EFFECT OF SOIL TYPE AND GRADE OF CONCRETE ON AMOUNT OF STEEL FOR REINFORCED CONCRETE HOSPITAL BUILDING WITH SEISMIC DESIGN

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SYAQIERAH TANG BINTI SAKA

Thesis submitted in fulfillment of the requirements
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ABSTRAK

Amalan semasa di Malaysia pada masa kini tidak mempertimbangkan langkah berjaga-jaga dalam seismik memandangkan Malaysia tidak terletak di zon seismik yan aktif. Kebanyakan bangunan di Malaysia telah direka bentuk berdasarkan BS8110. Jurutera menganggap Malaysia selamat daripada gempa bumi sehinggalah Jun 2015, Malaysia dikejutkan dengan gegaran yang tidak dijangka dengan magnitu M_w 6.0 pada 7.15 am di Ranau, Sabah. Gegara tersebut turut dirasai di Kundasang, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, dan Kota Belud. Kejadian ini membuka mata dan minda masyarakat tentang risiko gempa bumi. Memandangkan bangunan hospital adalah salah satu struktur yang penting untuk keperluan awam sebagai institut perubtatan dan perlu menampung jumlah orang yang ramai, ia haruslah boleh menahan beban seismik apabila gempa bumi berlaku dan it berkait rapat dengan kekuatan struktur itu. Oleh itu, kajian ini menyiasat jumlah besi tetulang untuk mengukuhkan konkrit bangunan hospital dengan reka bentuk seismik. Analisis dijalankan dengan menggunakan empat jenis tanah dan dua gred konkrit. Semiblan model digunakan untuk analisis yang direka bentuk berdasarkan Eurocode 8 dan dijalankan dengan menggunakan Tekla Structural Design Software. Berdasarkan kepada keputusan, ia boleh dikonklusikan bahawa tanah jenis D memerlukan besi tetulang 110% lebih tinggi bila dibandingkan dengan bangunan tanpa reka bentuk seismik apabila dibangunkan dengan menggunakan gred konkrit G30. Sementara itu, untuk pengaruh gred konkrit, gred konkrit G30 memerlukan lebih banyak besi tetulang daripada gred konkrit G40 sekitar 41.8% apabila struktur dibina di atas tanah jenis D. Oleh itu, jenis tanah dan gred konkrit perlu dipertimbangkan untuk bangunan yang menggunakan reka bentuk seismik.

ABSTRACT

Current practice in Malaysia nowadays is not consider the seismic precaution since Malaysia is not located in active seismic fault zone. Most building in Malaysia had been designed based on BS8110. Engineers considered Malaysia is safe from earthquake until in June 2015, Malaysia was surprised by an unexpected tremor with magnitude M_w 6.0 on 7.15 am in the morning in Ranau, Sabah. The tremors was felt in Kundasang, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud. This incident open people's eyes and minds about the risk of earthquake. Since hospital building is one of significant structure for public necessity as an 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 hospital building with seismic design. The analysis conducted by using four types of soil and two grades of concrete. There are nine models 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 Soil Type D required steel reinforcement 110% higher when compared to non seismic design when used concrete grade G30. While for the effect of grade of concrete, grade of concrete G30 required more amount of steel reinforcement than grade of concrete G40 around 41.8% when the structure built on Soil Type D. Therefore, type of soil and grade of concrete should be taken into consideration for seismic building design.

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LIST OF SYMBOLS

α_{gR}	Peak Ground Acceleration
q	Behavior 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

ACI	American Concrete Institute
BS	British Standard
DCL	Ductility Class Low
DCM	Ductility Class Medium
DCH	Ductility Class High
FEMA	Federal Emergency Management Agency
IDR	Interstorey Drift Ratio
IMRF	Intermediate Moment Resisting Frame
JKR	Jabatan Kerja Raya
MMI	Modified Mercelli Intensity
MS	Surface Wave Magnitude
NS	Non Seismic
PGA	Peak Ground Acceleration
PWD	Public Work Department of Malaysia
RC	Reinforced Concrete
SDOF	Single Degree of Freedom
UBC	Uniform Building Code
USGS	U.S. Geological Survey

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake is an unexpected situation happen where the earth are rolling and shaking suddenly in an area or space. Over 900,000 earthquake event occurred worldwide every year. This is caused by sudden slip of the fault where the sides of the fault pushed together by the stress in the earth's outer layer. Fault is a point of broken large pieces crust and mantle which the top layer of earth called plates meet each other. Plates also known as several pieces of the planet or earth's crust which is placed under the sea. The motion of the mantle (deepest part of the earth) caused the plates moved around. The movement speed of the plates such as pulling away and bumping each other is same as the speed of our nail growth. Figure 1.1 depicts the two block of earth slip past one another during earthquake.

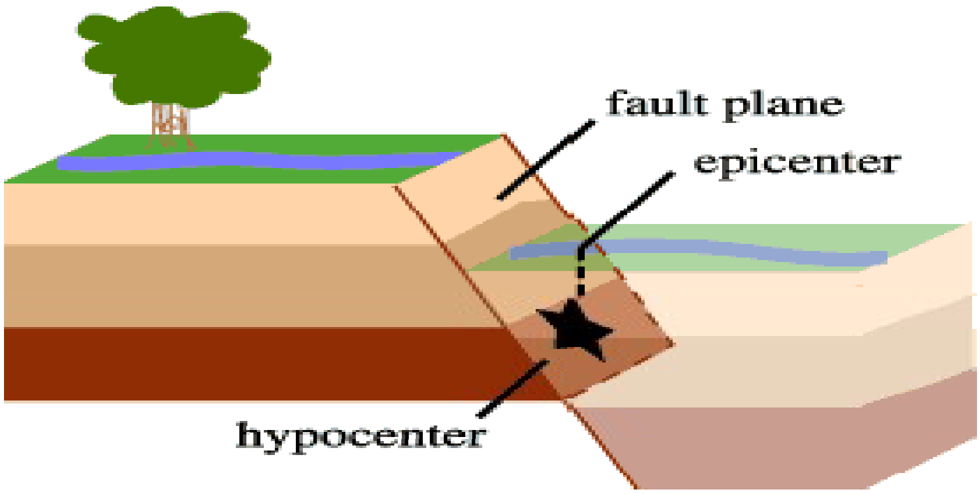

Figure 1.1 Slip of two block of earth during earthquake
(https://earthquake.usgs.gov/learn/kids/eqscience.php)

“Earthquakes don’t kill people, buildings do”. This quotes is from seismologist who believe that the human construction and buildings crashing down during earthquakes are the cause of the most deaths (SMS Tsunami Warning, 2017). The vibrations caused by the movement of the plates bring bad impacts to the earth surface. The main effect of earthquake that we can see clearly based on our daily life is people may lost their sources of income while wild life lost their habitat. Meanwhile, buildings, roads, retaining walls, and bridges are few examples of man-made structure that may affected by this natural disaster. Breakable characteristic in concrete and masonry structure influence their potential to damage and collapse, for steel and timber structures, they have far less damage because of their flexibility characteristic acted during hit by any motion or vibration. This situation also may contributes to lots of injury and fatality, lost of property, fire, flooding, and the most affliction is it can induce tsunami.

Seismology, a derived Greek word which means “to shake” is a study of seismic waves. Seismic waves is a shock waves that released energy where it can be felt and measured. One of instrument that can record the earthquakes is seismographs which also known as a simple pendulum. Seismogram is the record of the pendulum displacement changes over time produced by this instrument when it works as the vibration applied to it, where the inertia keeps pendulum bob in place as shown in Figure 1.2. Earthquake magnitude can be measured by using Richter Scale numbered 0 to 10 where it is a standard scale used to measure earthquake magnitude.

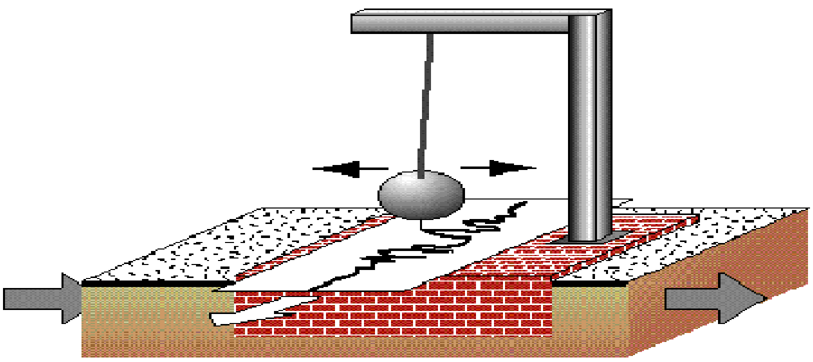

Figure1.2 A Seismograph (http://www-sms-tsunami-warning.com/pages/seismology-measurement#.WgURkGiczIU)

In Malaysia, most of the tremors occurred due to Sumatra Andaman and Philippines earthquakes. This is because of their region is lies at the boundary of two of Earth's tectonic plate (Majid, 2017). According to Minerals and Geoscience Department of Malaysia (2006), Malaysia belongs to the low seismicity group, except for the state of Sabah. In 1976, magnitude earthquake struck in Lahad Datu, Sabah, which caused lots of property damage and cracked building. Between the period, 16 earthquakes recorded at Sabah. 4 out of that 16 tremors occurred in Ranau, Sabah, which is in 1989 with magnitude M_w 5.6, in 1991 with magnitude M_w 5.1, in March 2005 with magnitude M_w 4.1 and M_w 2.6 in Febuary 2010. A study of Research and Innovation Centre of Universiti Malaysia Sabah find out that even though Sabah not located in the Pacific Ring of Fire, few area included of Kundasang, Ranau, Pitas, Lahad Datu, Kunak, and Tawau have high risk to be hit by earthquake activities.

Since Malaysia is not located in active seismic fault zones, majority of buildings in Malaysia had been designed according to BS8110 (1997), which not specify any seismic provision (Adiyanto, 2014). Engineers considered Malaysia is safe from earthquake and current practice in structure design not include any seismic precaution until in June 2015, Malaysia was surprised by an unexpected tremor with magnitude M_w 6.0 on 7.15 am in the morning in Ranau, Sabah. This incident jolted the Malaysia's Mount Kinabalu caused fatality of public 11 hikers and another 8 hikers was missing. It also damaged the Donkey's Ear, the pride symbol of Mount Kinabalu. This earthquake also felt by West Coast Sabah people included of Tambunan, Tuaran, Kota Kinabalu, and Kota Belud. Weak aftershocks occurred about 47 times around M_w 2.2 to M_w 3.3. The quake alerting the Malaysian engineers about the earthquake awareness on building structure. Figure 1.3 shows the location of 2015 Ranau Earthquake.

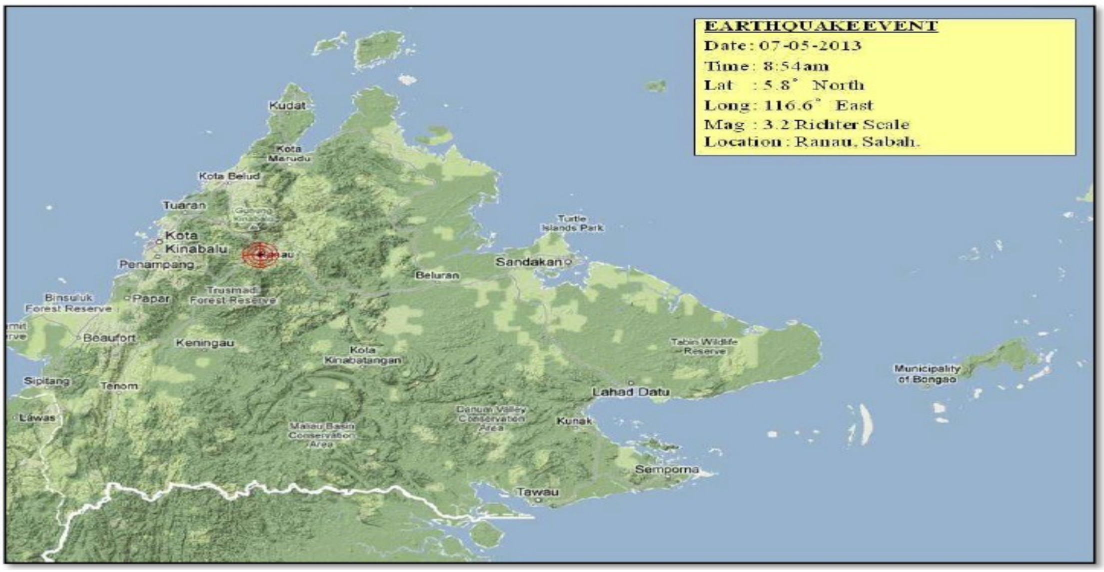

Figure 1.3 Earthquake at Sabah on 5 June 2015 (http;//www.met.gov.my/)

Few study in earthquake engineering stated that seismic activity happen effected by various factor. One of them is Soil Type. Type of soil become one of factor that influence in seismic design because different Soil Type have different amplification factor by referring Eurocode 8 (2004). Having different grade of concrete used in reinforced concrete (RC) design also give impact in seismic design. Different concrete grade also have its own strength. It is possible to be one of factor should be consider in designing earthquake resistant building.

1.2 Problem Statement

High seismicity regions is strongly associated with the subduction zones between the Eurasian and Philippines plates at the east part (Pappin et al. , 2011). This review can tell us that high seismicity regions surrounded 3 out of 4 main divided parts of Malaysia which is east, west, and south. Yet, local authorities in Malaysia still didn’t realize the importance of considering seismic action in design and construction.

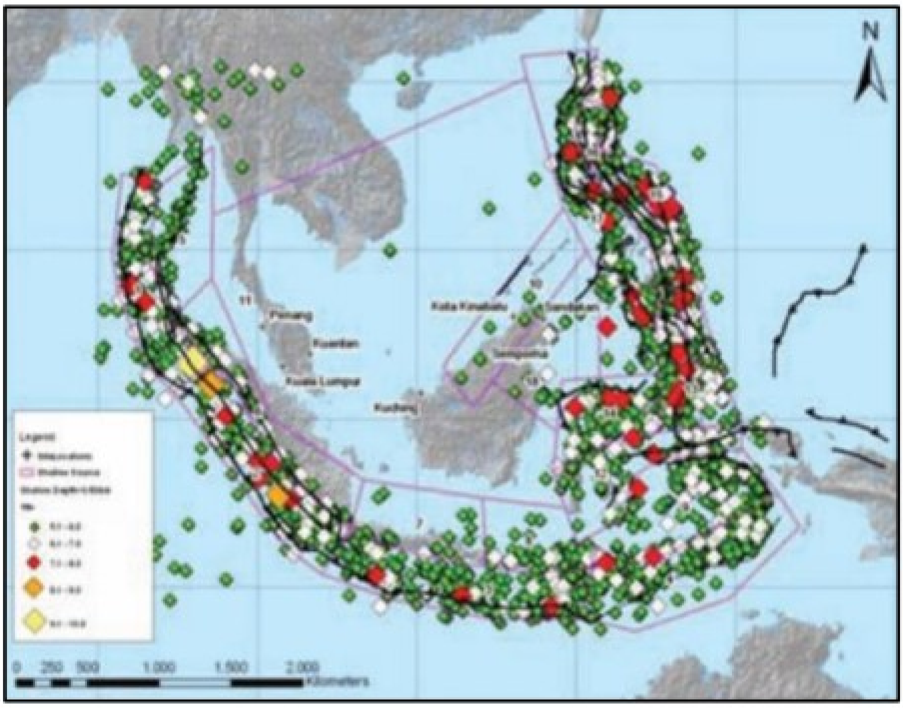

Figure 1.4 Earthquake events since 1972 to a depth of 50 km (Pappin et al., 2011)

The 5th June 2015 disaster open people's eyes and minds about risk of earthquake. Unexpected natural disaster which can happen anytime without warning or sign. The 6.0 Richter scale earthquake hit Ranau, Sabah, which lasted for 30 seconds announced as the strongest earthquake in Malaysia since 1976. It caused fatalities and property and structure damage. 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 Adiyanto (2016), mostly RC moment resisting frame buildings were constructed and used widely in Malaysia compared to steel, timber, and masonry wall system. This type of building can be found anywhere and for various type of function, from residential to working places and other public assembly. RC hospital building is one of significant structure for public necessity as an institution which provide medical and surgical treatment service and consist of few parts including clinics and wards. The buildings need to accommodate a lot of people and must be able to resist seismic load whenever earthquake happen. In designing hospital building, it has its own properties and specification which need to follow properly along the process 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 purpose.

Seismic design of structure aims at ensuring, in the event of occurrence of a reference earthquake, the protection of human lives, the limitation of damage to the structures, and operational continuity of constructions important for civil safety (Elghazouli, 2009). Since hospital building consist a lot of people especially for people who need special help and care, the design of the building should be protective enough from earthquake event or any natural disaster. 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. In Malaysia, existing RC hospital building had been designed based on BS8110 (1997) without consideration of seismic action.

The strength of soil which based on Soil Type 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 most important but less controllable aspects is to know the real state of the local soil conditions. Depending on the stiffness characteristics and on the seismic wave velocities, the Soil Type are ones of the main elements in performing a correct seismic design. Base on this study, how many steel need to be used for seismic design influenced by Soil Type can be estimated.

Concrete is a mixture of cement, aggregate, and water with specific ratio. Concrete come with various grade according to their compressive strength. Normally, the grade of concrete used based on type of building constructed. Grade of concrete basically divided into 3 group; ordinary concrete, standard concrete, and high-strength concrete. Normal structure usually using grade 25 (G25) to grade 30 (G30) while for high-rise building use grade 40 (G40) to grade 80 (G80), for example Petronas Twin Tower, Malaysia, which is classified as high performance concrete (40-80 MPa). Concrete grade also affected the amount of steel used for seismic design.

1.3 Objectives

Objective of the study are:

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. A 6 storey RC hospital building used as the basic model.

II. A total of 10 sets of 6 storey RC hospital building had been designed based on different Soil Type (A, B, C, D) and concrete grade (G30 and G40)

III. The Peak Ground Acceleration (PGA) value used is fixed as α_{gR} = 0.10g for all models.

IV. All the models had been designed for ductility class medium (DCM).

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

VI. The comparison is made in term of amount of steel required as reinforcement per $1m^3$ of concrete for every model.

1.5 Thesis Outline

Chapter 1 covers the introduction of this research, the objective to be investigate, and the explanation of the problem statement and the scope of work along this research.

Chapter 2 covers the literature reviews that related with the aspects involved in this research. This chapter is discussing about the analysis of model by considering the Soil Type and grade of concrete.

Chapter 3 describes about the methodology used along the research is conducted. In this chapter also explain about the variables used and aspects to be considered during the analysis. It also explain the step-by-step process of this research clearly from the setup model stage to perform taking off stage.

Chapter 4 discusses the result of this research. This chapter explain the effect of the Soil Type and grade of concrete on amount of steel required per $1m^3$ hospital building based on the analysis results generated by using Tekla Structural Design software. In addition, in this chapter also discuss about the comparison of building with seismic design and non seismic design consideration.

Chapter 5 is all about the summary of the whole single thing in this research which roll all chapter become a conclusion. In this chapter also provide a recommendation for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Earthquake is one of natural disaster happened caused by ground shaking and movement in vibration mode. Safety issues and limit building damage are the main things concerning by people surround although it is just a small movement of the building by the earthquake vibration. Due to the sudden force, it can effect the building structure to undergo displacement from its original position in a short period. If the damage of building and number of people died or injured increase caused by the tremors, each inch of this things will be refer back to the first step before construction of project which is the specification and parameters of seismic performance considered in the RC building design. In this chapter, it will covered literature review from previous study that related and relevant with this current study.

2.2 Earthquake disaster

Vickery (1982) has studied about the school building and natural disaster in this world and in his studies, he stated that earthquake is listed of one of natural disaster. From his studies, the safety aspect become a main priority especially for a school building. All school building in this world that experienced the tremors must be considered the earthquake resistant specification in its designed and constructed which can bring damage by this disaster and may cause lot of injure and fatality after several historical earthquakes disaster attacked and damage the school building. As a result, Peru start to organize a programme of earthquake-resistant in school building.

Majid et al. (2017) has conducted a research about preliminary damage assessment due to 2015 Ranau earthquake. In their research, they stated that several local earthquakes happened at Bukit Tinggi, Pahang on 2007. They believed that most of the tremors expected produced by the Sumatra Andaman and Philippine earthquake. On 5 June 2015, an earthquake with magnitude M_w 5.9 occurred in Ranau, Sabah, reported by Malaysian Meteorological Department where the epicenter located at 16 kilometers northwest from Ranau ad 54 kilometers depth beneath the earth. As reported also, several vibration followed after the main shock called as after-shock. Two days pass after the main shock, a reconnaissance mission took action to identify the buildings damage effected by the earthquake. From the investigation, they detected that the column structures have experienced a serious damage compared to beam structures. The failure mechanism namely as Weak Column-Strong Beam.

Figure 2.1 Significant damage on RC column due to 2015 Ranau earthquake (Majid et. al., 2017)

Figure 2.2 Damage on RC beam-column joint due to 2015 Ranau earthquake (Majid et. al., 2017)

2.3 Earthquake hazard in Malaysia

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.

Mexico City was attack by a tremor with surface wave magnitude (MS) of 8.1 on September 19th, 1985. About 10,000 people had to face loss of property especially their houses and damage in the city (Wikipedia, 2010). Mexico City had severe damage even though the earthquake focused on about 350 kilometers far away from it. Malaysia is situated about 300-600 kilometers from the Sumatron faults that have historically produced large earthquake with ground motions that were felt in buildings in Kuala Lumpur as well in Singapore (Pan et al., 2001). this historical 1985 tragedy can be an effective lesson to tell Malaysian that distant is not a barrier for earthquake disaster effect Malaysia.

Through the Ministry of Science, Technology, and Innovation (MOSTI), Malaysia's government has contributed lot of efforts to approach and overcome the risk related with potential earthquake events since 2005. The Public Work Department of Malaysia (PWD) has collaborated with academicians from various of local universities to authorize relevant seismic design force that can apply in the building design.

In the midst of 1984 and 2007, Peninsular Malaysia experienced weak local earthquake where East Malaysia felt the shakes with magnitude of 3.5 and 6.5 tremors scale recorded. The main shock actually happened at Sumatra, Indonesia which is one of region that has high seismic activity. Even though Sumatra is quite far from Malaysia but still Malaysia can felt the earthquake vibration.

Figure 2.3 A section of the ceiling of Ranau District Mosque that collapsed due to the earthquake (http://www.theborneopost.com/2015/06/07/psychosocial-team-in-ranau-to-help-victims/

Highest ground motions country has recorded by the state of Sabah since 1897 which is 77 tremors events that mostly happened at the local origin contributed by several active faults. The maximum intensity of VII was reported in the Modified Mercalli Intensity (MMI) scale which on that scale, it can cause human injuries and fatality and damage of property. Record of seismic activities within Malaysia and around its region over past 35 years among 1973 and 2008 illustrated in Figure 2.4.

