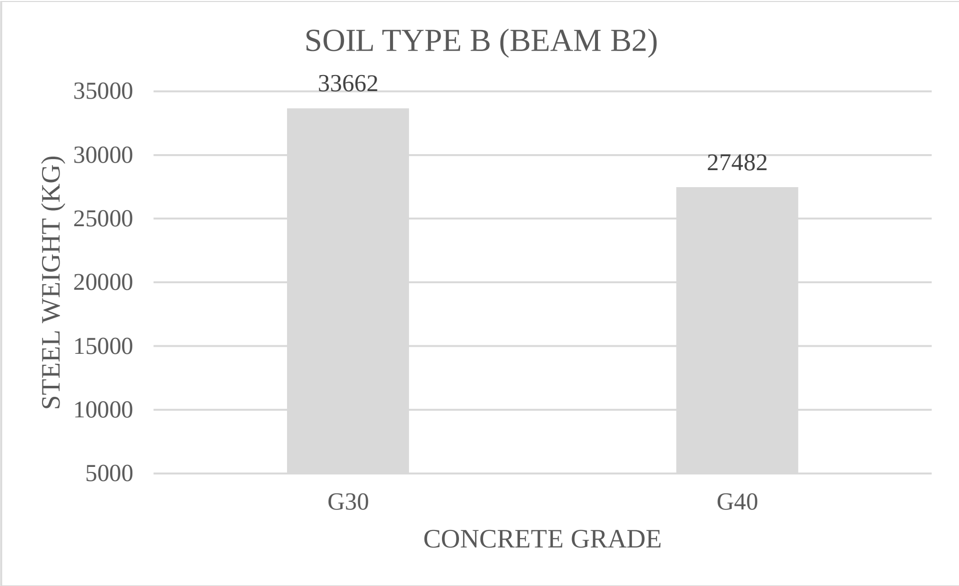

Figure D2b Total amount of steel reinforcement of Beam B2 influenced by Concrete Grade

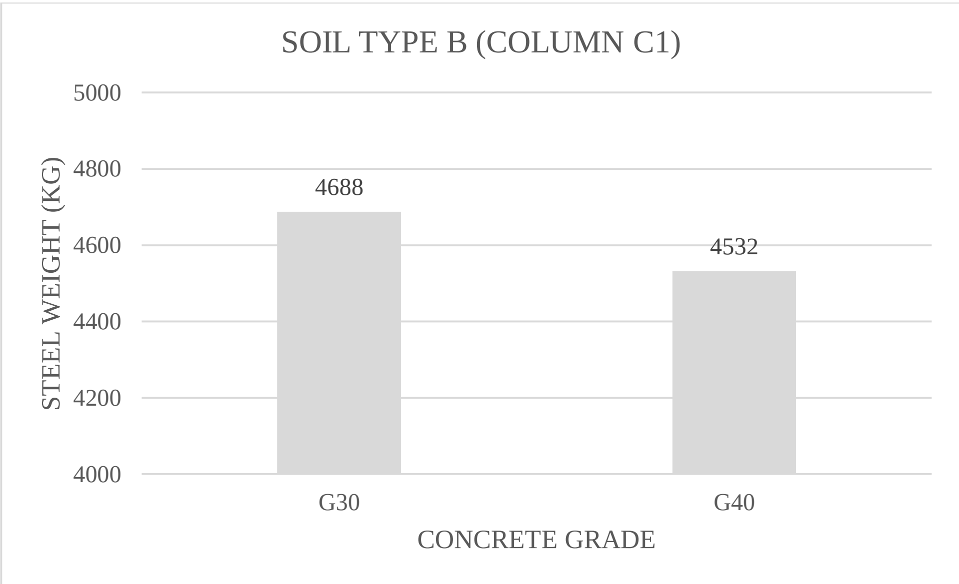

Figure D2c Total amount of steel reinforcement of Column C1 influenced by Concrete Grade