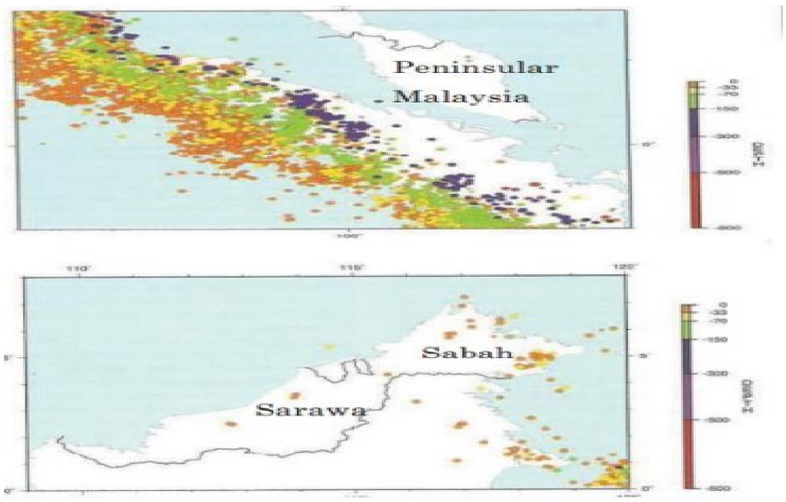

Figure 2.4 Records of earthquake epicenter in Malaysia and neighboring countries between 1973 and 2008 (USGS, 2011)

According to Emporis Standard (2011) about the definition of low rise building, it is a block off structure with architectural height below 35 meters and divided into several level with regular intervals was consider as low rise building. This low rise building includes all regular multi-storey building which are enclosed, the height is low than high rise and not fully underground. Mostly building in Malaysia constructed with height of 3 to 6 storeys which can be classified as low rise building and the earthquake consequence will become a significant aspect to be deal with such as hospital building, school building, houses, offices and many more. After experienced several tremors originating from neighboring countries especially from Sumatra, Indonesia, the Malaysian start to ask questions on integrity of existing structures in Malaysia to withstand the earthquake load (Adiyanto, 2014).

Thus, in the event of an earthquake, the effect will not only affected on general commercial buildings, but also police office, communication center, and hospital building which categorized as public-service building where include large volume of life and may cause economic downturn as well as contributed to the severe disruption with the function of the nation.

2.4 Seismic design

Park et al., (1984) studies about the seismic damage analysis for the RC building in Japan. Olive View Hospital, Taiyo Gyogyo building, Kinoshita Menko building, Obisen Office building, Fukushi Kaikan building, Tohoku Kogyo University, Saigo School, Tonan High School, and Izumi High School are nine different buildings used as models in this research. Structural damage evaluation on RC structure under the earthquake ground motion is the main research proposed for all models used. Along this study, a linear combination of the maximum deformation and repeated cyclic loading's effect are stated by the building's damage. From the analysis of damage on various RC buildings, an intensity scale was derived to interpret the potential destructiveness of ground motion. From the research, suggestion to use seismic damage model for RC structure is accepted.

Adiyanto et al., (2008) studies about the analysis and design of 3-storey Hospital Structure subjected to seismic load using STAAD.Pro. Three analytical reactions which is bending moment, shear force, and inter storey drift of 3-storey hospital building are analyzed in this study when subjected to various intensity of seismic load. From the 3-storey hospital building, one of selected beam is designed to hold seismic load with different intensity. The analysis result shows that bending moment value increased for the three cases classes of structural load which is low, medium, and high at all support. Same goes with the value of shear force increased at all supports from gravity load to low, medium, and high seismic load applied. From this study, the value of bending moment and shear force produced are higher as the seismic load applied to the structure.

An investigation about seismic design for the school building in Malaysia has been conducted by Hossam (2010). Two different type of school buildings used in his research which include of low rise 4-storey school building and medium rise 5-storey school building. Uniform Building Code (UBC 97) and American Concrete Institute (ACI 95) provision is used as the requirement reference in design. For modeling process, he used the STAAD.Pro software. The result of this study shows that the quantities of concrete (m^3) increased from 0.0% to 1.5% and 11.8% to 21.0% for the steel toonage based on the UBC 97 and ACI 95 recommendation between the existing and the seismic design of two different school building. Thus, consideration of seismic design for future school in design and construction phases in Malaysia as a low or moderate earthquake resistant building is recommended.

2.5 Ground motion

Vibration that can cause critically damage structure produced by the ground motion due to the earthquake. The most cases amplified when the ground acceleration, velocity, and displacement transmitted through the structure. Force and displacement produced by the amplified motion which may exceed the capacity of the structure can sustain.

The ground motion can be illustrated in three dimension in general act for both lateral and vertical. The inertia contained I the mass structure tends to remain at rest as the base of the structure is shaken, produce in deformation of the structure. The carrying member load of the structure try to build up the structure to its original condition. In material deformation process, the energy be permeated as the the structure deforms rapidly. This features can be effectively modeled for Single Degree of Freedom (SDOF).

2.6 Relationship between steel tonnage and concrete volume

Taresh (2010), has conducted an investigation about the seismic design of reinforced concrete school buildings in Malaysia based on UBC 97 and ACI 95. the purpose of this study is to investigate the relationship of steel tonnage and concrete volume of existing structural design of school building in Malaysia and the seismic design based on UBC 97 and ACI 95 requirement. This investigation used two type of models which the first model labeled as School 1 where it is a 4 stories rectangular shape building in plan that generally used in Malaysia and another one labeled as School 2, L shape building consist of 5 stories in plan. The seismic analysis conducted by using STAAD.Pro 2006 software. By referring the UBC 97 and ACI 95 recommendation, Intermediate Moment Resisting Frame (IMRF) is applied in the structure design. In the end of this study, the result shows that the total percentage for both aspects, steel tonnage and concrete volume, on School 1 and School 2 between the existing (without seismic consideration) and seismic design brought a difference in range which for the total percentage difference of concrete volume is in the range of 0-15% while for the steel tonnage is 11.8-21.0%.

An analysis of the seismic design of 4 storey RC standard JKR school building in Malaysia based on UBC 97 had been performed by Suhaimi (2011) and the objective of this analysis is to identify the steel reinforcement tonnage percentage and volume of concrete (m^3) used for the building structure. The building with seismic provision had been compared with building without seismic provision code based on the usage percentage difference of steel reinforcement and concrete volume. Equivalent static procedure is applied in designing the seismic load, the structure designed referred to the UBC 97 requirement, and the analysis performed using STAAD.Pro (2007) software. In this cases, only the main structural elements are involved which consist of column and beam element. The result of this study stated that the steel tonnage percentage difference of building with seismic design consideration is about 21.71% while the percentage difference of concrete volume is about 26.03%.

Rahman (2011) has managed a research on comparing the steel tonnage and concrete volume in terms of percentage for beam and column element of existing local design RC school building (BS 8110) in Malaysia and the seismic design based on Uniform Building Code (UBC 97). A 3 stories school building used as the model but only one block is considered in this research. The school analysis has been carried out by using static equivalent method and the STAAD.Pro software is used in the seismic analysis. The structures are designed as Intermediate Moment Resisting Frame (IMRF) based on UBC 97 and ACI 95 recommendation. The analysis result show that about 26.16% of total percentage difference between existing design (without seismic code provision) and seismic design for steel tonnage and about 13.05% for concrete volume.

2.7 Basic concept of behavior factor, *q* and its influence on structural performance

In a project process, structural response is absolutely influenced by the designing stage. In order to achieve total elastic response, the design of the structure should be refer on extremely high magnitude of seismic force then the result will give very large section of structural member and due to it, the amount of steel reinforcement needed for use also high. A structure designed which can response elastically during attacked by tremors is quite costly (FEMA 451B, 2007). Due to it is not a cost-effective thing, then the structure allowed to respond inelastically by allowing earlier yield state to occur. So, a concept or term has been suggested in seismic design called behavior factor, q. The behavior factor, q is a factor which is used for design purpose to reduce the forces obtained from a linear analysis, in order to account for the nonlinear response of a structure (Eurocode 8, 2004)

To understand the concept, given a situation where a developer want to construct a new 5 storey RC building in a moderate seismic zone. Two design for same building labeled as Structure A and Structure B proposed by the designer where the design reacted for elastic and inelastic response when subjected to earthquake. Structure A is expected has high base shear force, F_b size of section and total weight of steel reinforcement used compared to Structure B.

At the end of analysis, Structure B is selected as the final design because of economical factor despite the fact it will response inelastically during tremors. In this example that represented by Figure 2.5, by using behavior factor, q is equal to 4, the base shear force, F_b for Structure B is determined which the based shear force, F_b is reduced fromm 2000 kN to 500 kN.

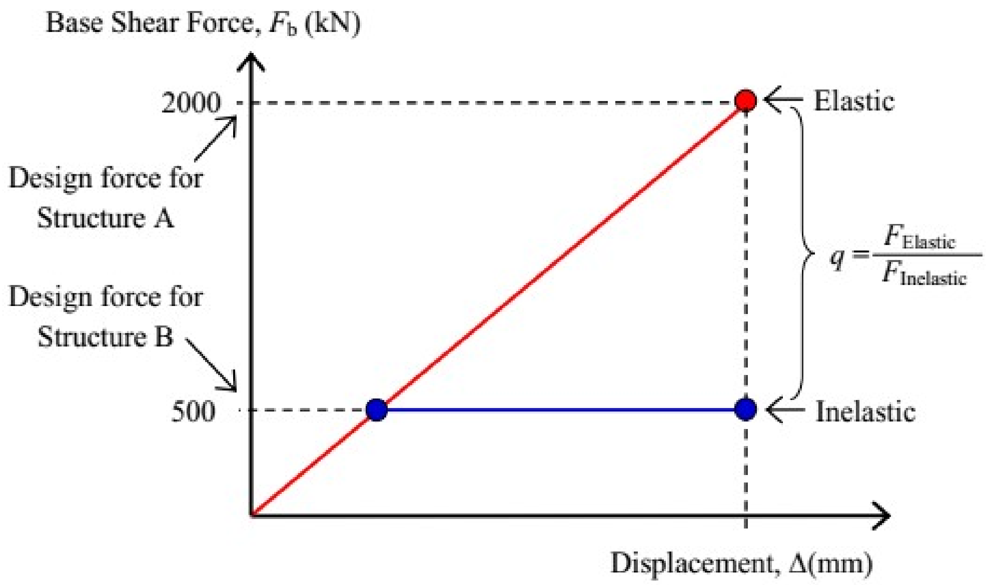

Figure 2.5 Comparison between elastic and inelastic design force (Adiyanto, 2016)

On 2002, Miranda and Ruiz-Garcia conducted a study of behavior factor, q is affected by different Soil Type. The analysis of behavior factor, q with ground motion has been done on two type of soil which is rock or firm soil and soft soil. The analysis result recorded shows that there is a significant different on rock or firm soil site compared with soft soil on the behavior factor, q value. From this study, any design or evaluation of structure build on soft soil cannot use the behavior factor, q that recorded on the rock site ground motion. Analysis on SDOF models was conduct in between 0.1 sec to 3.0 sec with 5 level of ductility which is 2, 3, 4, 5, and 6, Eser et al. (2011) concluded that for the sake of safety, the behavior factor, q for soft soil should be decreased. Ganjavi and Heo (2012) also came with same outcome.

2.8 Cost implication of Seismic Design in RC Building

Adiyanto and Majid (2014) has studied about the economic effect of the seismic design of Malaysian RC buildings. A redesigned two-storey RC office building based on seismic provision undergone a non-linear time history analysis by using various level of PGA. The different value of PGA influenced the total cost of materials in design and construction of the building which is increased 6% to 270%. Same with the inter storey drift ratio (IDR) has increased as well around 8% to 29% if subjected to repeated earthquake.

A research of the effect of behavior factor, *q* on total cost of material for three storey RC hospital building was conduct by Adiyanto et al. (2014). By using Eurocode 8 as reference in design stage, the typical frame had been designed for ductility class medium with five different value of behavior factor, *q* (2.3, 3.1, 3.9, 4.7, 5.5). From this study, the result shows that the amount of steel toonage and total cost of materials were strongly influenced by the behavior factor, *q*. When the behavior factor, *q* decrease, the total weight of steel bar used increase and cause the total material cost increase as well. However, the material costing can be deduct up to 22% if the behavior factor, *q* value selected correctly and reasonably.

2.9 Soil Type influenced in seismic performance

Nasai (2016), examined the effect of Soil Type on seismic performance of RC school building. 2 and 4 storey of RC school buildings designed based on BS8110 (1997) and modeled by using ESTEEM software has been used as the model in this research. Nonlinear time history analysis method is used in analysis stage by considering 7 different values of ground motion and two type of earthquake motion where motion 1 is single ground motion (main shock) and motion 2 is repeated ground motion (foreshock - mainshock - aftershock). Two different Soil Types labeled as Soil Type B (soft rock) nd Soil Type D (soft soil) as been referred to Eurocode 8 (2004) had been consider in this analysis. The PGA used is 0.12g as ground motion to represent the seismicity in Sabah. IDR has been the aspect to evaluate the seismic performance. From the study, repeated earthquake has higher IDR value compared to single earthquake which is increased from single tremor to repeated tremors about 5.0% to 6.0%. Soil Type D has higher IDR value about 14% than Soil Type B while the pattern for both single and repeated earthquake remained the same. Therefore, type of soil is one of aspect that should be consider in seismic design.

2.10 Summary

From this chapter, it can be concluded as the journey of earthquake term. From how it can produce, listed as one of natural disaster, some historical earthquake in few areas, its effect to the people and building structure, the application of seismic design, some factors that influenced the seismic design, the comparison on certain aspects due to the seismic consideration, until the cost implication when seismic design applied. Most of the seismic design referred the UBS 97 and ACI 95 requirement and absolutely Eurocode 8. Lot of aspect should be consider in seismic design.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, it will consist of summary of methodology used along this research to evaluate the effect of Soil Type and grade of concrete on amount of steel needed for RC hospital building. Sequence of steps from setup model until taking off phase included in this chapter. Eurocode 8 is the main reference used in design stage. Tekla Structure Software used in modelling and analysis phase. There are few parameters 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 4 stages included in this study. Firstly is setup the model which is selection of the type of building use as the model in this research. Secondly is seismic design using software and refer on seismic design code. Third is modelling process where include of design of element or component of the building. Next is seismic analysis which conducted using same software used in designing stage. Last but not least is carry out taking off of the structure building.

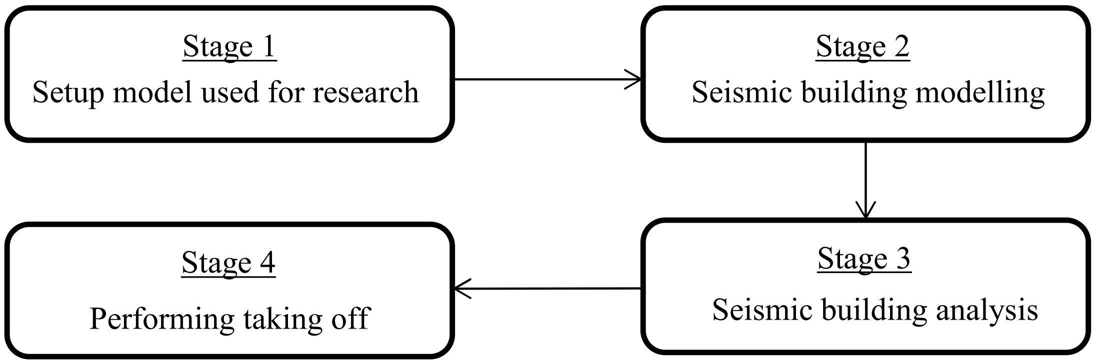

Figure 3.1 Flow chart of research methodology

3.3 Stage 1: Setup model used for research

6 storey RC moment resisting frame hospital building has been used in this study as the model. According to Bureau of Planning and Sustainability (2013), 6 storey RC building is categorize in low-rise RC building. The number of storey of a building and its class of rise can be refer in Table 3.1. Due to emergency cases that always related with hospital, high-rise building is not recommended for hospital building due to its ineffectiveness evacuation process if any emergency happen.

Table 3.1 Number of storey and its class of rise (Bureau of Planning and Sustainability, 2013)

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

3.4 Stage 2: Seismic design - Building modelling by using Tekla Structure Software

In this stage, the 6 storey RC hospital building modeled by using Tekla Structure Software and AutoCAD. This 6 storey RC hospital building has 21.6 meter height up from ground level and 1.5 meter down from ground level. and area for each level is 585 square meter. The view of the RC hospital building shown in Figure 3.2, and the layout for each level shown in Figure 3.3. There are two dimension of beam used for the building model which is 350mm x 600mm for the beam on floor 1 until floor 5 and 250mm x 550mm for roof beam. Both different dimension of beam use concrete beam. While for the column size, this building also designed that had two sizes of column where first column labeled as Column A for roof level level until third fourth, it use 450mm x 450mm column size and from third level until foundation level labeled as Column B , it use 450mm x 450mm column size. The material of column used is concrete. For the thickness of slab, the design used 150mm for all floor.

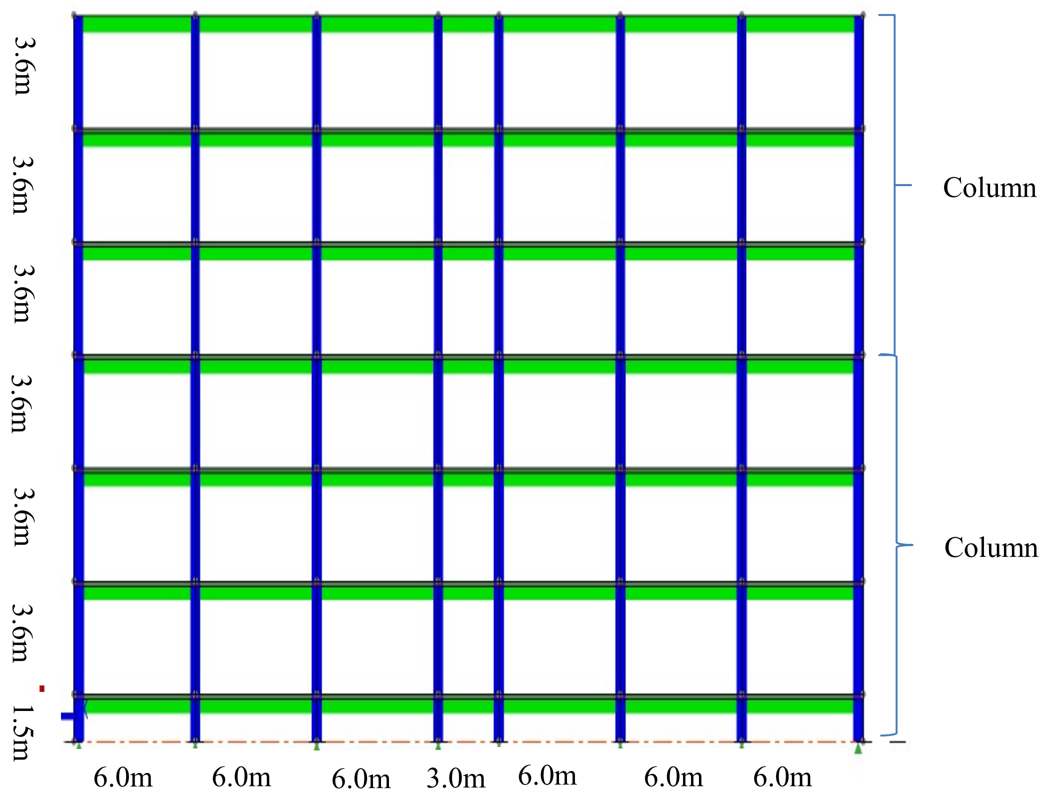

Figure 3.2 Front view of RC hospital building generated in Tekla Structure software

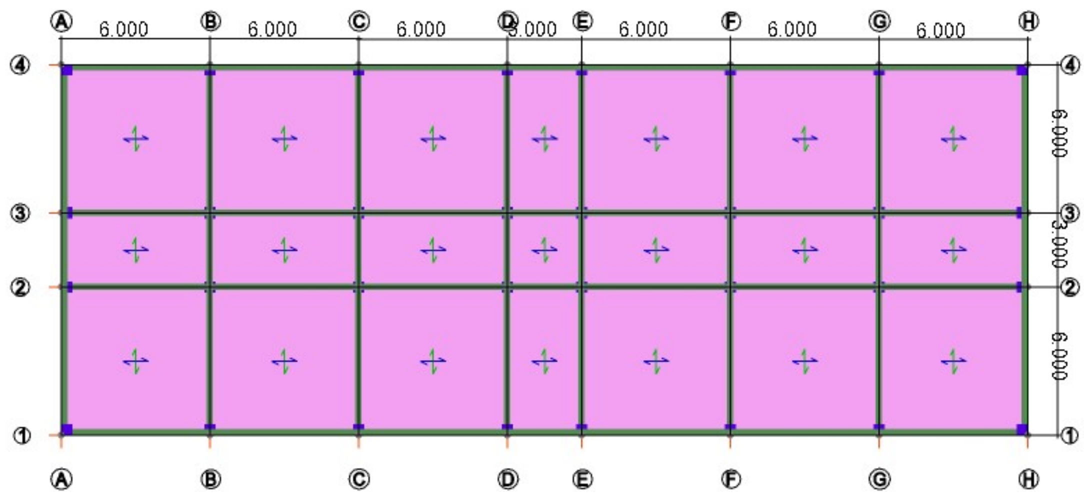

Figure 3.3 Layout of RC hospital building

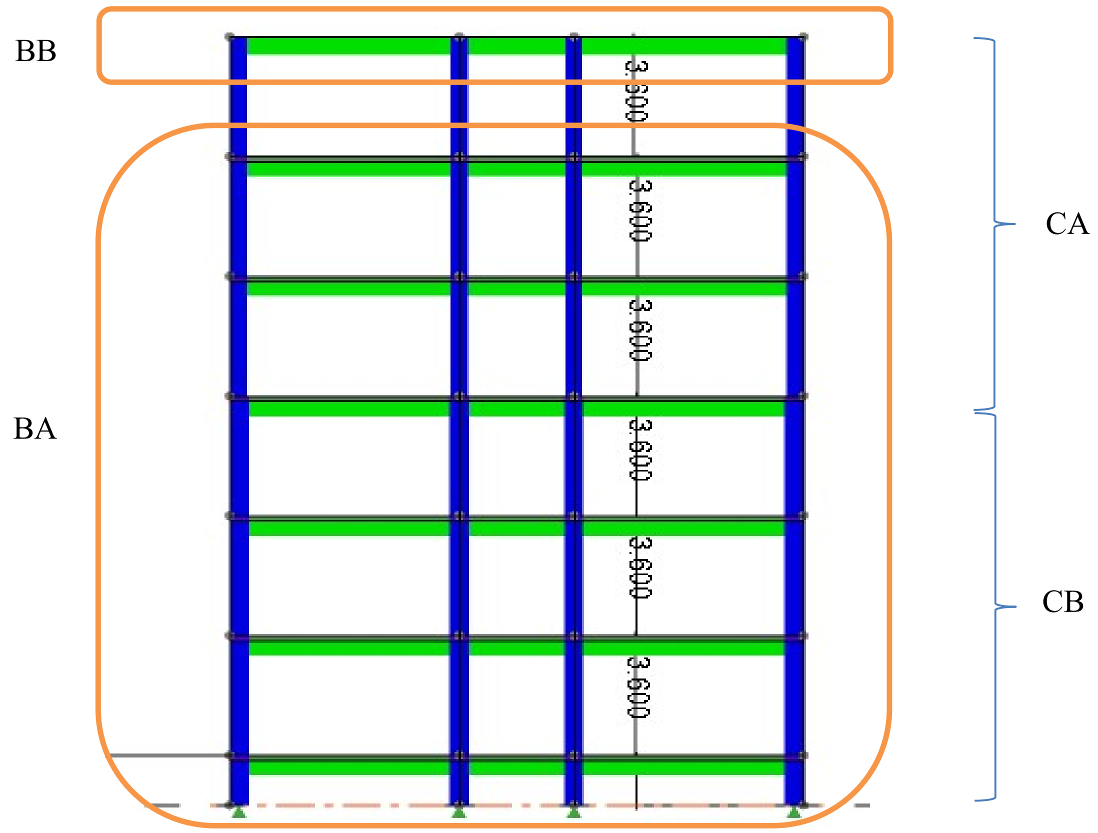

Figure 3.4 Side view of 6 storey RC hospital building

Table 3.2 Dimension of the structural members of the frame

BEAM	DIMENSION (mm)
BA	250 x 550
BB	350 x 600
COLUMN	DIMENSION (mm)
CA	450 x 450
CB	500 x 500

STEP 1

DEFINING

1. Model setting
2. Material properties
3. Plan grid and story data

↓

STEP 2

ASSIGNING

1. Columns
2. Beams
3. Slabs
4. Load cases
5. Lateral loads

↓

STEP 3

1. Setting analysis option
2. Run analysis

Figure 3.5 Steps involved in building modelling using Tekla Structure software

3.4.1 Load cases

A building load is simply a force that a building frame need to resist. The frame must be designed to withstand eight of these load which included wind, earth, and snow without catastrophic stress on the structure. In load cases, the load divided into three part, dead load, imposed load, and lateral load. Figure 3.6 shown load cases in the 6 storey RC hospital building.

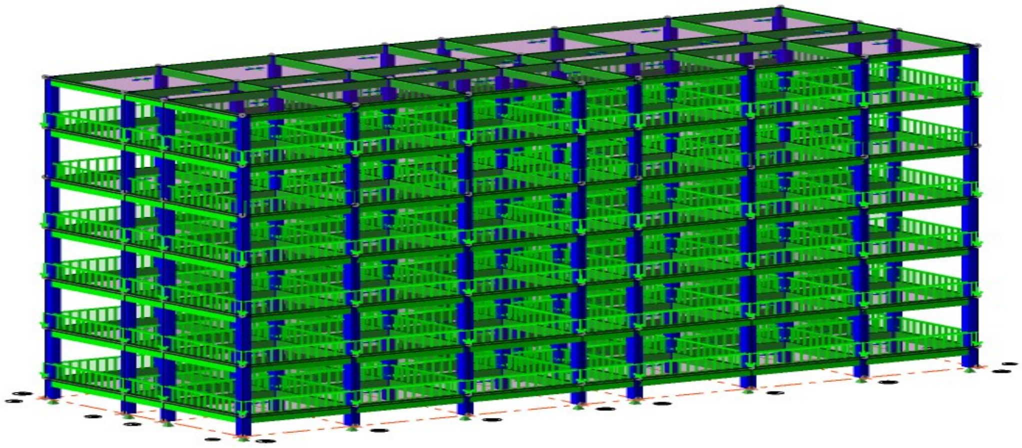

Figure 3.6 Load cases in 6 storey RC hospital building

Dead load is a load on a structure resulted of the weight of the permanent components such as beams, columns, walls, floor, and slabs. These component will produce the same dead load during the lifespan of the building. For this design building, the dead load involved is contributed by the brick walls and the slab. The equation to find the dead load transferred from brick walls and slab can be referred in Eurocode 2 (2002). The self-weight of the material can be refer in Table 3.3. In this case, the load transferred from the brick wall has been calculated equal to 7.8 kN/m^2. But since the self-weight is calculated automatically by the software used which is Tekla Structural Design software, the dead load for beam is assumed as 1.0 kN/m$^{2.}$

$$\begin{aligned}\text{Brick wall load} &= \text{Brick wall self-weight x clear height of column} \\ &= 2.6\ \text{kN/m}^3 \times 3.0\text{m} \\ &= 7.8\ \text{kN/m}^2\end{aligned} \tag{3.1}$$

While for the dead load of slab transferred to beam has been calculated with its own equation is equal to 3.75 kN/m^2.

$$\text{Slab load} = \text{Slab self-weight x thickness of slab} \tag{3.2}$$
$$= 24 \text{ kN/m}^3 \text{ x } 0.15\text{m}$$
$$= 3.75 \text{ kN/m}^2$$

Table 3.3 Weight of material (Mc Kenzie, 2004)

Material	Weight	Unit
Concrete	24.0	kN/m3
Finishing	1.0	kN/m2
Water proofing	0.5	kN/m2
Suspended ceiling	0.15	kN/m2
Mechanical and electrical	0.30	kN/m2
Brickwall	3.0	kN/m2/m height

Imposed load is defined as the load that is applied to the structure that is not permanent and can be variable. In Eurocode phraseology, it described as a 'quasi-permanent variable action'. In Eurocode 1 (2002), each type of building or area has its own imposed load. Eurocode 1 (2002) has been categorized some of type of building and area and provide in a table. For this study, the building chose as the model is RC hospital building which categorized in Category A, area for domestic and residential activities. The categories of use and its imposed load shown in Table 3.4 and Table 3.5. While for roof floor, the categories of loaded area and its use and the recommended imposed load at roof according to Eurocode 1 (2002) shown in Table 3.6 and Table 3.7, respectively. The roof floor for this building categorized in Category H. The imposed load used for the slab of this building is 1 kN/m^2 and for roof of this building is 0.4 kN/m^2.

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 house; bedrooms and wards in hospitals; bedrooms in hotels and hotels kitchen and toilets.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B, and D)	C1: Areas with tables, etc. E.g. areas in schools, cafes, restaurants halls, reading rooms, receptions. C2: Areas with fixed seats, E.g. areas in churches, theaters or cinema, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms. C3: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts. C4: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages C5: Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platform.
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/m2]	Qk [kN]
Category A		
- Floors	1,5 to 2,0	2,0 to 3,0
- Stairs	2,0 to 4,0	2,0 to 4,0
- Balconies	2,5 to 4,0	2,0 to 3,0
Category B	2,0 to 3,0	1,5 to 4,5
Category C		
- C1	2,0 to 3,0	3,0 to 4,0
- C2	3,0 to 4,0	2,5 to 7,0 (4,0)
- C3	3,0 to 5,0	4,0 to 7,0
- C4	4,5 to 5,0	3,5 to 7,0
-C5	5,0 t 7,5	3,5 to 4,5
Category D		
- D1	4,0 to 5,0	3,5 to 7,0 (4,0)
- D2	4,0 to 5,0	3,5 to 7,0

Table 3.6 Categorization of roofs (Eurocode 1, 2002)

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

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

Roof	qk [kN/m2]	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/m2 . 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)

Lateral loads are live loads whose main component is a horizontal forces will acting on the structure. Typically lateral load would be a wind load against a facade, an earthquake, the earth pressure against the front retaining wall or the earth pressure against the basement wall.

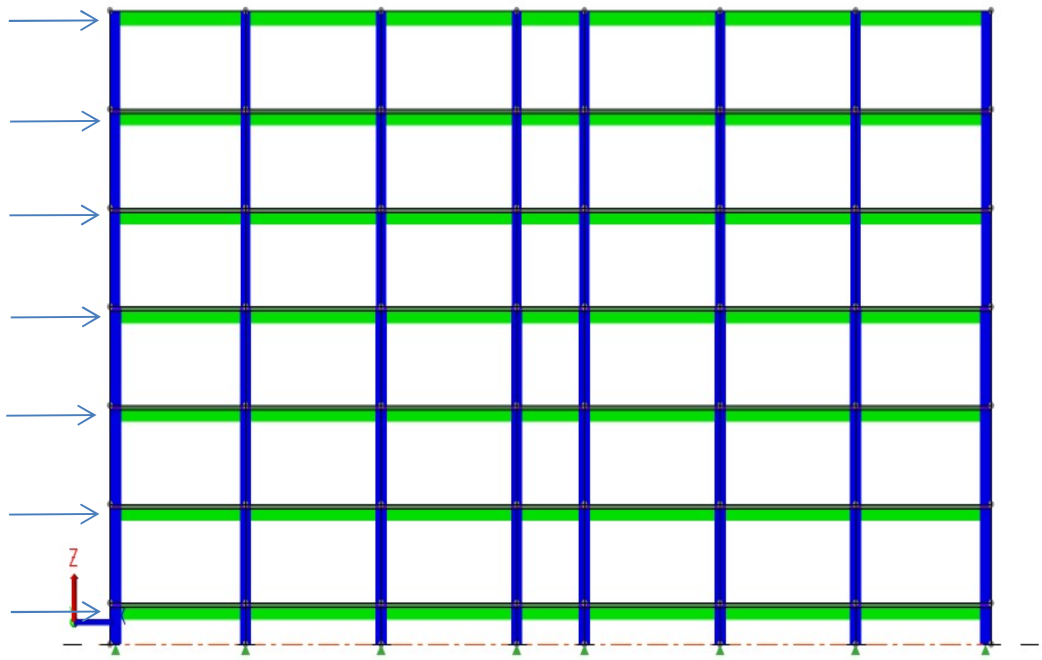

Figure 3.7 6 storey RC hospital building with lateral load

According to Clause 4.3.3.2.3 in Eurocode 8 (2004), the distribution of the lateral seismic load can be made by this following equation;

$$F_i = F_b \frac{z_i m_i}{\in z_j m_j} \tag{3.3}$$

Where; F_i = Lateral load acting on storey I

F_b = Base shear force

z_i, z_j = Height of the masses m_i, m_j

3.5 Stage 3: Seismic analysis using Tekla Structure Software

In this stage, Tekla Structure Software has been used to run analysis of this research same as software used in design modeling. During setting up before start analysis, it involved few type of parameters to insert in the setting option. The main parameters in this study which is Soil Type and grade of concrete also involve int the parameters that need to be insert in the setting analysis option by using various value or condition of that parameters. Some parameter were constant value due to it is not the main parameters that need to be study such as PGA, class of ductility, base shear force, behaviour factor, and importance factor.

3.5.1 Soil Type in seismic design

Soil come from various type and it has it own classes. Type of soil 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 om amount of steel needed for the RC hospital building.

According to Eurocode 8 (2004), type of soil has been classified into few categories based on its behaviour. It shown in Table 3.8. 4 type of soil has been inserted in the analysis option which is Soil Type A, B, C, and D 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, it will become more weaker. A soil texture that contain or mix with gravel or rock, it will make the soil become more 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_{SPT}	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
D: Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	<180	<15	<70

3.5.2 Grade of concrete

Concrete come from various type and grade. The grade of concrete differentiate the concrete strength to be use in building construction and at the same time it also influence 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 modeling and also inserted in analysis option.

3.5.3 Base Shear Force, F_b

Base shear force is an 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 base shear force, 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 base shear force, F_b that act on each level in horizontal direction can be determine by using following expression;

$$F_b = S_d(T_1).m.\lambda \qquad (3.4)$$

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 $T_1 \leq 2T_c$ and the building has more than two storey, or λ=1.0

$S_d(T_1)$, m, and λ correspond to the ordinate of the design spectrum at period T_1, the total mass of 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.

$$T_1 = C_t \,.\, H^{3/4} \qquad (3.5)$$

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

3.5.4 Design response spectrum

From equation 3.4 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 base shear force, 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, Soil Type C, and Soil Type D. Equation (3.6) to (3.9) had been referred to develop the design response spectrum.

$$0 \leq T \leq T_B : S_d(T) = \alpha_g .S.[\frac{2}{3} + \frac{T}{T_B}.(\frac{2.5}{q} - \frac{2}{3})] \tag{3.6}$$

$$T_B \leq T \leq T_C : S_d(T) = \alpha_g .S.\frac{2.5}{q} \tag{3.7}$$

$$T_C \leq T \leq T_D : S_d(T)\{= \alpha_g .S.\frac{2.5}{q}.[\frac{T_C}{T}] / \geq \beta.\alpha_g \tag{3.8}$$

$$T_D \leq T : S_d(T)\{= \alpha_g .S.\frac{2.5}{q}.[\frac{T_C T_D}{T^2}] / \geq \beta.\alpha_g \tag{3.9}$$

Where;

T	= vibration period of a linear single-degree-of-freedon 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
$S_d(T)$	= 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, $S_d(T_1)$ (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

3.5.4.1 Design ground acceleration, α_g

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

$$\alpha_g = \gamma_1 . \alpha_{gR} \tag{3.10}$$

Where; γ_1 = Importance factor
α_{gR} = Reference peak ground acceleration

γ_I 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. The recommended importance factor, γ_I is to offer better protection of life for such buildings due to its importance after disaster (Fardis et al., 2015).

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

Important class	Buildings	Improtant 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 α_{gR} is based on peak ground acceleration (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 constant which is 0.1g.

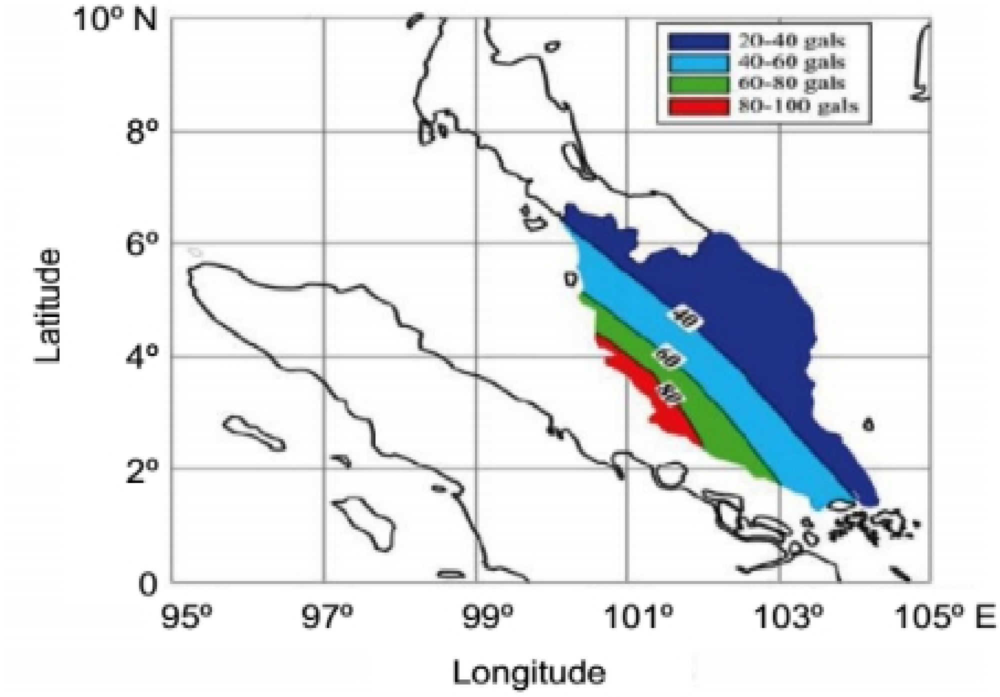

Figure 3.8 Seismic hazard map on Peninsular Malaysia (MOSTI, 2009)

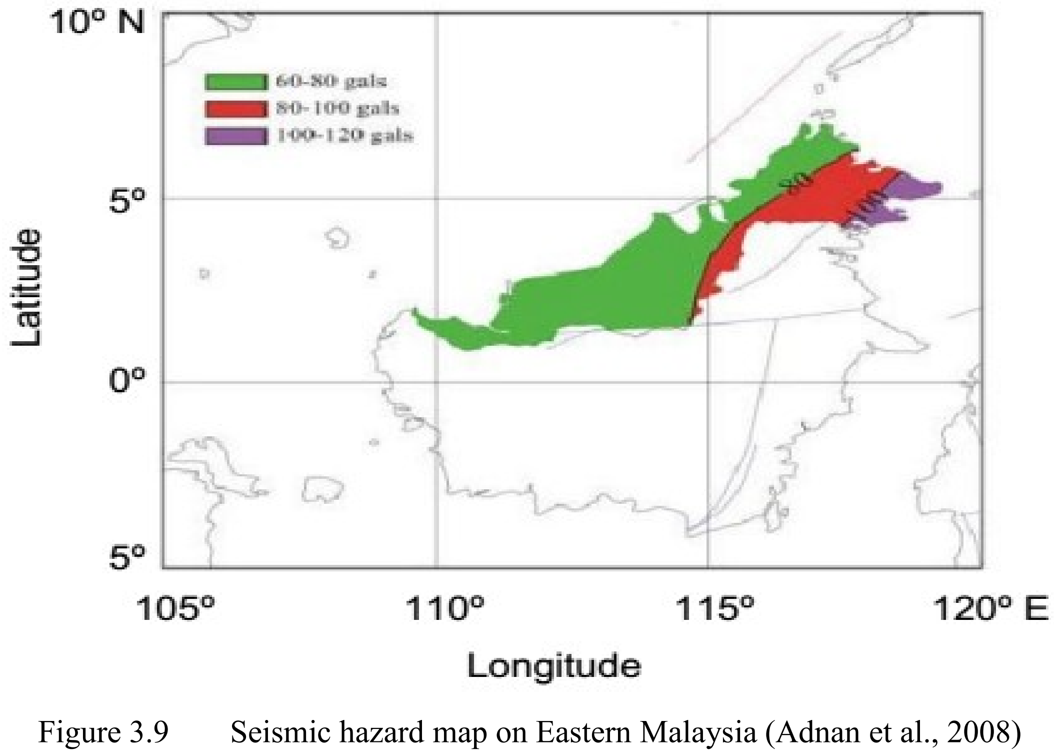

Figure 3.9 Seismic hazard map on Eastern Malaysia (Adnan et al., 2008)

3.5.4.2 Behaviour factor, *q*

One of the important parameter in seismic design is behaviour factor, q. According to Eurocode 8 (2004), the force obtain from a linear analysis reduced by the behaviour factor in order to take into account for non-linear response of a structure. 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 behaviour factor depends on material used, type of structure and its ductility class as stated on Clause 5.2.2.2 in Eurocode 8 (2004). 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 (3.11) below;

$$q = q_0 . \mathrm{k_w} \geq 1.5 \tag{3.11}$$

Where; q_0 = Basic value of behvior factor
$\mathrm{K_w}$ = Reflecting factor

Where q_0 is depart of structural type and its regularity in elevation. $\mathrm{K_w}$ represent the factor reflecting the prevailing failure mode in structural system with wall. Value $\mathrm{K_w}$ equal to 1.0 for frame and frame-equaivalent dual system but for other systems, clauses 5.2.2.2 (111)P in Eurocode 8 (2004) stated the derivation of $\mathrm{K_w}$. 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. Multy-storey, one-bay frames: $\alpha_U / \alpha_I = 1.2$
iii. Mult-storey, multi-bay frames or frame equivalent dual structure: $\alpha_U / \alpha_I = 1.3$

The value of $\alpha_U / \alpha_I = 1.3$ since this research is focus on the multi-storey nd multi-bay RC frame. Table 4.0 shown the proposed value of behaviour factor in Eurocode 8 (2004). Since the ductility class is one of constant parameter in this study by using DCM, based on the Table 3.12, the value of behaviour factor for DCM is 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

3.5.5 Seismic design to Eurocode 8

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.

3.5.5.1 Seismic design of beam

This subsection will explain the flow of seismic design of beam. Figure 3.9 show the flow of beam seismic design.

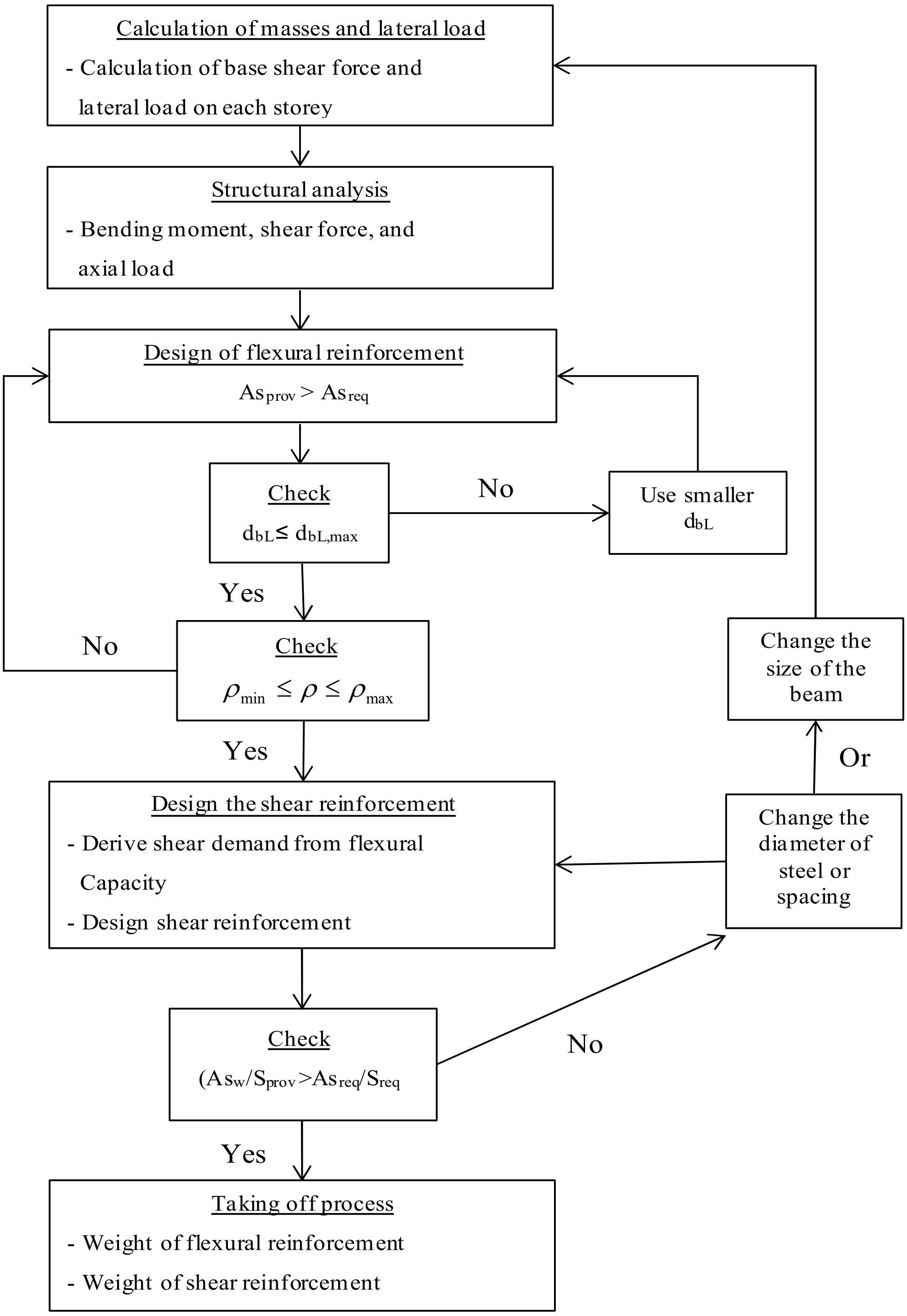

Figure 3.10 Beam seismic design flow based on Eurocode 8 (Adiyanto, 2016)

In this study, beam designed into few section which is exterior section, interior section, and middle span and may divided into two part, top and bottom. Due to the different magnitude of bending moment, M, at top part of both section, the flexural reinforcement at top part and the bottom part of the beam may be different.