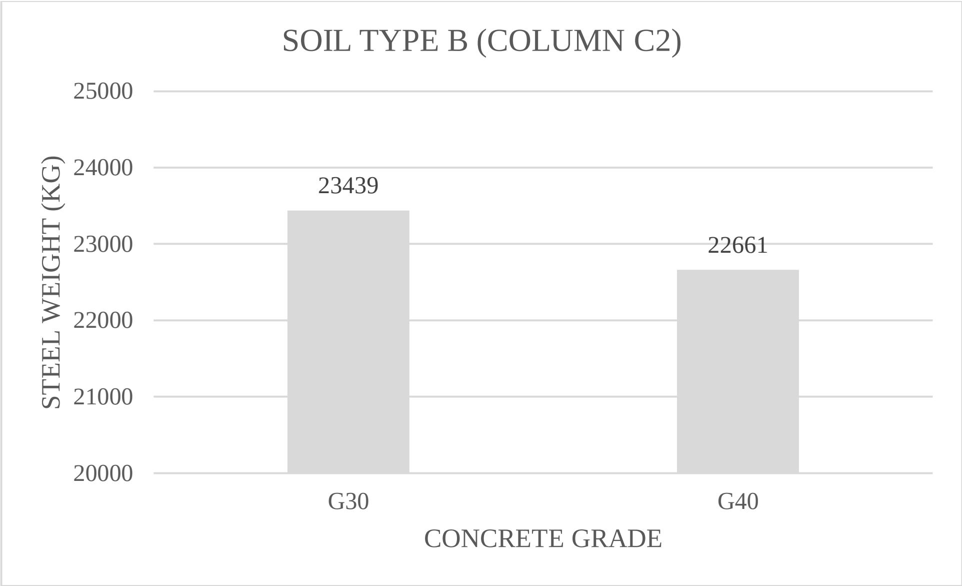

Figure D2d Total amount of steel reinforcement of Column C2 influenced by Concrete Grade

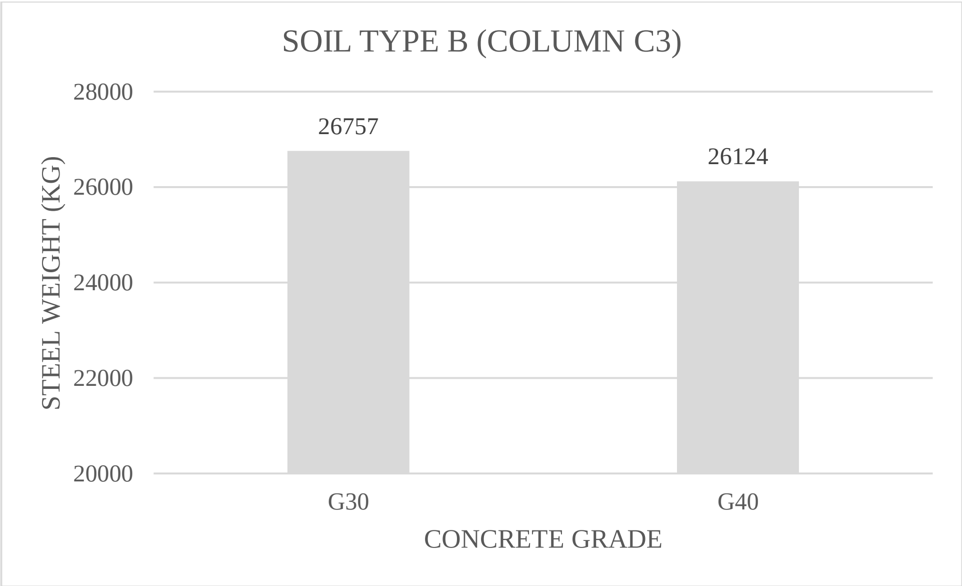

Figure D2e Total amount of steel reinforcement of Column C3 influenced by Concrete Grade