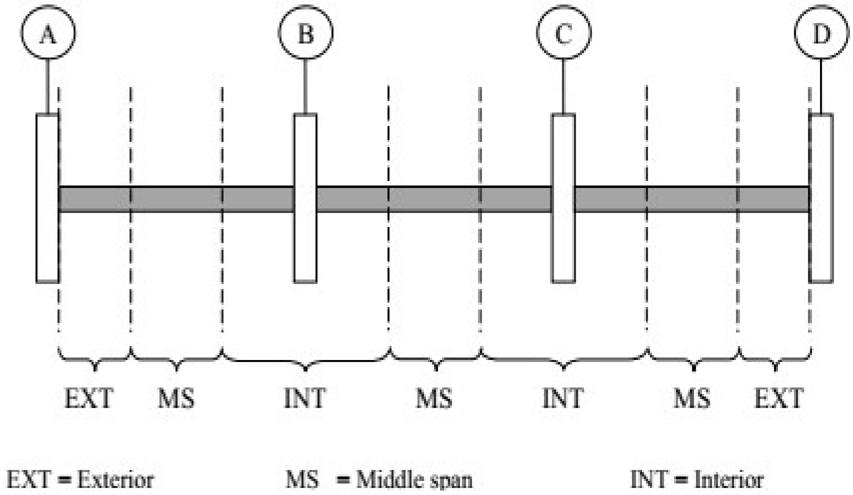

Figure 3.11 Span of beam element (Eurocode 8, 2004)

3.5.5.2 Seismic design of column

In this subsection will discuss about the step involved in seismic design of column. According to Filiatrault et al. (1998a); Elnashai and Sarno (2008); Kirtas and Kakaletsis (2015), strong column - weak beam concept is proposed in seismic design. The column designed by considering the earthquake is very important to resist earthquake load. Strength of steel reinforcement, concrete compressive strength, amount of longitudinal reinforcement, amount of transverse reinforcement, magnitude of axial load, and the slenderness ratio are several parameters which bring strong influence to RC column behaviour (Erduran and Yakut, 2007). Figure 3.12 show the flow of step involved in seismic design of column.

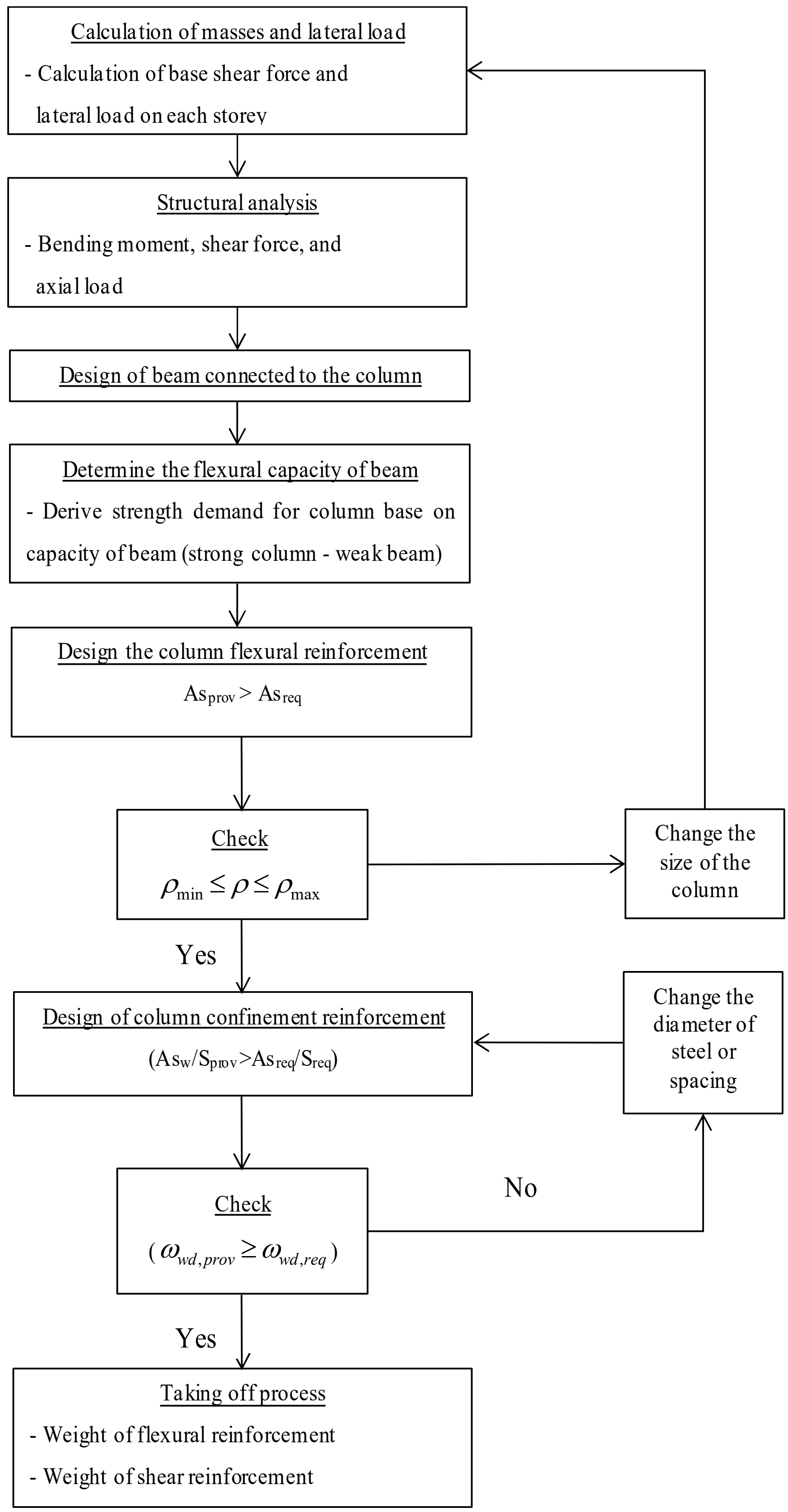

Figure 3.12 Column seismic design flow based on Eurocode 8 (Adiyanto, 2016)

3.6 Stage 4: Performing taking off

Based on the structural elements of the building which is beam and column, taking off is performed to determine the amount of steel required for the seismic design models of 6 storey RC hospital building. Comparison of taking off will be made base on result of each model differ by two main parameters used in this study which is Soil Type and grade of concrete.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result and discussion based on analysis and design performed is presented. The discussion is about the comparison of the result value based on various type of variables and aspects. The discussion start with the design response spectrum which produced by considering four different Soil Type, followed by effect of Soil Type and grade of concrete on amount of steel required for seismic and non seismic reinforced concrete hospital building. The analysis and design had been conducted in order to get the amount of steel needed for each beam element and column element and the total amount of steel for overall beam and column element for the whole building which called as grand total of amount of steel required.

4.2 Design Response Spectrum

In 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 3.6 to 3.9.

The value of design spectrum, $S_d(T)$ is parameter which play the main role in this analysis and design result. There are few constant 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 base 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 important factor, γ_I is equal to 1.4. The classification table can be refer in Eurocode 8 as shown in Chapter 3, Table 3.10.

Next value used is behaviour factor, q. Since this research use the constant ductility class which is ductility class medium, the behaviour factor, q used is 3.9. The PGA value, α_{gR}, is 0.10g constantly and it bring the value for design ground acceleration, α_g, is equal to 0.14 where produced form the the expression as previously discussed in Chapter 3, equation 3.10.

The range of the time, T, for the design spectrum used is 0.05 second. The various value of S, T_B, T_C, and T_D used is based on the various type of Soil Type and in this research, the Soil Type used is Soil Type A, B, C, and D. 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, B, C, and D.

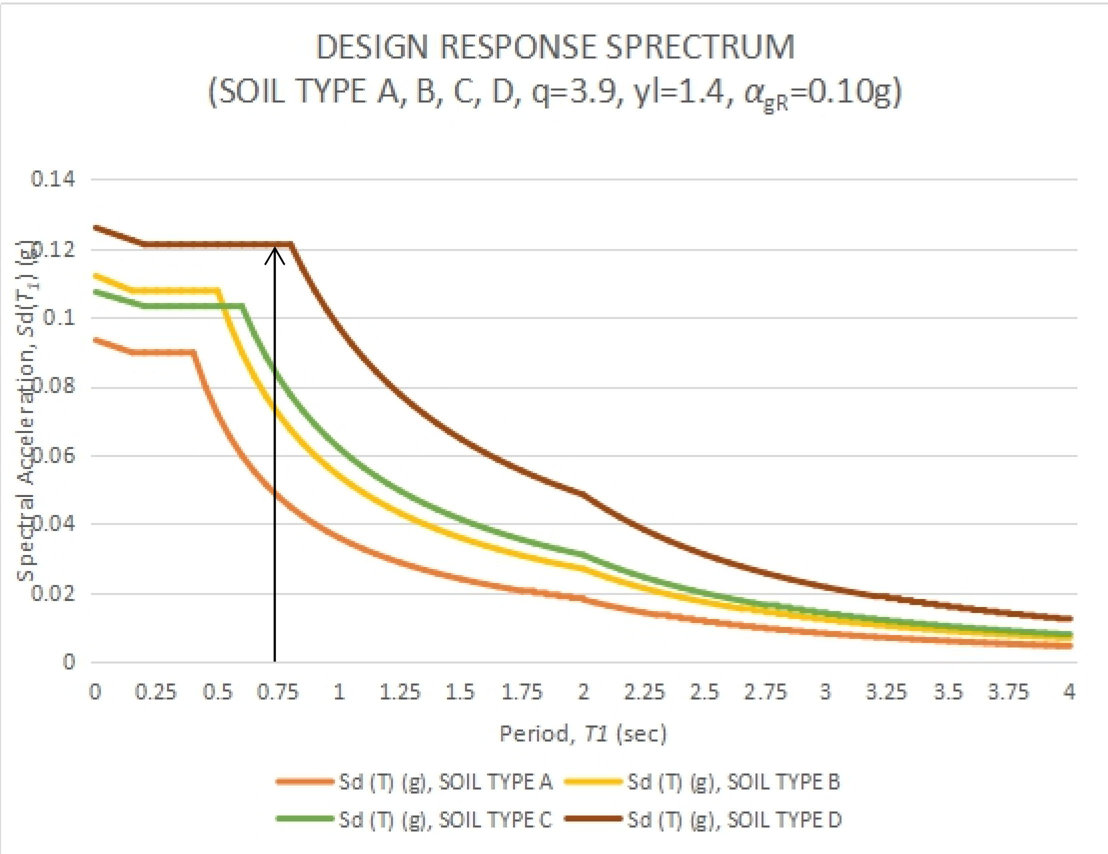

Figure 4.1 Design response spectrum for four Soil Type A, B, C, and D

The combination design response spectrum for four different Soil Type shows four different values of design spectrum, $S_d(T)$. The lowest design spectrum, $S_d(T)$ value is from Soil Type A and the highest one is from Soil Type D. The design spectrum, $S_d(T)$ value is 0.09g, 0.102g, 0.11g, and 0.12g when defined by using Soil Type A, Soil Type B, Soil Type C, and Soil Type D, respectively.

The value of design spectrum, $S_d(T)$ can be defined by determine the value of period, T_1 by using equation as previously discussed in Chapter 3, equation 3.5. The period, T_1 defined is equal to 0.75s and it makes the value of design spectrum, $S_d(T)$ is equal to 0.12g which is on Soil Type D. The value of design spectrum is strongly related with the base shear force, 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, the base shear force, F_b related directly to the design spectrum, $S_d(T)$ which means the value of base shear force, F_b increase as the value of design spectrum, $S_d(T)$ increase.

4.3 Effect of Soil Type on Amount of Steel Reinforcement

This research conducted by using four different types of soil which is Soil Type A, B, C, and D. Each Soil Type gives its own effect on the amount of steel reinforcement for the building. The amount of steel reinforcement per $1m^3$ of concrete for each Soil Type are compared to the non-seismic building. The analysis and design has been conducted by using concrete grade G30. The result for concrete grade G40 can be referred in Appendix A.

There are two type of element considered for discussion namely as beam and column. Beam at grid line B/1-4 labeled as Beam B2 and column at grid line B/2 level 1 to level 3 labeled as Column C6 are selected for discussion. The position of the selected beam and column are shown in Figure 4.3 and Figure 4.3, respectively.

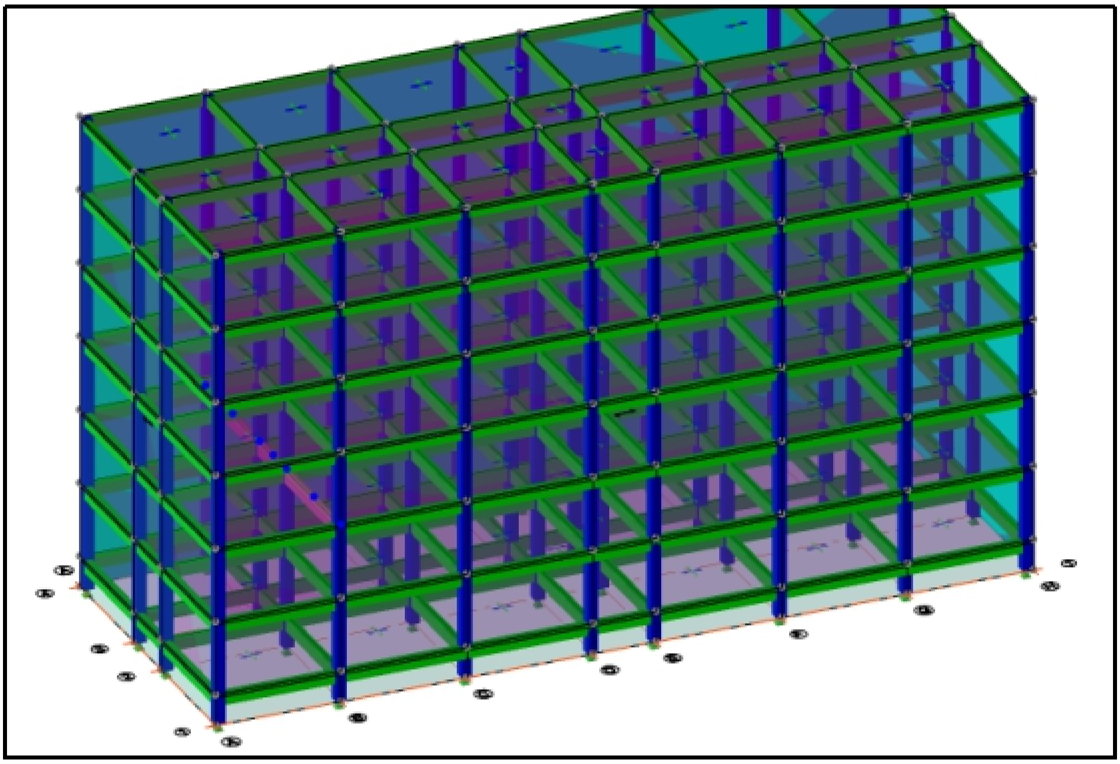

Figure 4.2 Position of beam B2

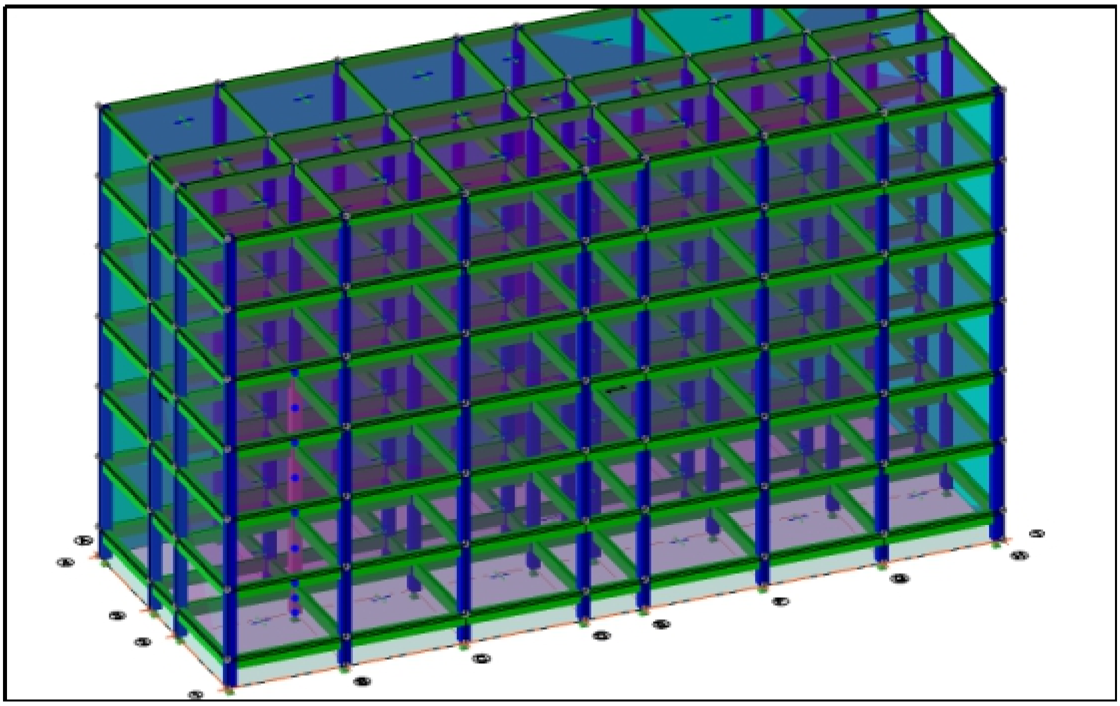

Figure 4.3 Position of column C6

4.3.1 Effect of Soil Type on amount of steel reinforcement for beam element

In order to discuss on the effect of Soil Type on amount of steel reinforcement for beam element, main reinforcement graph and shear reinforcement graph has been developed with building model of non seismic design, Soil Type A, Soil Type B, Soil Type C, and Soil Type D. Figure 4.4 and Figure 4.5 show the amount of steel reinforcement per $1m^3$ of concrete for main reinforcement and shear reinforcement of Beam B2, respectively.

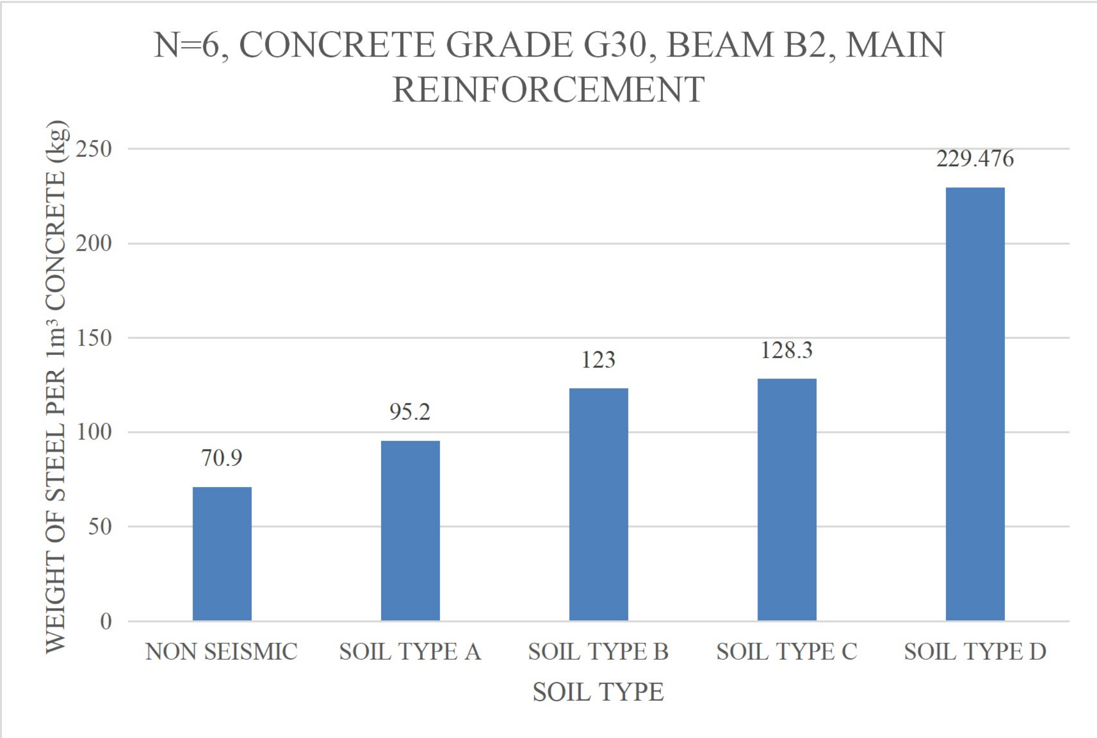

Figure 4.4 Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by Soil Type

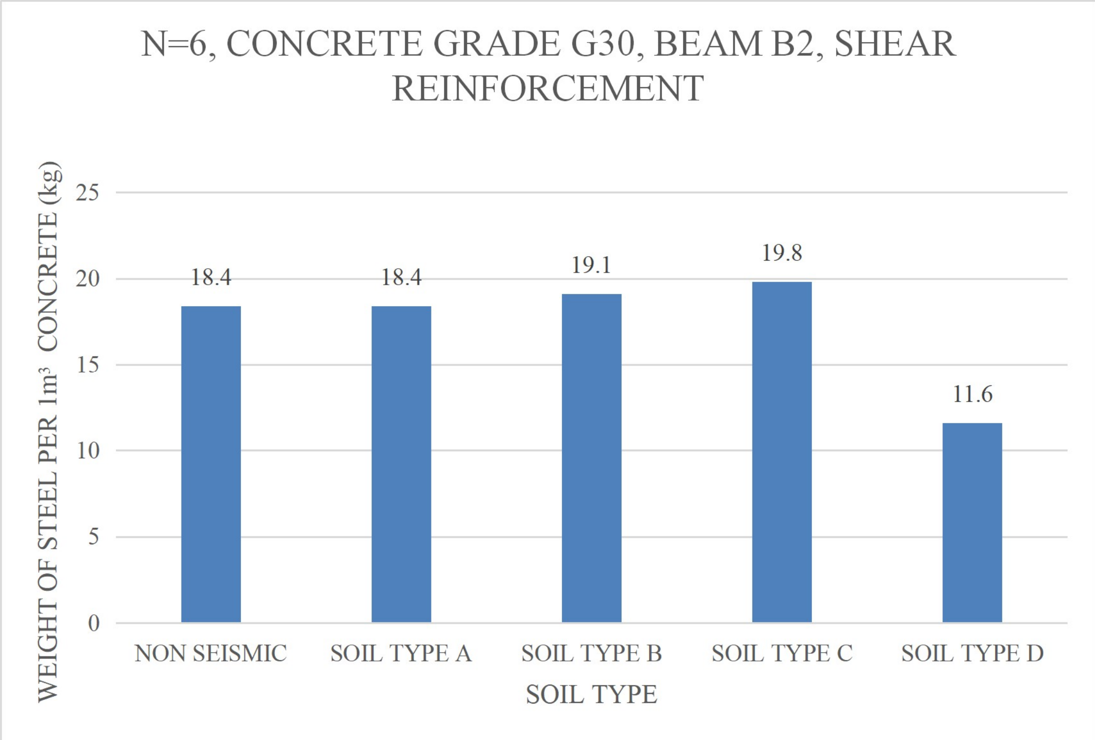

Figure 4.5 Total amount of steel required for 1m3 of concrete of Beam B2 for shear reinforcement influenced by Soil Type

Figure 4.4 shows a cumuliform pattern of graph where the building model with the lowest amount of steel reinforcement for $1m^3$ of concrete is non seismic design with 70.91 kg and the highest is Soil Type D which is 229 kg for Beam B2 with concrete volume of 3.15 m^3. Figure 4.5 shows varies pattern of graph where the building model with lowest amount of steel reinforcement per $1m^3$ of concrete is Soil Type D with 11.60 kg and the highest one is Soil Type C which is 19.81 kg for Beam B2 with concrete volume of 3.15 m^3.

The amount of steel reinforcement is strongly related with the with the strength of the element to hold itself from bending which occurred caused by the shear force. The highest the bending moment of he element, the amount of steel reinforcement required increase, respectively. Table 4.1 an Table 4.2 show the bending moment, M_{Ed}, and area of steel, $A_{s,req}$, of main reinforcement and shear reinforcement of Beam B2, respectively, when built on non seismic design, Soil Type A, Soil Type B, Soil Type C, and Soil Type D. Soil Type D has the highest bending moment, M_{Ed} and area of steel

$A_{s,req}$ for main reinforcement and shear reinforcement, respectively, compared to others as shown in Table 4.1 and Table 4.2 below.

Table 4.1 Main reinforcement of Beam B2 influenced by Soil Type

SOIL TYPE	GRADE CONCRETE	Med (kNm)	K/K'	As,req (mm2)	As,min (mm2)	As,prov (mm2)
NON SEISMIC	30	117.4	0.19	513	320	603
A	30	199.2	0.32	877	311	1473
B	30	256.8	0.41	1149	311	1473
C	30	282.7	0.45	1275	311	1473
D	30	391.3	0.67	1908	306	2415

Table 4.2 Shear reinforcement of Beam B2 influenced by Soil Type

SOIL TYPE	GRADE CONCRETE	As,req (mm2)
NON SEISMIC	30	240
A	30	242
B	30	260
C	30	285
D	30	367

4.3.2 Effect of Soil Type on amount of steel reinforcement for column element

In order to discuss on the effect of Soil Type on amount steel reinforcement for column element, main reinforcement graph and shear reinforcement graph has been developed with building model of non seismic design, Soil Type A, Soil Type B, Soil Type C, and Soil Type D. Figure 4.6 and Figure 4.7 below show the amount of steel reinforcement per 1m^3 of concrete for main reinforcement and shear reinforcement of Column C6, respectively.

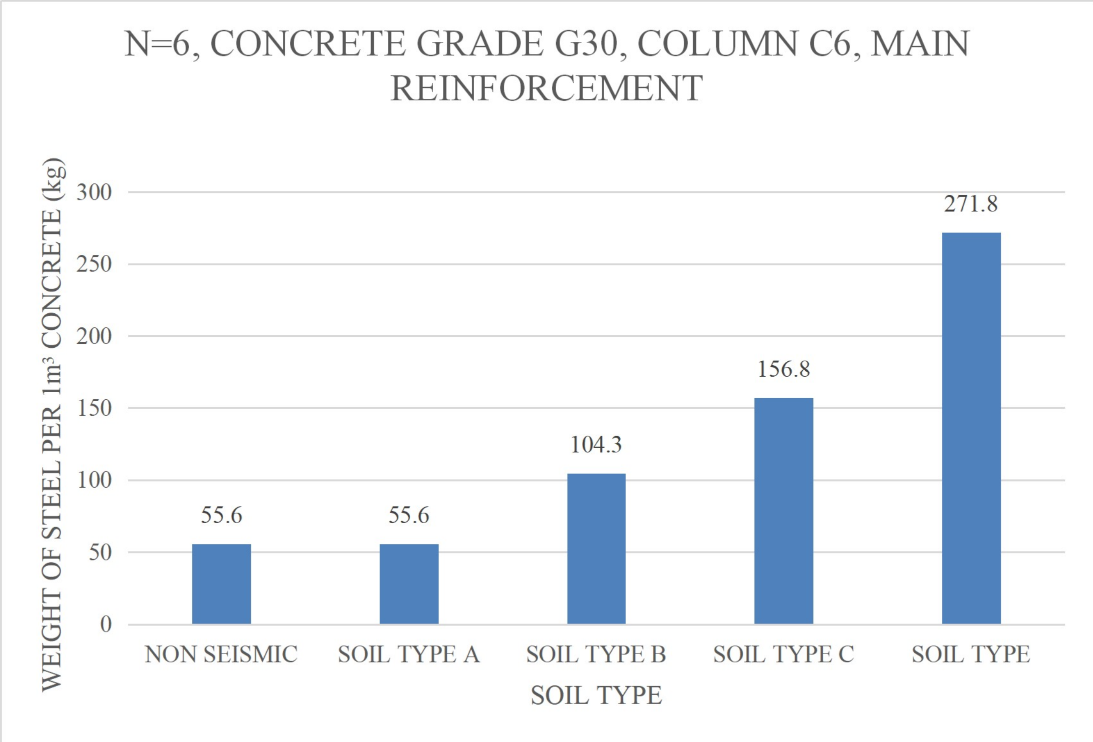

Figure 4.6 Total amount of steel reinforcement for $1m^3$ of concrete of Column C6 for main reinforcement influenced by Soil Type

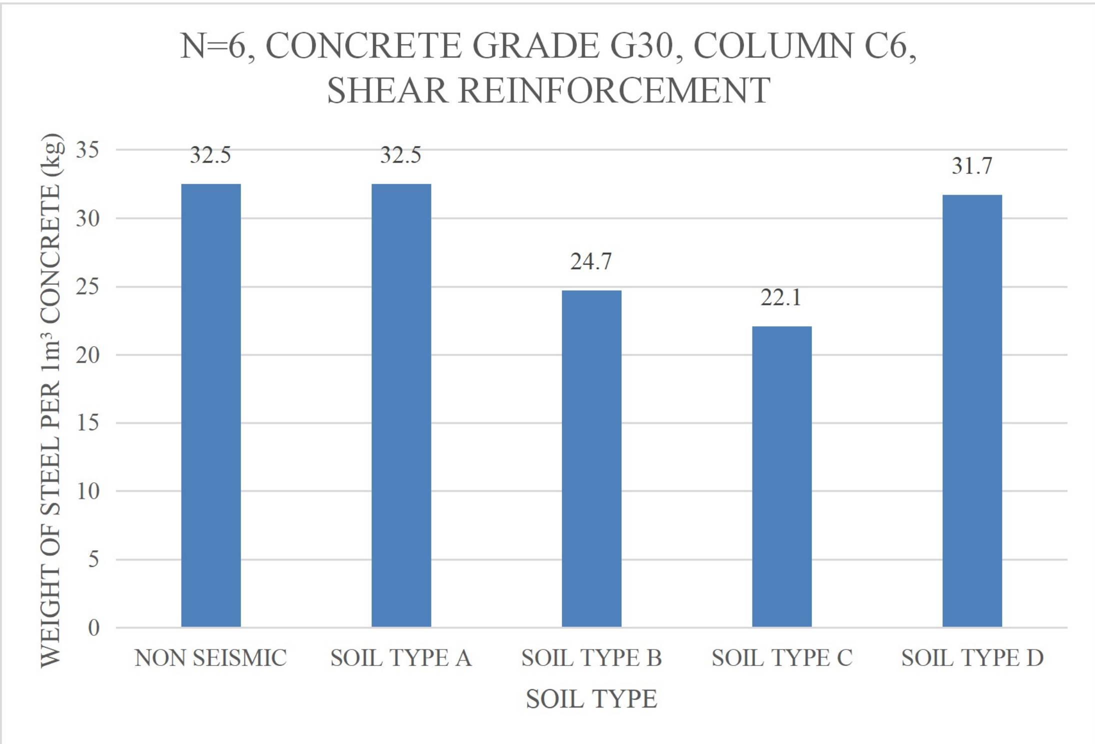

Figure 4.7 Total amount of steel reinforcement for $1m^3$ of concrete of Column C6 for shear reinforcement influenced by Soil Type

Figure 4.6 shows a linear pattern of graph where the building model with the lowest amount of steel required for 1m^3 of concrete is non seismic design and Soil Type A with 55.62 kg and the highest is Soil Type D which is 271.8 kg for Column C6 with concrete volume of 3.075 m^3. Figure 4.7 shows undefined pattern of graph where the building model with lowest value of steel reinforcement per 1m^3 of concrete is Soil Type C with 22.11 kg and the highest one is non seismic design which is 32.47 kg for Column C6 with concrete volume of 3.075 m^3.

Bending moment of an element absolutely influenced the amount of steel reinforcement required where the strength of the steel reinforcement help to resist or reduce the element from bend which cause by the shear force. The amount of steel reinforcement increase when the bending moment of the element increase. Table 4.3 an Table 4.4 show the bending moment, M_{Ed} and area of steel, $A_{s,req}$, of main reinforcement and shear reinforcement of Column C6, respectively, when built on non seismic design, Soil Type A, Soil Type B, Soil Type C, and Soil Type D. Soil Type D has the highest bending moment, M_{Ed} and area of steel, $A_{s,req}$ for main reinforcement and shear reinforcement, respectively, compared to others as shown in Table 4.3 and Table 4.4 below.

Table 4.3 Main reinforcement of Column C6 influenced by Soil Type

SOIL TYPE	GRADE CONCRETE	Med (kNm)	Mres (kNm)	As,min (mm2)	As,max (mm2)	As,l (mm2)
NS	30	90.2	296.2	1000	10000	1357
A	30	140.8	332.4	1000	10000	1357
B	30	188.1	387.3	1000	10000	2413
C	30	210.1	459.2	1000	10000	3770
D	30	302.6	555.4	1000	10000	5890

Table 4.4 Shear reinforcement of Column C6 influenced by Soil Type

SOIL TYPE	GRADE CONCRETE	As,req (mm2)
NON SEISMIC	30	804
A	30	804
B	30	574
C	30	698
D	30	1005

4.3.3 Effect of Soil Type on amount of steel reinforcement for beam element and column element

Figure 4.8 below shows the total amount of steel reinforcement for $1m^3$ of concrete for overall beam and column element in the whole building for main reinforcement and shear reinforcement, respectively, when constructed on non seismic design, Soil Type A, Soil Type B, Soil Type C, and Soil Type D by using concrete grade G30.

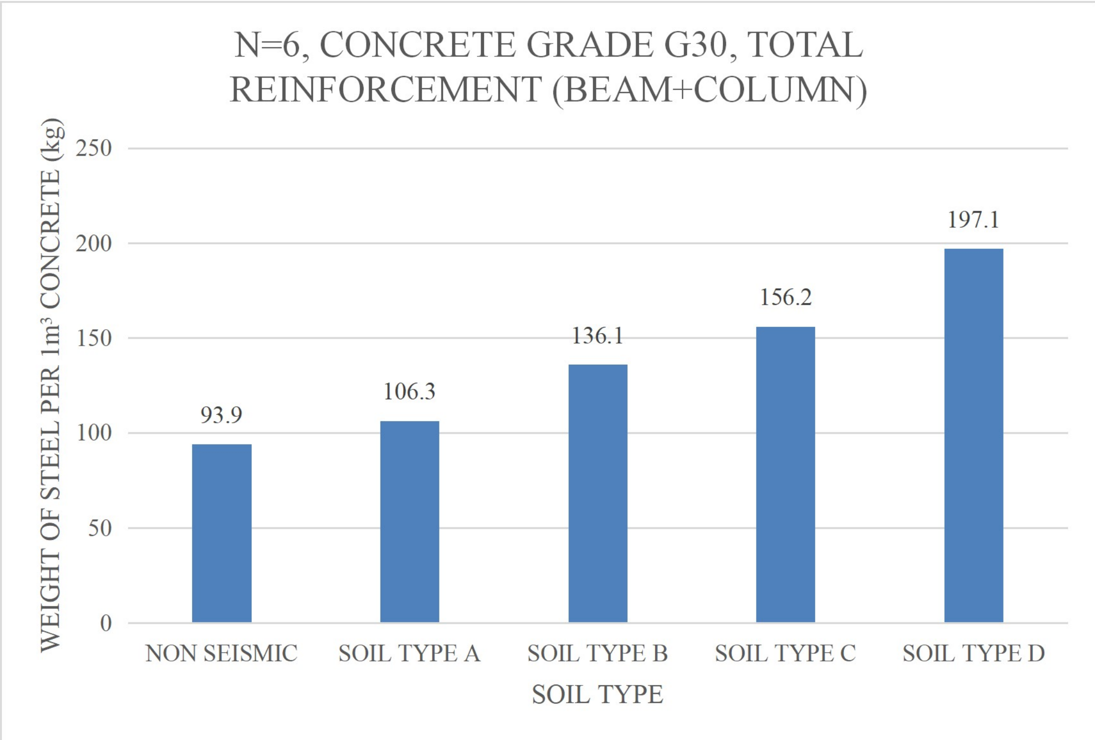

Figure 4.8 Total amount of steel reinforcement for $1m^3$ of concrete of overall beam and column element in the whole building influenced by Soil Type

From Figure 4.8, it can be conclude that the graph is increase linearly and obviously the total amount of steel reinforcement per $1m^3$ of concrete is strongly influenced by the main reinforcement. It also prove that the shear reinforcement is only contribute a little bit impact to the total of amount of steel required.

As in the Figure 4.8, the amount of steel reinforcement as main reinforcement and shear reinforcement for beam and column increase around 13.2% to 110% when compared to the non seismic design. For more detail, the increment is equal to 13.2%, 44.9%, 66.3%, and 110% when built on Soil Type A, Soil Type B, Soil Type C, and Soil Type D, respectively. Non seismic design has the lowest amount of steel required while Soil Type D is the highest one.

The result is strongly related to the value of spectrum design, $S_d(T)$, on various of Soil Type. Based on the previous design spectrum, $S_d(T)$ on Figure 4.1, Soil Type D has the highest design spectrum, $S_d(T)$ value. It is affect the value of base shear force, F_b, of the design where the base shear force, F_b value increase perpendicularly with the design spectrum, $S_d(T)$ value. When the base shear force, F_b value increase, the bending moment of the element also increase indirectly. When the bending moment increase, the area of steel required, $A_{s,req}$ 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 D can be classified as the critical Soil Type since it has the softer soil texture which didn't strong enough to hold the concrete without large amount of steel reinforcement used and the bending moment, M_{Ed} and area of steel required, $A_{s,req}$ for Soil Type D is the highest compared others.

4.4 Effect of Concrete Grade on Amount of Steel Reinforcement

This research 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 base on its strengthness which depends on its compressive strength. The amount of steel reinforcement per 1m^3 of concrete for each grade of concrete are compared for each grade of concrete. The analysis and design has been conducted by assumed the model built on Soil Type D. The result for Soil Type A, B, C and non seismic design can be refer at Appendix B.

There are two type of element considered for discussion namely as beam and column. Beam at grid line B/1-4 labeled as Beam B2 and column at grid line B/2 level 1 to level 3 labeled as Column C6 are selected for discussion. The position of selected beam and column are shown in Figure 4.2 and Figure 4.3, respectively.

4.4.1 Effect of concrete grade on amount of steel reinforcement for beam element

In order to discuss on the effect of grade of concrete on amount of steel reinforcement for beam element, main reinforcement graph and shear reinforcement graph has been developed with building model built Soil Type D by using concrete grade G30 and G40. Figure 4.9 and Figure 4.10 below show the amount of steel reinforcement per $1m^3$ of concrete for main reinforcement and shear reinforcement of Beam B2.

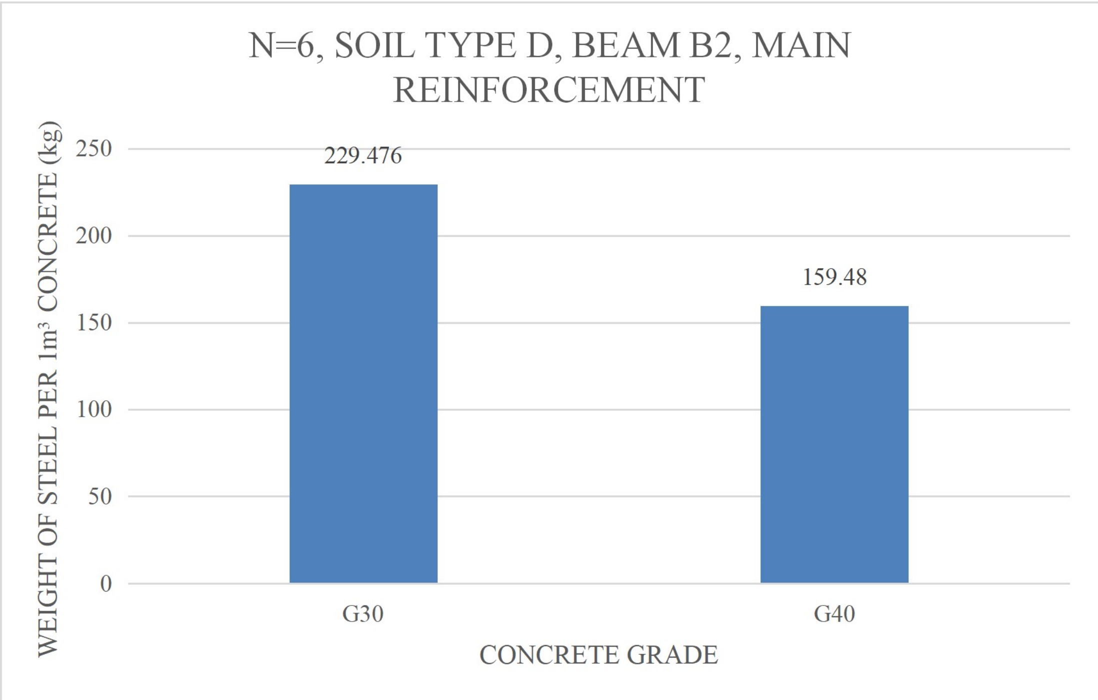

Figure 4.9 Total amount of steel reinforcement for $1m^3$ of concrete of Beam B2 for main reinforcement influenced by concrete grade

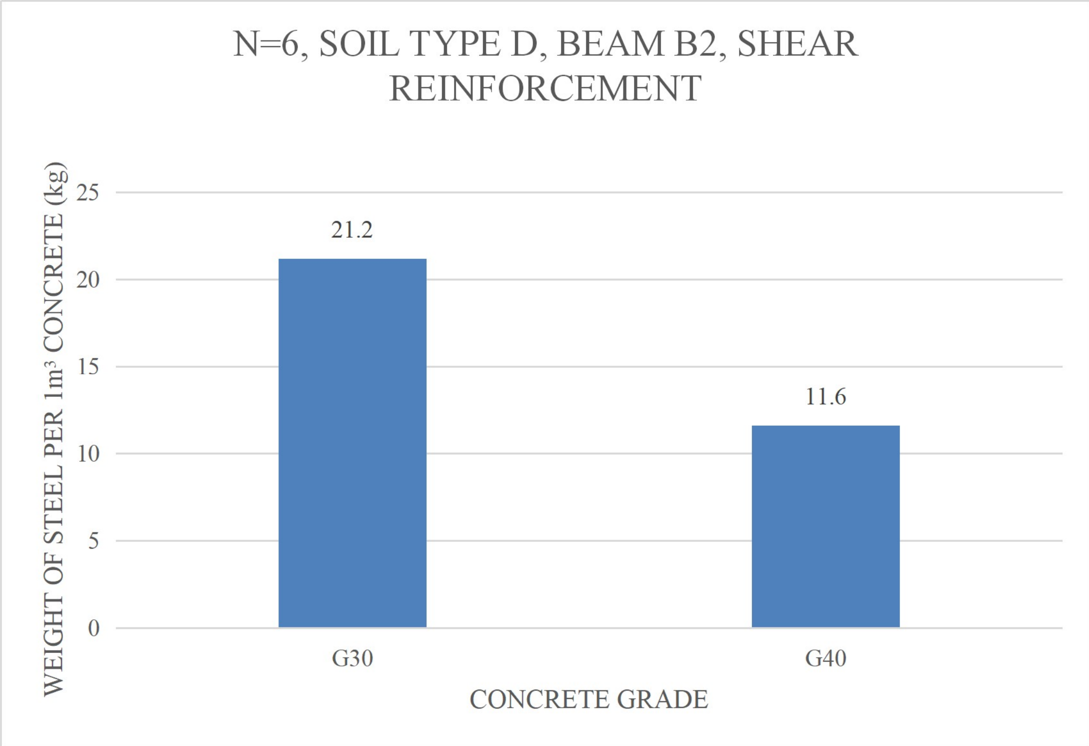

Figure 4.10 Total amount of steel reinforcement for $1m^3$ of concrete of Beam B2 for shear reinforcement influenced by concrete grade

Figure 4.9 shows that the amount of steel reinforcement for $1m^3$ of concrete of main reinforcement for concrete grade G30 is higher than concrete grade G40 which is 229.48 kg while for concrete grade G40 is 123 kg. The difference between the two grades of concrete is about 86.6% for Beam B2 with concrete volume of 3.15 m^3. Figure 4.10 shows that the amount of steel reinforcement for $1m^3$ of concrete of shear reinforcement for concrete grade G30 is higher than concrete grade G40 which is 21.2 kg while for concrete grade G40 is 11.6 kg. The difference between the two grades of concrete is about 75% for Beam B2 with concrete volume of 3.15 m^3.