SOIL TYPE C

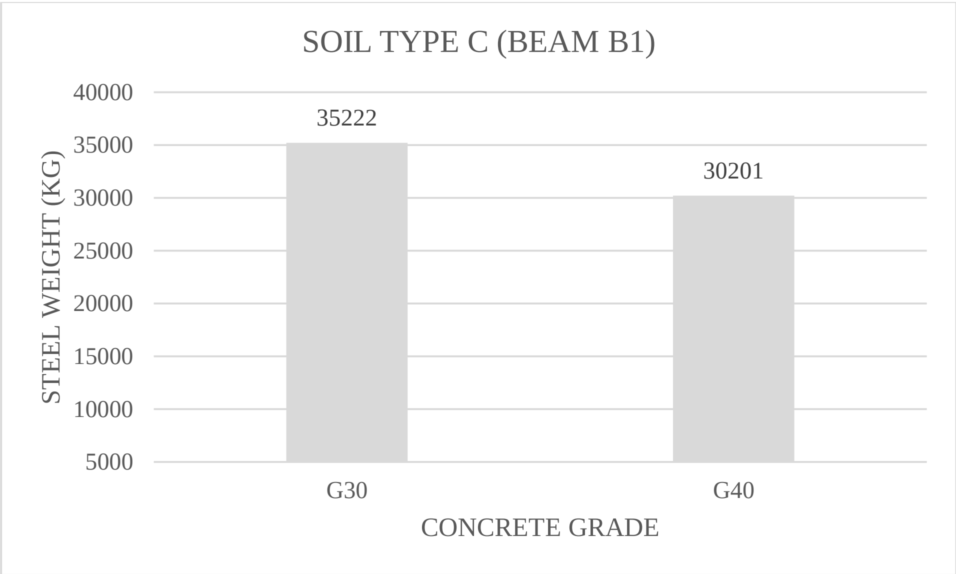

Figure D3a Total amount of steel reinforcement of Beam B1 influenced by Concrete Grade

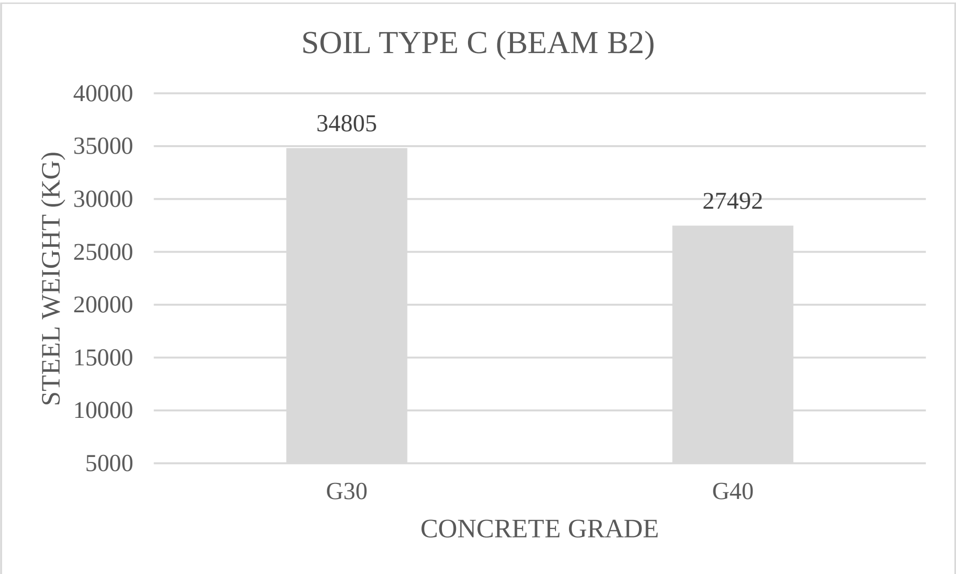

Figure D3b Total amount of steel reinforcement of Beam B2 influenced by Concrete Grade

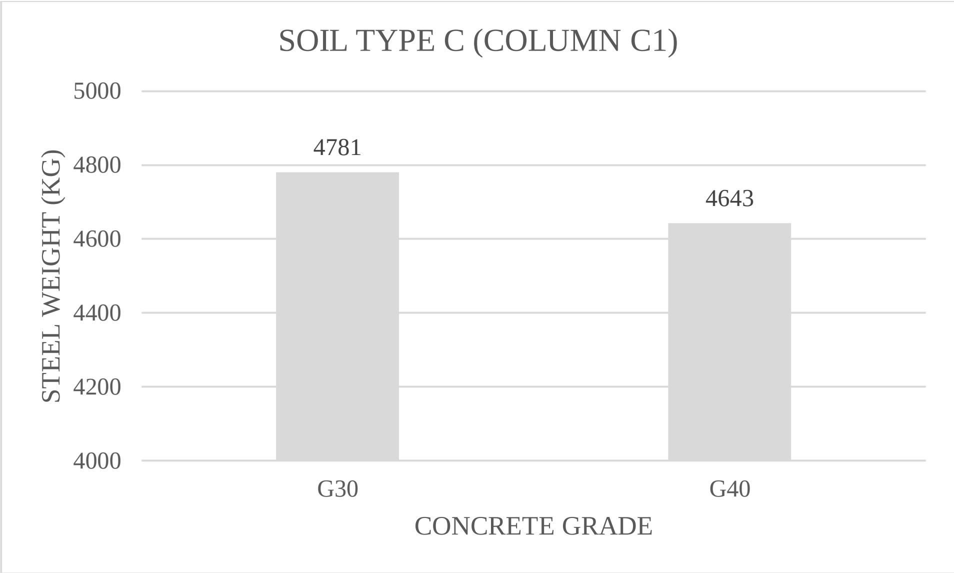

Figure D3c Total amount of steel reinforcement of Column C1 influenced by Concrete Grade