The amount of steel reinforcement is strongly related with the with the strength of the element to hold itself from bending which occurred caused by the shear force. The highest the bending moment of he element, the amount of steel reinforcement required increase, respectively. Table 4.5 an Table 4.6 show the bending moment, M_{Ed}, and area of steel, $A_{s,req}$, of main reinforcement and shear reinforcement of Beam B2, respectively, when built on Soil Type D 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 bending moment, M_{Ed} and area of steel, $A_{s,req}$ for main reinforcement and shear reinforcement, respectively, compared to grade of concrete G40 as shown in Table 4.5 and Table 4.6 below.

Table 4.5 Main reinforcement of Beam B2 influenced by concrete grade

SOIL TYPE	GRADE CONCRETE	Med (kNm)	K/K'	As,req (mm2)	As,min (mm2)	As,prov (mm2)
D	G30	391.3	0.67	1908	306	2415
	G40	376.1	0.5	1826	374	2101

Table 4.6 Shear reinforcement of Beam B2 influenced by concrete grade

SOIL TYPE	CONCRETE GRADE	As,req (mm2/m)
D	G30	398
	G40	367

4.4.2 Effect of concrete grade on amount of steel reinforcement for column element

In order to discuss on the effect of grade of concrete on amount of steel required for column element, main reinforcement graph and shear reinforcement graph has been developed with building model built on Soil Type D by using concrete grade G30 and G40. Figure 4.11 and Figure 4.12 below show the amount of steel reinforcement per $1m^3$ of concrete for main reinforcement and shear reinforcement of Column C6.

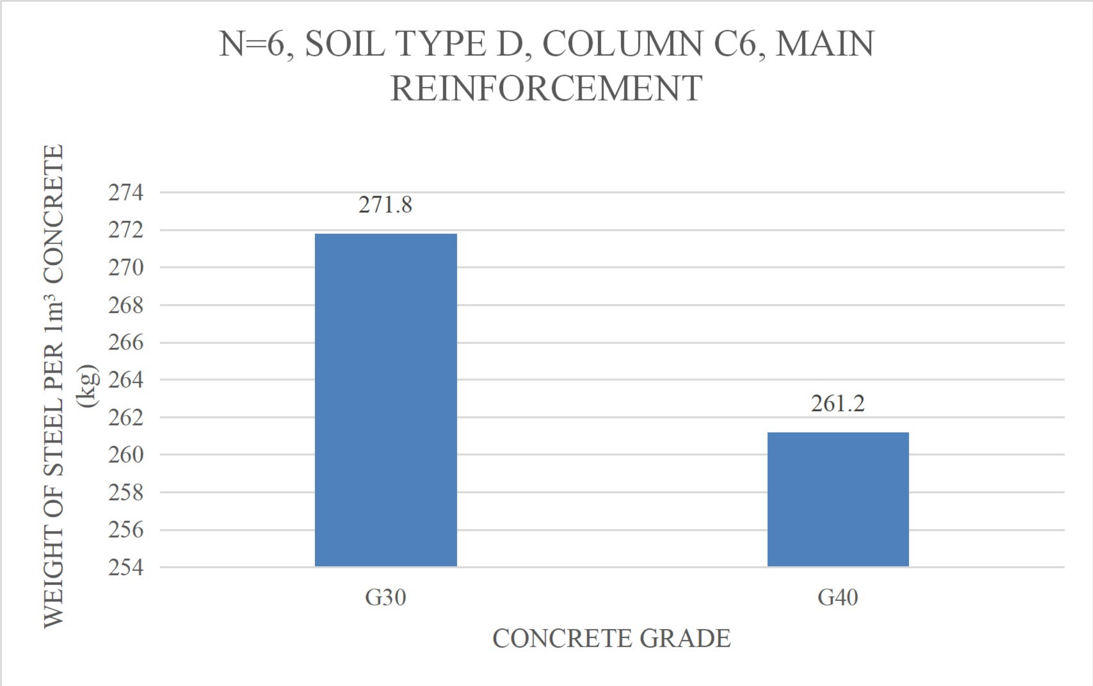

Figure 4.11 Total amount of steel reinforcement for $1m^3$ of concrete of Column C6 for main reinforcement influenced by concrete grade

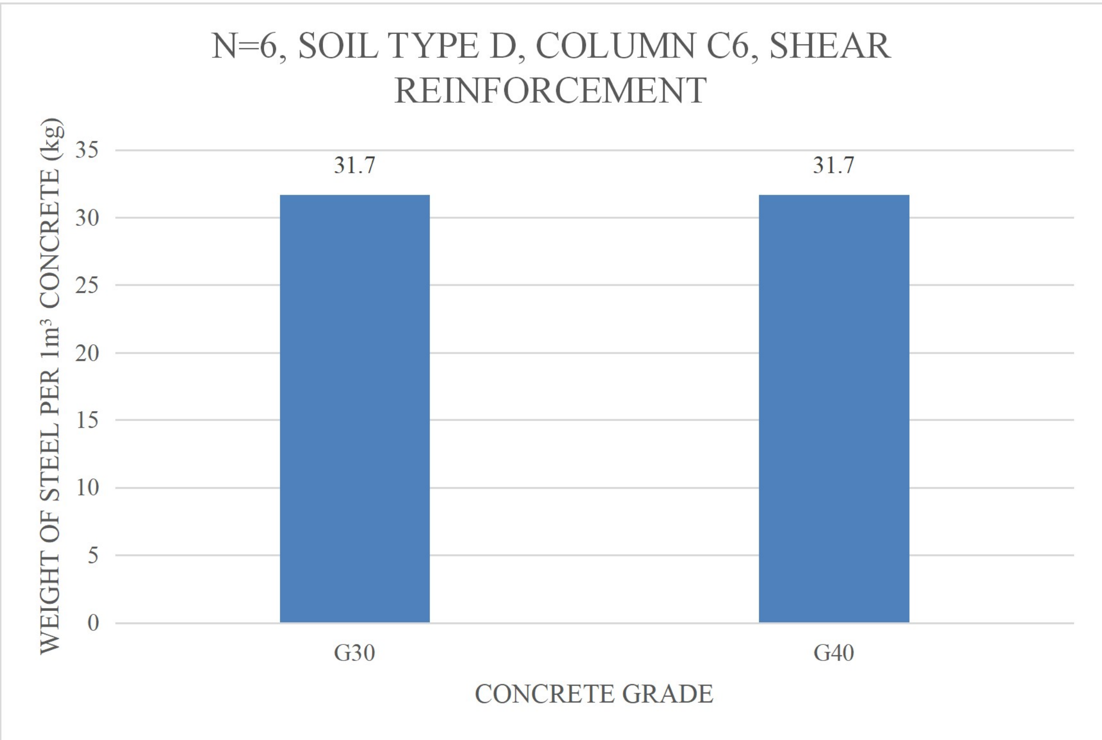

Figure 4.12 Total amount of steel reinforcement for $1m^3$ of concrete of Column C6 for shear reinforcement influenced by concrete grade

Figure 4.11 shows that the amount of steel reinforcement for $1m^3$ of concrete of main reinforcement for concrete grade G30 is higher than concrete grade G40 which is 271.8 kg while for concrete grade G40 is 261.2 kg. The difference between the two grades of concrete is about 4.2% for Column C6 with concrete volume of 3.075 m^3. Figure 4.12 shows that the amount of steel required for $1m^3$ of concrete of shear reinforcement for both concrete grade G30 and concrete grade G40 is equal which is 31.65 kg for Column C6 with concrete volume of 3.075 m^3. It obviously will give no significant effect to the amount of steel required for Column C6 built on Soil Type D by using concrete grade G30 and G40.

Bending moment of an element absolutely influenced the amount of steel reinforcement required where the strength of the steel reinforcement help to resist or reduce the element from bend which cause by the shear force. The amount of steel reinforcement increase when the bending moment of the element increase. Table 4.7 an Table 4.8 show the bending moment, M_{Ed} and area of steel, $A_{s,req}$, of main reinforcement and shear reinforcement of Column C6, respectively, when built on Soil Type D 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 bending moment, M_{Ed} and area of steel, $A_{s,req}$ for main reinforcement and shear reinforcement, respectively, compared to others as shown in Table 4.7 and Table 4.8 below.

Table 4.7 Main reinforcement of Column C6 influenced by concrete grade

SOIL TYPE	GRADE CONCRETE	Med (kNm)	Mres (kNm)	As,min (mm2)	As,max (mm2)	As,l (mm2)
D	G30	392.47	591.8	1000	10000	7639.3
	G40	302.6	555.4	1000	10000	5890

Table 4.8 Shear reinforcement of Column C6 influenced by concrete grade

SOIL TYPE	GRADE CONCRETE	As,req (mm2/m)
D	G30	1087
	G40	1005

4.4.3 Effect of concrete grade on amount on steel reinforcement for beam element and column element

Figure 4.13 below shows the total amount of steel reinforcement for $1m^3$ of concrete of overall beam and column in the whole building for main reinforcement and shear reinforcement, respectively, when built on Soil Type D by using two different grade of concrete which are grad of concrete G30 and grade of concrete G40.

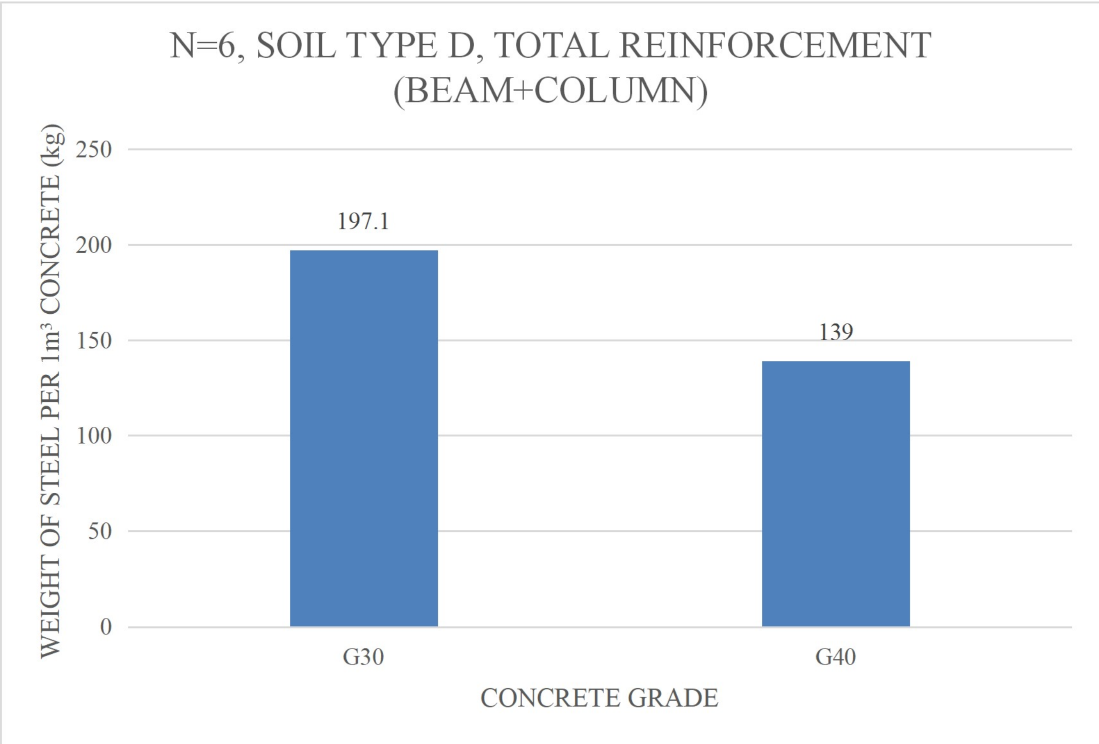

Figure 4.13 Total amount of steel reinforcement for $1m^3$ of concrete of overall beam and column element in the whole building influenced by concrete grade

From Figure 4.13, it can be conclude that the concrete grade G30 required high amount of steel reinforcement compared to concrete grade G40 and it clearly can be seen the total amount of steel reinforcement per $1m^3$ of concrete is strongly influenced by the main reinforcement. It also shown that the amount shear reinforcement is only slightly effected to the total of amount of steel required.

As in the Figure 4.13, the difference of amount of steel as main reinforcement and shear reinforcement for beam and column of concrete grade G30 and concrete grade G40 is about 41.8% where the grand total of amount of steel reinforcement for concrete grade G30 is 197.1 kg and 139 kg for 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 increase and make it more strong to hold the building without using large amount of steel reinforcement. When the concrete become weaker, the bending moment, M_{Ed}, of an element increase and also it cause the area of steel required, $A_{s,req}$, become more larger. Hence, the amount of steel reinforcement for the building also increase. Thus, since grade of concrete G30 has compressive strength of 30 MPa while grade of concrete G40 is 40 MPa, it prove that grade of concrete G30 can be classified as the critical concrete grade and required more steel reinforcement compared to grade of concrete G40.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This research studies of the effect of Soil Type and grade of concrete on the amount of steel reinforcement for $1m^3$ concrete of RC hospital building with seismic design. The non-seismic design was also carried out as the comparison to the seismic design. 10 sets of 6 storey RC hospital building have been use as the models to achieve the objective of this 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 of 0.10g, DCM, behaviour factor of 3.9 and designed based on Eurocode 8 (2004). The analysis and design of the models for both seismic design and non seismic design conducted by using Tekla Structural Design Software. The conclusion reached from this research are listed as follows.

- 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. Based on the overall beam and column element for the whole building, it show the total amount of steel reinforcement for the beam and column element per $1m^3$ of concrete for Soil Type D is about 110% higher compared to the non seismic design which need about 197 kg of steel per $1m^3$ of concrete for main reinforcement and shear reinforcement when constructed by using grade of concrete G30. While for concrete grade G40, it 78.4% higher and need about 139 kg of steel per $1m^3$ of concrete. In addition, for building constructed by using concrete grade G30 and concrete grade G40 on Soil Type D, the total amount of steel required of beam element and column element for whole building estimated as 95416 kg and 67309 kg, respectively. Thus, it proves that Soil Type D with seismic design consideration required large amount of steel reinforcement since its soil texture is the softer compared others and it can be classified as critical Soil Type and it is not strong enough to hold the building structure.

- 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. Grade of concrete G30 and grade of concrete G40 required about 197.1 kg and 139 kg of steel reinforcement per $1m^3$ of concrete, respectively. While for non seismic design building which there is no seismic design consideration, the concrete grade G30 is 20.5% higher than concrete grade G40. Thus, the building required more amount of steel when constructed by using concrete grade G30 either with or without seismic design consideration. Grade of concrete G30 required more steel reinforcement since its compressive strength is lower than grade of concrete G40 which is 30 MPa while for grade of concrete G40 is 40 MPa, respectively. It proves that when the higher of grade of concrete, the compressive strength also become more strong and it didn't need a large amount of steel reinforcement to support it since its compressive strength of concrete itself can cover up the strength to hold the building structure.

5.2 Recommendation for further research

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

i. This study could be conducted by using other Soil Type based on Eurocode 8 (2004) which is Soil Type E by using same model.
ii. Various of grade of concrete should be considered.
iii. Since this research is more focus on beam and column element, further investigation for other element such as slab and foundation should be carried out.

REFERENCES

Adiyanto, M. I., Majid, T. A. and Zaini, S. S. (2008). Analysis and Design of 3 Storey Hospital Structure Subjected To Seismic Load Using STAAD PRO, International Conference Construction and Building Technology Kuala Lumpur.

Adiyanto, M.I. & Majid, T.A. (2014). Seismic Design of Two Storey Reinforced Concrete Building in Malaysia with Low Class Ductility.' *Journal of Engineering Science and Technology*, vol.9, no. 1, pp. 27-46.

Adiyanto M.I, Majid T.A, (2014), Seismic performance of Three storey hospital RC frame subjected to multiple earthquake in moderate seismic region, Kyoto, Japan Conference proceedings, ICNSE, , pp.619-626.

Adiyanto, M. I., & Majid, T. A. (2014). Seismic design of two storey reinforced concrete building in Malaysia with low class ductility. *Journal of Engineering Science and Technology*, *9*(1), 27-46.

Adiyanto, M. I., Majid, T. A. (2014). Effect of behaviour factor on column design of reinforced concrete frame. *Proc. of the Intl. Conf. on Advances in Civil, Structural, Environmental, & Bio-Technology*. Institute of Research Engineers and Doctors.

Adiyanto. M.I. (2016). Influence of behaviour factor on seismic design and performance of reinforced concrete moment resisting frame in Malaysia, PhD Thesis, Universiti Sains Malaysia

CEN (2001). Eurocode 1: Action on structures. Part 1-1: General actions - densities, self weight, imposed loads for buildings, European Committee for Standardization, Brussels.

CEN (2004). Eurocode 8: Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings, European Committee for Standardization, Brussels.

Earthquake.usgs.gov. (2013). *The Science of Earthquakes*. [online] [Accessed 19 Oct. 2017] Available at: https://earthquake.usgs.gov/learn/kids/eqscience.php .

Elghazouli, A.Y. (2009). Seismic Design of Buildings to Eurocode 8. London and New York, Spon Press. pp.106-173.

Elnashai, A.S., and Sarno, L.D. (2008). Fundamentals of earthquake engineering. West Sussex, John Wiley & Sons Ltd, pp.97-98.

Endsley, K. (2007). *Earthquakes in the Midwestern and Eastern United States?!*. [online] Geo.mtu.edu.[Accessed 10 Oct. 2017] Available at: http://www.mtu.edu/404/?url=www.geo.mtu.edu/UPSeis/area.html%20.

Erduran, E., and Yakut, A. (2007). Component damage functions for reinforced concrete frame structures. *Journal of Engineering Structures*, 29, pp.2242-2253.

Eser, M., Aydemir, C., and Ekiz, I. (2011). Effects of soil structure interaction on strength reduction factors. *Procedia Engineering*, 14, pp.1696-1704.

Fardis, M. N., Carvalho, E. C., Fajfar, P., and Pecker, A. (2015). Seismic design of concrete buildings to Eurocode 8. Boca Raton, Taylor & Francis, pp.2-8.

FEMA (2007). NEHRP recommended provisions for new buildings and other structures: training and instructional materials, FEMA 451B, *Building Seismic Safety Council for the Federal Emergency Management Agency*, Washington D.C.

Filiatrault, A., Lachapelle, E., and Lamontagne, P. (1998b). Seismic performance of ductile and nominally ductile reinforced concrete moment resisting frames; II Analytical study. *Canadian Journal of Civil Engineering*, 25, pp.342-352.

Ganjavi, B., and Hao, H. (2012). Ductility reduction factor for multi degree of freedom system with soil structure interaction. *15th World Conference on Earthquake Engineering*, October 12-17, Lisbon, Portugal.

GmbH, E. (2000). *low-rise building | Emporis Standards | EMPORIS*. [online] Emporis.com. [Accessed 12 Oct. 2017]. Available at: https://www.emporis.com/building/standard/15/low-rise-building

Hossam, M. A. T. (2010). Seismic Design of Reinforced Concrete School Buildings in Malaysia based on UBC 97 and ACI 95. *Dissertation Master Degree of Science (Structural Engineering)*, Universiti Sains Malaysia, Malaysia.

Kirtas, E., and Kakaletsis, D.J. (2013). Numerical investigation of influential parameters concerning the experimental testing of RC frames under cyclic loading. *The Open Construction and Building Technology Journal*, 7, pp.230-243.

Majid, T. A., Adnan, A., Adiyanto, M. I., Ramli, M. Z., Ghuan, T. C. (2017). Preliminary damage assessment due to 2015 Ranau earthquake. '*International Jounal of Civil Engineering and Geo-Environmental.*

Malaysian Meteorological Department (2017) [Online], [Accessed 20 Oct. 2017]. Available from World Wide Web: http://www.met.gov.my/

Miranda, E., and Ruiz-Garcia, J. (2002). Influence of stiffness degradation on strength demands of structures built on soft soil sites. *Journal of Engineering Structures*, 24, pp.1271-1281.

MOSTI. (2009). Seismic and tsunami hazards and risks study in Malaysia, Final Report.

Nasai, N. A. B. M. (2017). Effect of soil type on seismic performance of reinforced concrete school building (Doctoral dissertation, Universiti Malaysia Pahang).

Oldham, R. (1906). *Seismic Tomography*. [online] Colorado.edu. [Accessed 12 Oct. 2017].
Available at: https://www.colorado.edu/physics/phys2900/homepages/Marianne.Hogan/index.html

Pan T.C., Megawati K., Brownjohn J.M.W. and Lee C.L. (2001). The Bengkulu, Southern Sumatra, Earthquake of 4 June 2000 (Mw = 7.7): Another Warning to Remote Metropolitan Areas. *Seismological Research Letters*, 72 (2), March, pp. 171-185.

Pappin, J.W., Yim, P.H.I., and Koo, C.H.R. (2011). An approach for seismic design in Malaysia following the principles of Eurocode 8. *Bulletin Jurutera*, pp.22-28.

Park, Y.J., Ang, A.H-S. and Wen, Y.K. (1984). Seismic Damage Analysis and Damage-Limiting Design of R.C Buildings. *Technical Report of Research*, University of Illinois, Urbana, Illinois.

Rahman M. F. B. A. (2011). A Comparison of Structural Design of a Three-Storey Reinforced Concrete School Building in Malaysia based on UBC 97 and BS8110. BSc Dissertation, School of Civil Engineering, Universiti Sains Malaysia.

Ramli, M. Z, Adnan, A., Kadir, M. A, A., Alel, M. N. A. (2017). 'Cost Comparison for Non Seismic (EC2) and Seismic (EC8) Design in Different Ductility Class. ' *International Journal of Civil Engineering and Geo-Environmental.*

Rangin, C., LePichon, X., Mazzotti, S., Pubellier, M., Chamot-Rooke, N., Aurelio, M., Walpersdorf, A., Quebral, R. (1999). Plate convergence measured by GPS across the Sundaland/Philippine Sea Plate deformed boundary: the Philippines andeastern Indonesia. Geophys. J. Int. 139, 296–316.

Stockton, N., Stockton, N., Simon, M., Thompson, A., Gonzalez, R., Chen, S., Allain, R. and Simon, M. (2011). *Earthquakes Don't Kill People, Buldings Do*. [online] WIRED. [Accessed 10 Oct. 2017]
Available at: https://www.wired.com/2015/04/earthquakes-dont-kill-people-buildings/

Suhaimi, N. H. B. M. (2011). Seismic Design of 4 -Storey Reinforced Concrete Standard JKR School Building in Malaysia based on UBC 97. BSc Dissertation, School of Civil Engineering, Universiti Sains Malaysia.

Taresh H. M. A. (2010). Seismic Design of Reinforced Concrete School Buildings in Malaysia based on UBC 97 and ACI 95. MSc Dissertation, School of Civil Engineering, Universiti Sains Malaysia.

United States Geological Survey (2011) [Online]. [Accessed 13th Nov. 2017].
Available from World Wide Web:
http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/quakes_all.html

Vickery, D. J. (1982). School Buildings and Natural Disaster. United Nations, Educational, Scientific and Cultural Organization (UNESCO), Paris, pp. 29-33

APPENDIX A
EFFECT OF SOIL TYPE

GRADE OF CONCRETE G40

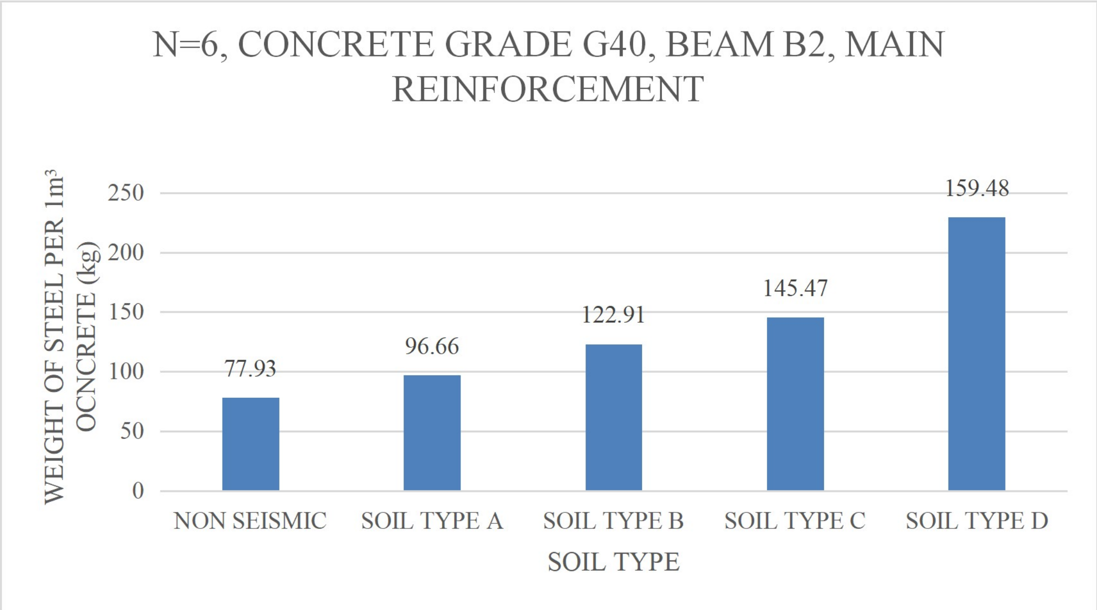

Figure A1a Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by Soil Type

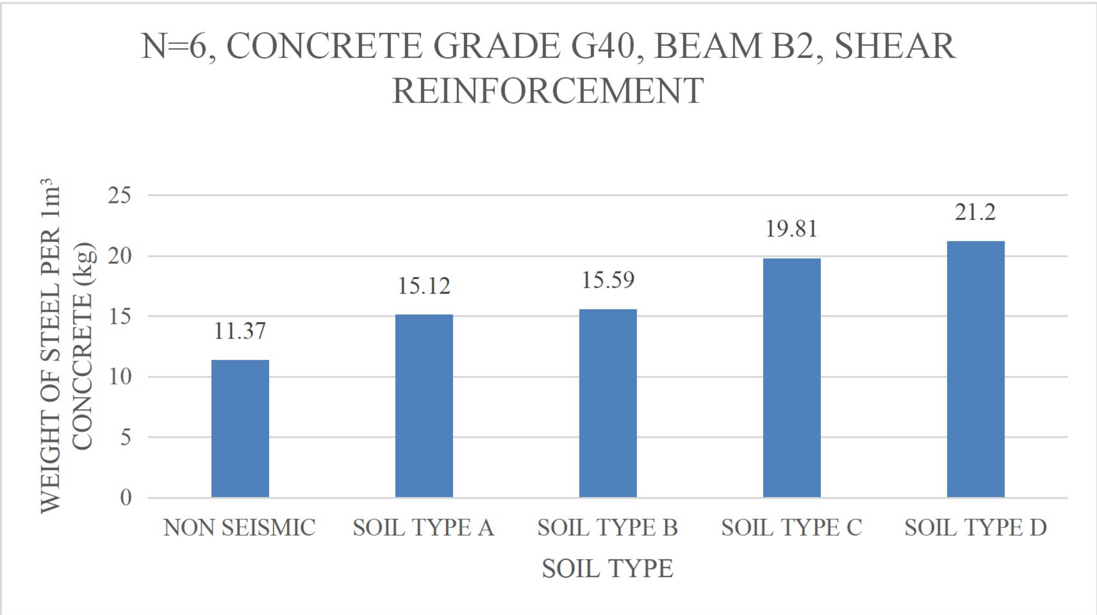

Figure A1b Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for shear reinforcement influenced by Soil Type

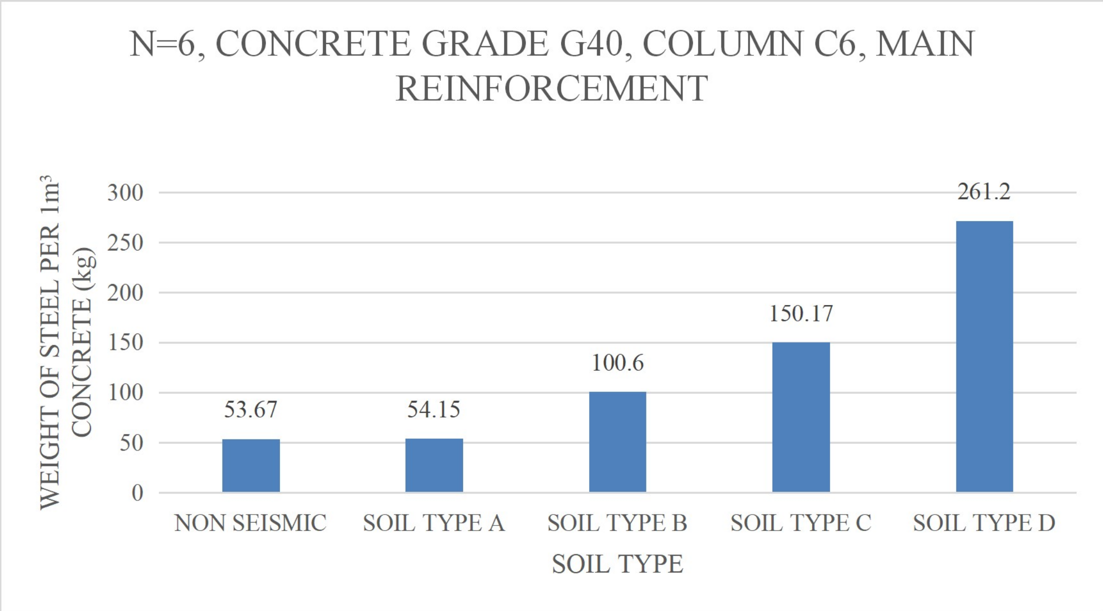

Figure A1c Total amount of steel reinforcement for 1m3 of concrete of Column C6 for main reinforcement influenced by Soil Type

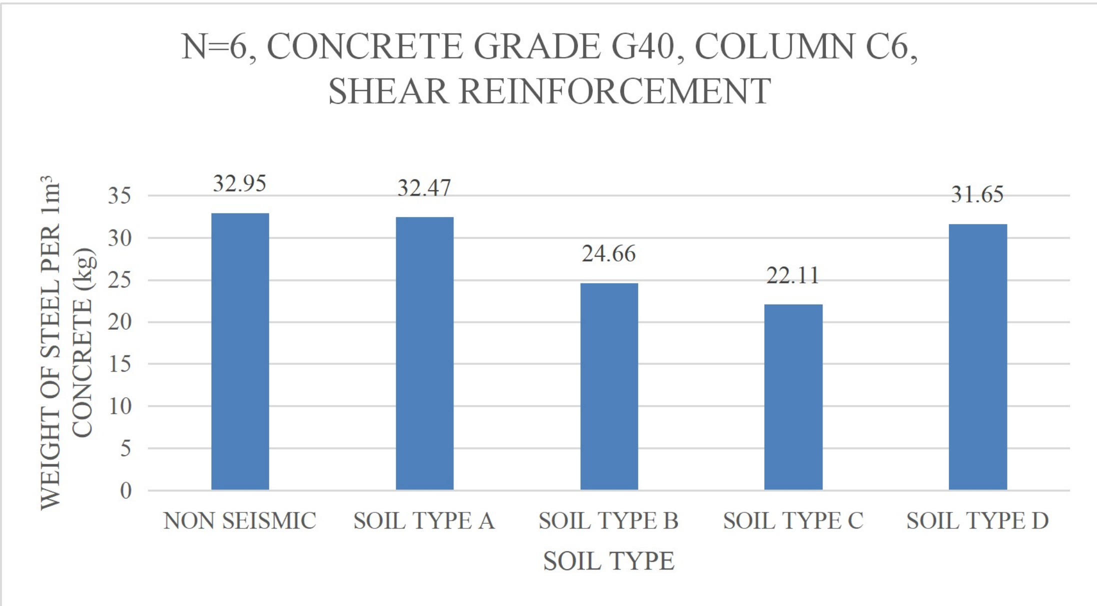

Figure A1d Total amount of steel reinforcement for 1m3 of concrete of Column C6 for shear reinforcement influenced by Soil Type

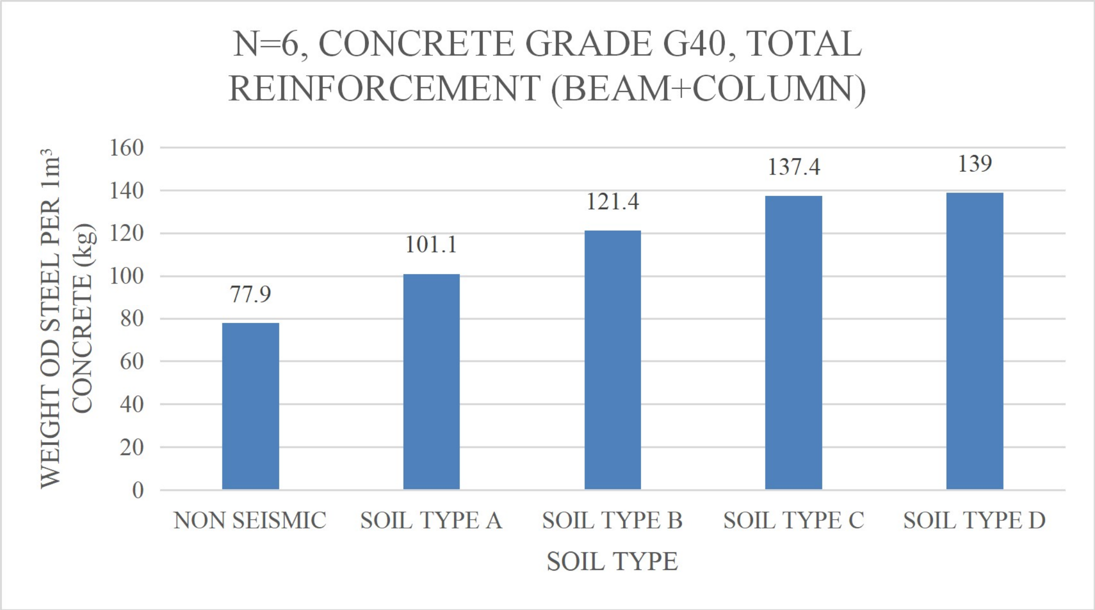

Figure A1e Total amount of steel reinforcement for $1m^3$ of concrete of overall beam and column element in the whole building influenced by Soil Type

APPENDIX B
EFFECT OF GRADE OF CONCRETE

SOIL TYPE A

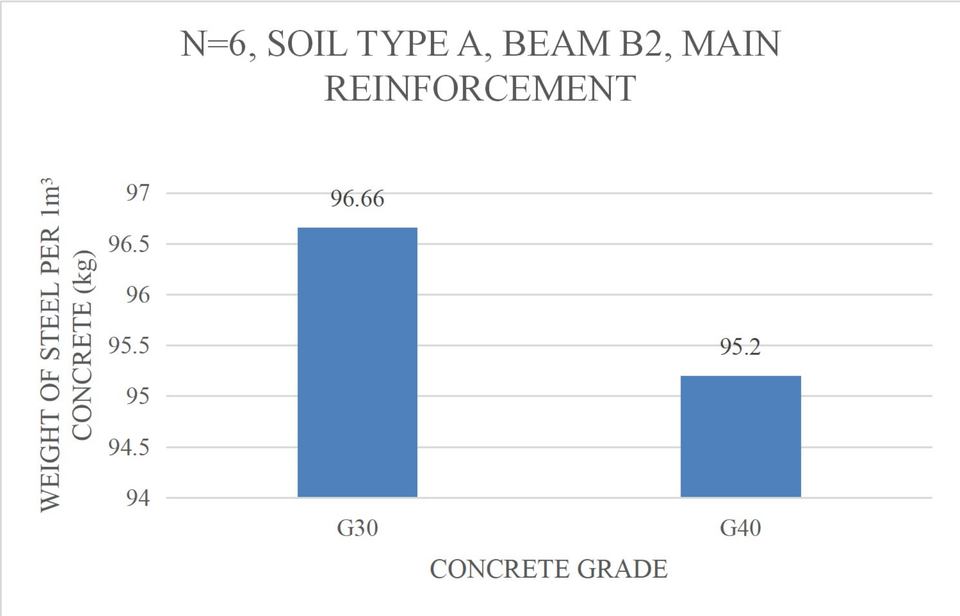

Figure B1a Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by concrete grade

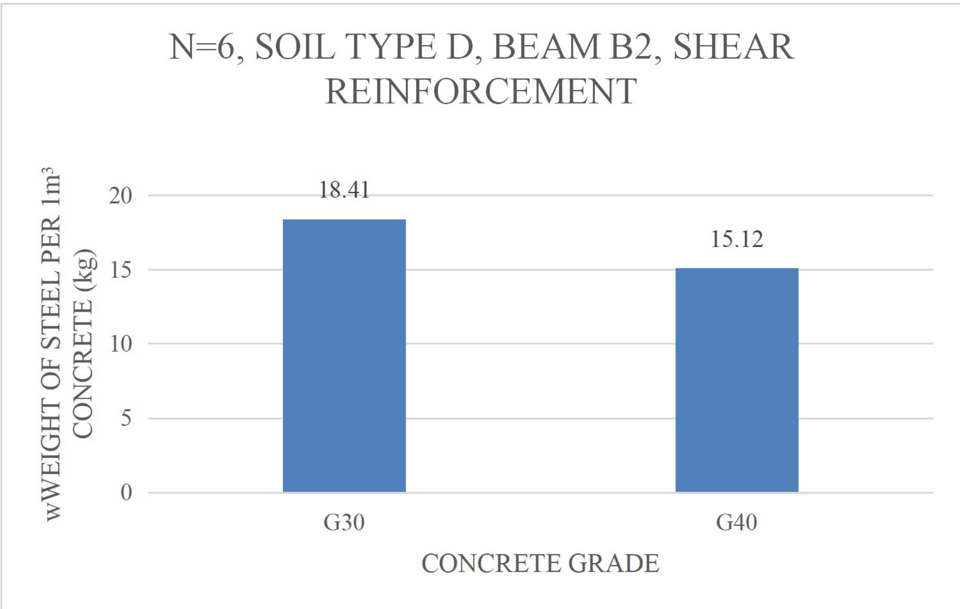

Figure B1b Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for shear reinforcement influenced by concrete grade

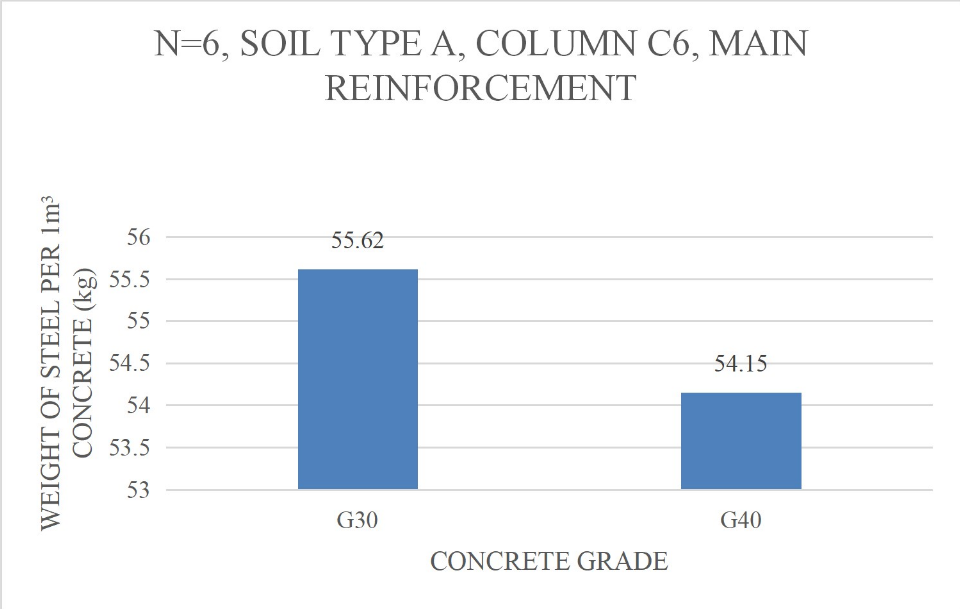

Figure B1c Total amount of steel reinforcement for 1m3 of concrete of Column C6 for main reinforcement influenced by concrete grade

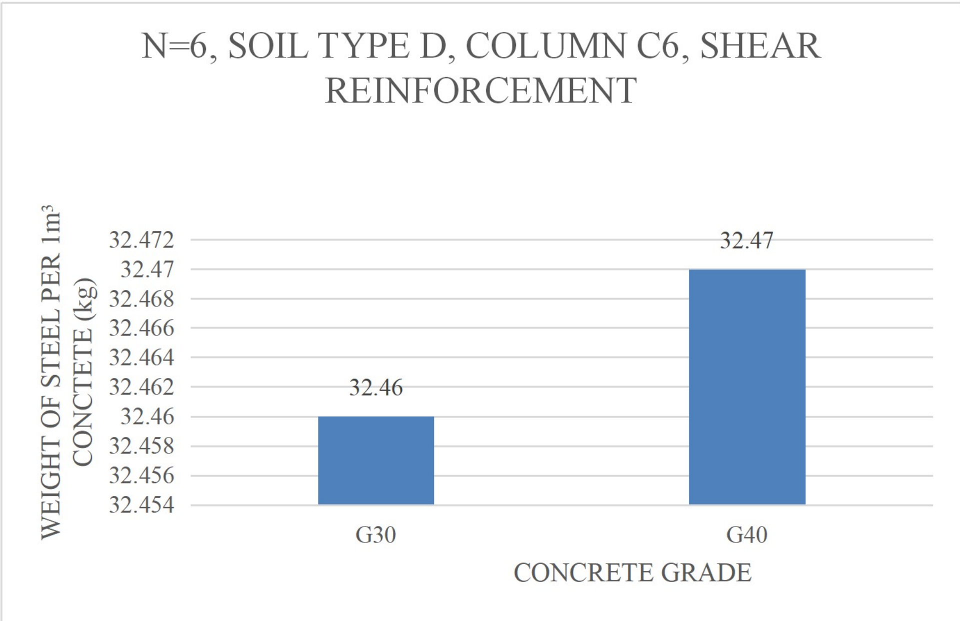

Figure B1d Total amount of steel reinforcement for 1m3 of concrete of Column C6 for shear reinforcement influenced by concrete grade

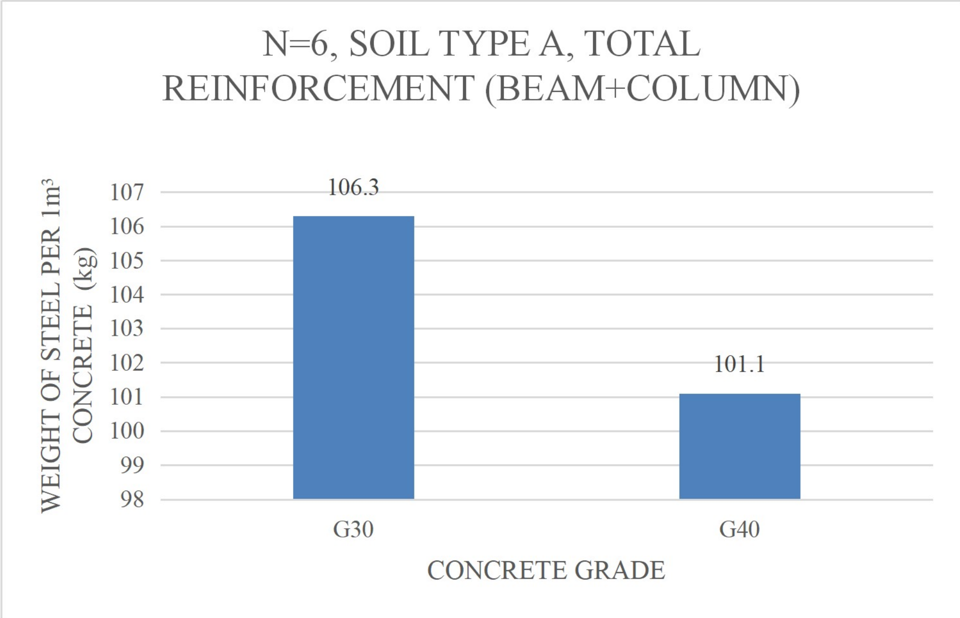

Figure B1e Total amount of steel reinforcement for 1m^3 of concrete of overall beam and column element in the whole building influenced by concrete grade