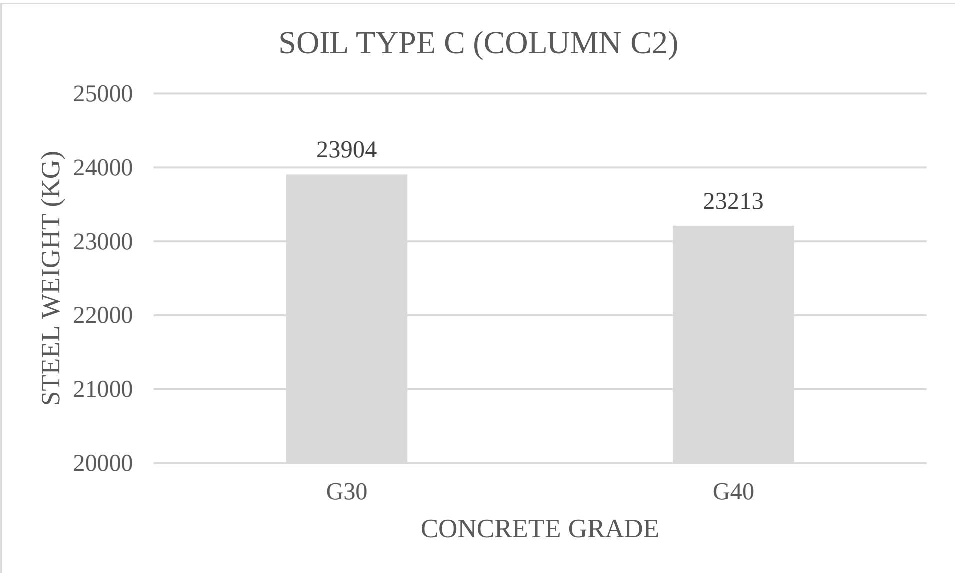

Figure D3d Total amount of steel reinforcement of Column C2 influenced by Concrete Grade

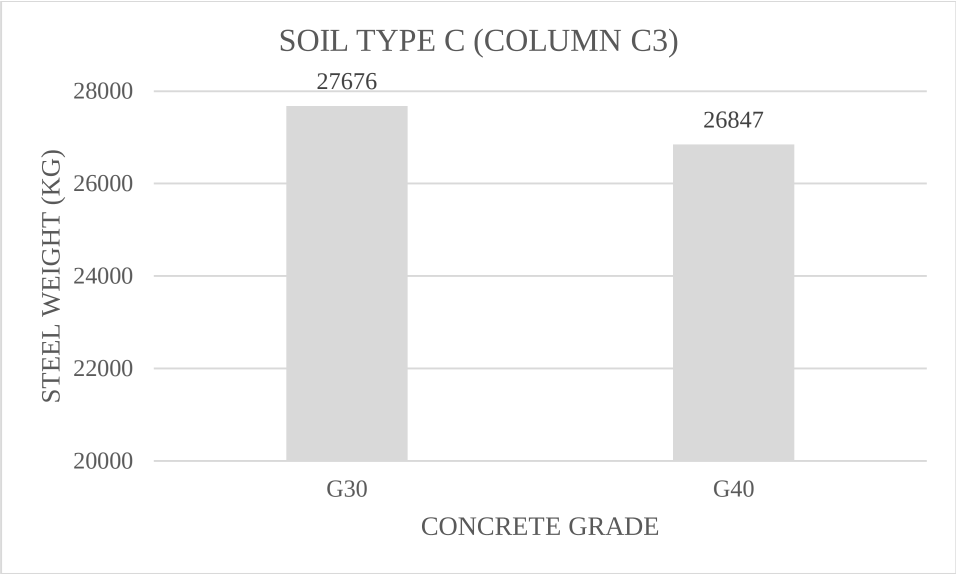

Figure D3e Total amount of steel reinforcement of Column C3 influenced by Concrete Grade