SOIL TYPE B

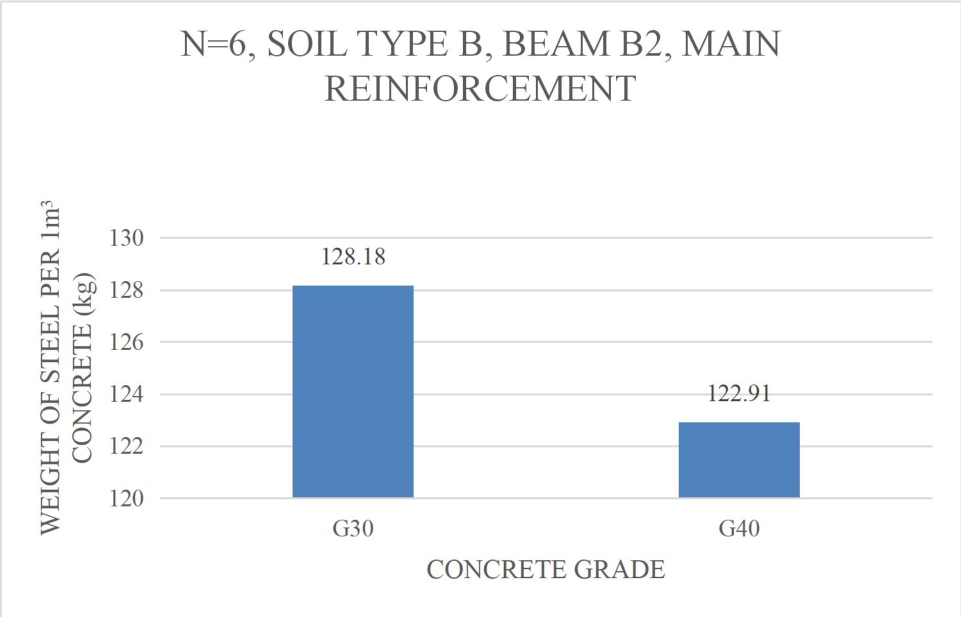

Figure B2a Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by concrete grade

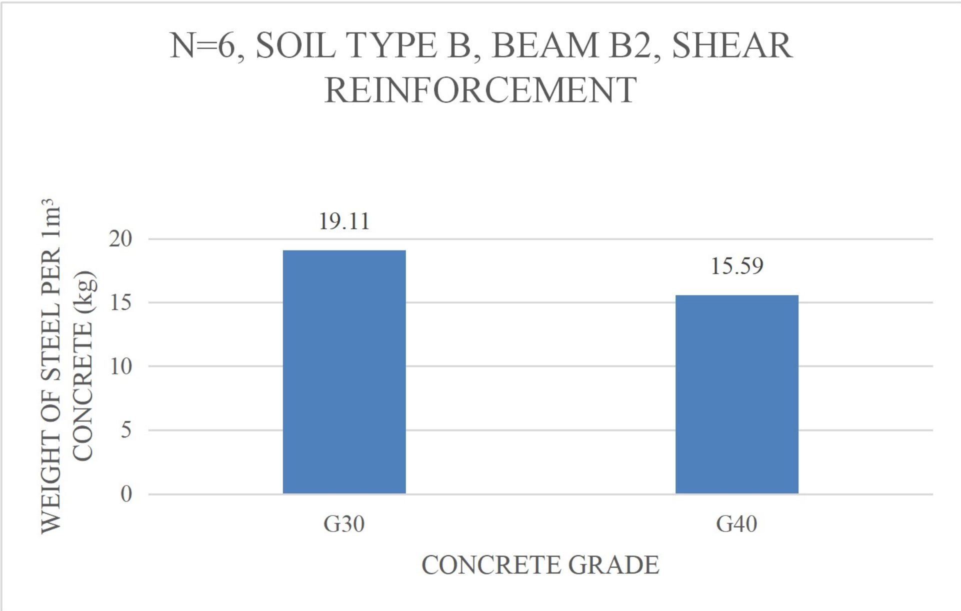

Figure B2b Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for shear reinforcement influenced by concrete grade

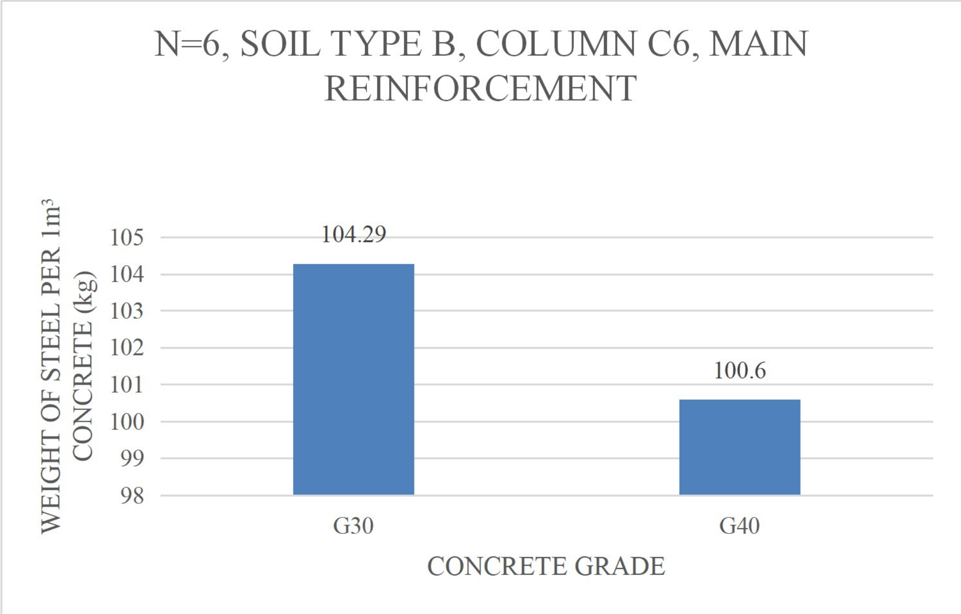

Figure B2c Total amount of steel reinforcement for 1m3 of concrete of Column C6 for main reinforcement influenced by concrete grade

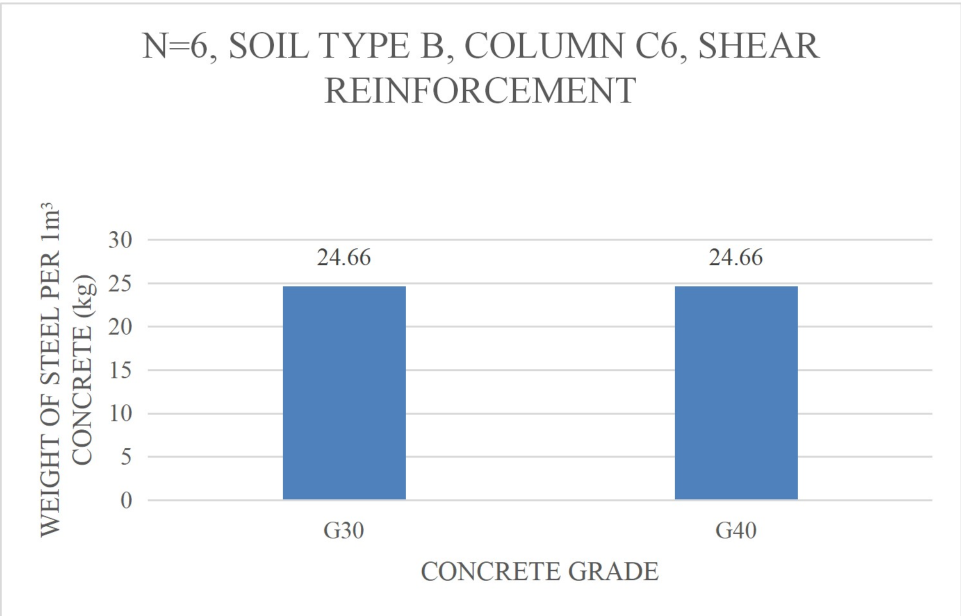

Figure B2d Total amount of steel reinforcement for 1m3 of concrete of Column C6 for shear reinforcement influenced by concrete grade

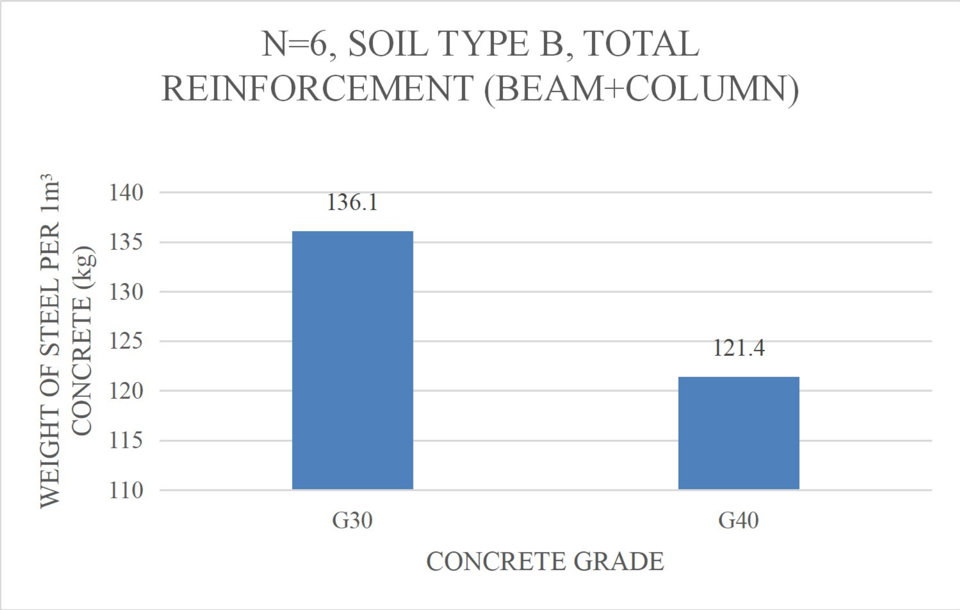

Figure B2e Total amount of steel reinforcement for 1m^3 of concrete of overall beam and column element in the whole building influenced by concrete grade

SOIL TYPE C

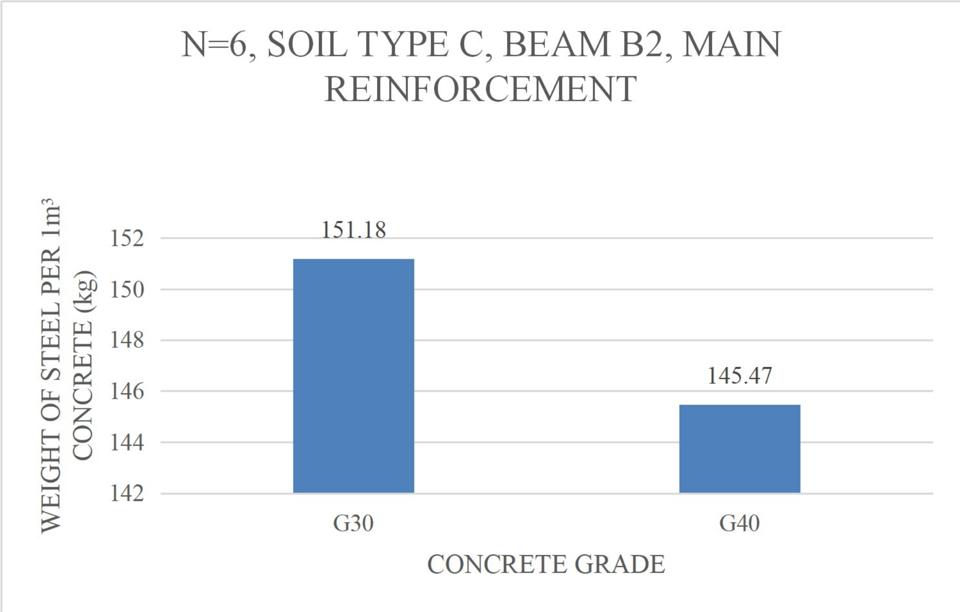

Figure B3a Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by concrete grade

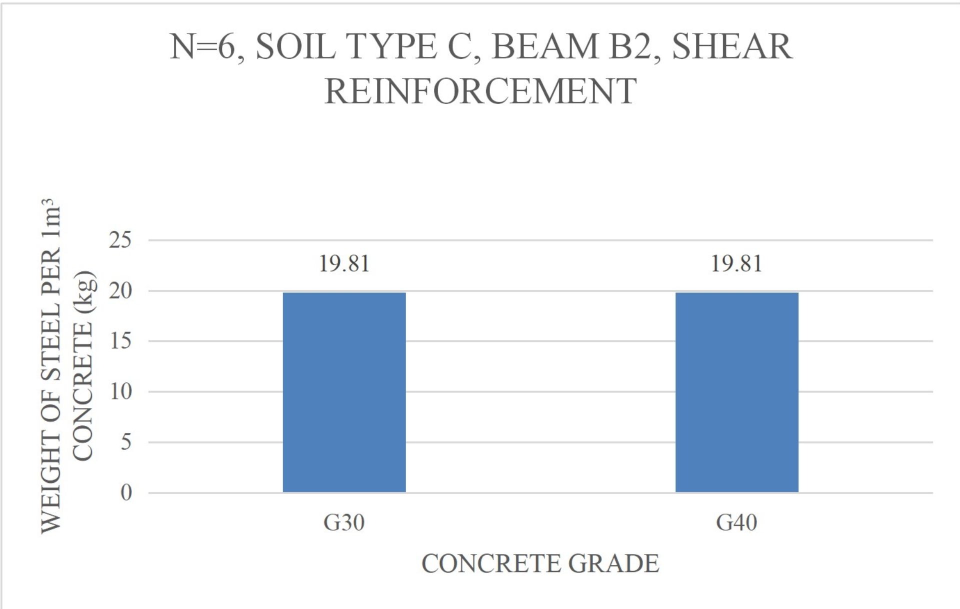

Figure B3b Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for shear reinforcement influenced by concrete grade

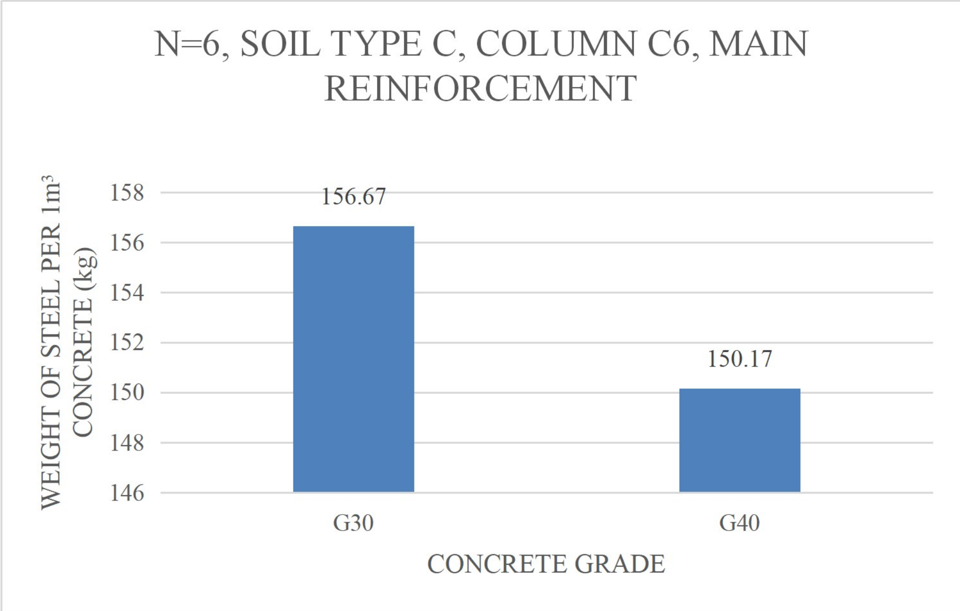

Figure B3c Total amount of steel reinforcement for 1m3 of concrete of Column C6 for main reinforcement influenced by concrete grade

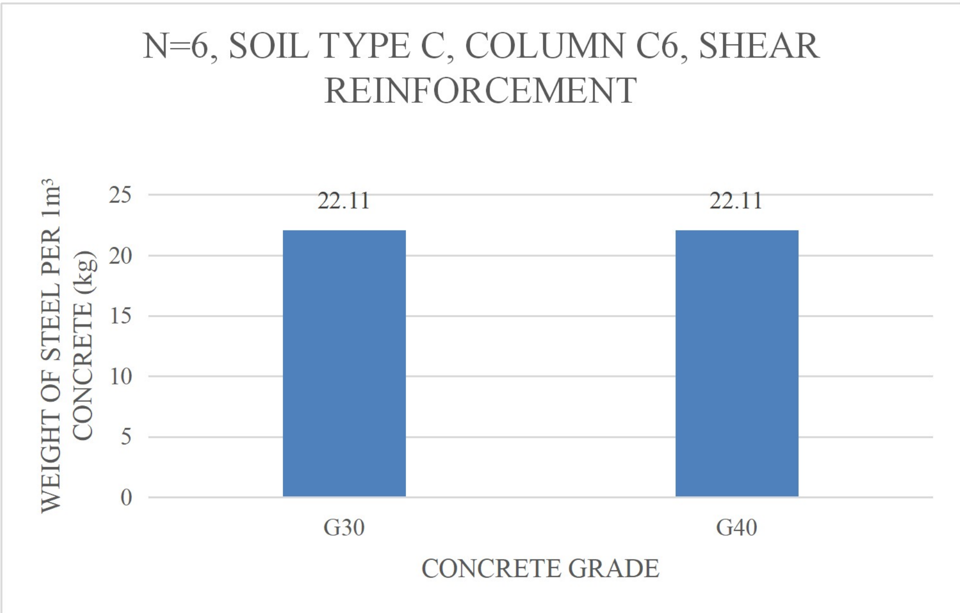

Figure B3d Total amount of steel reinforcement for 1m3 of concrete of Column C6 for shear reinforcement influenced by concrete grade

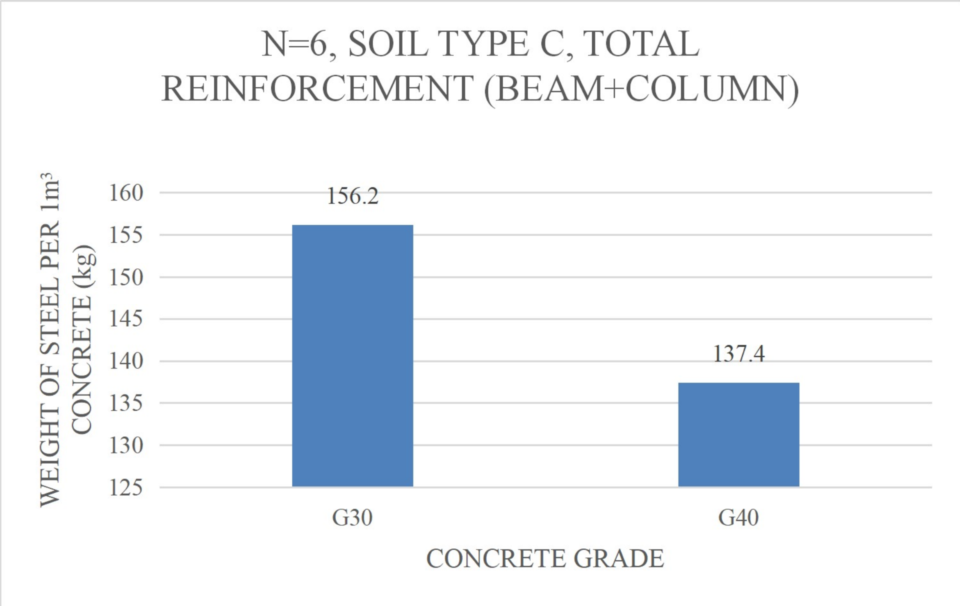

Figure B3e Total amount of steel reinforcement for 1m^3 of concrete of overall beam and column element in the whole building influenced by concrete grade

NON SEISMIC DESIGN

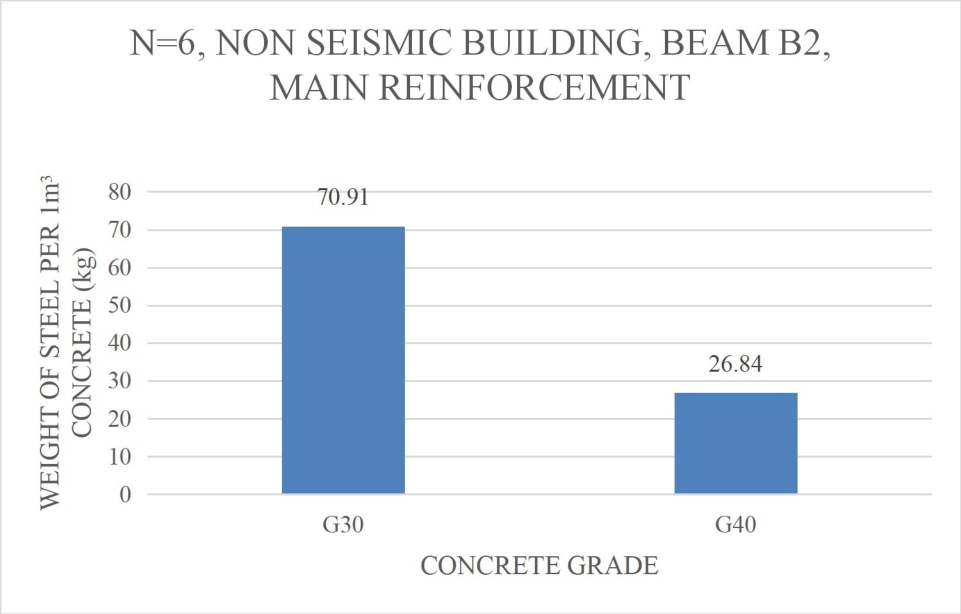

Figure B4a Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for main reinforcement influenced by concrete grade

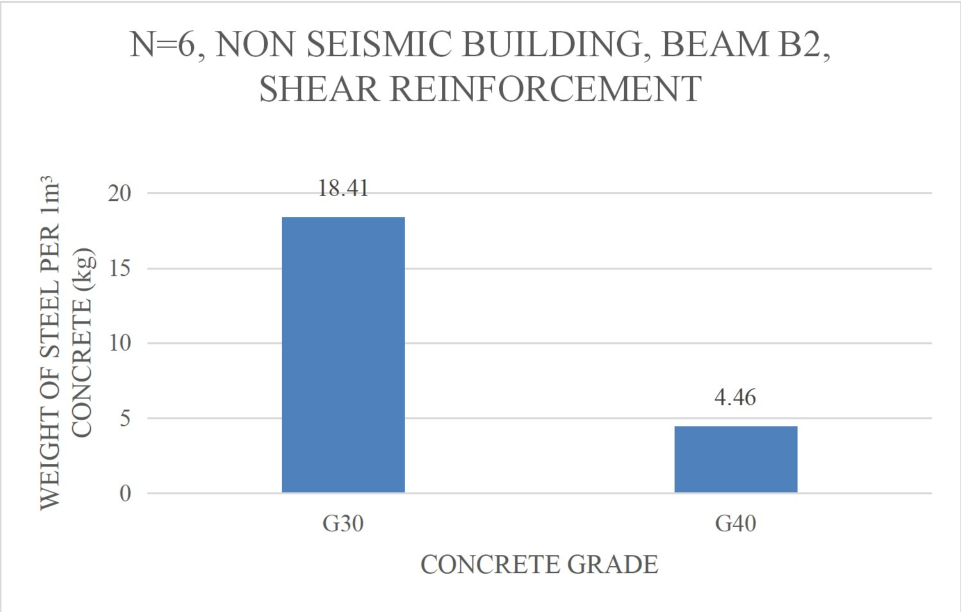

Figure B4b Total amount of steel reinforcement for 1m3 of concrete of Beam B2 for shear reinforcement influenced by concrete grade

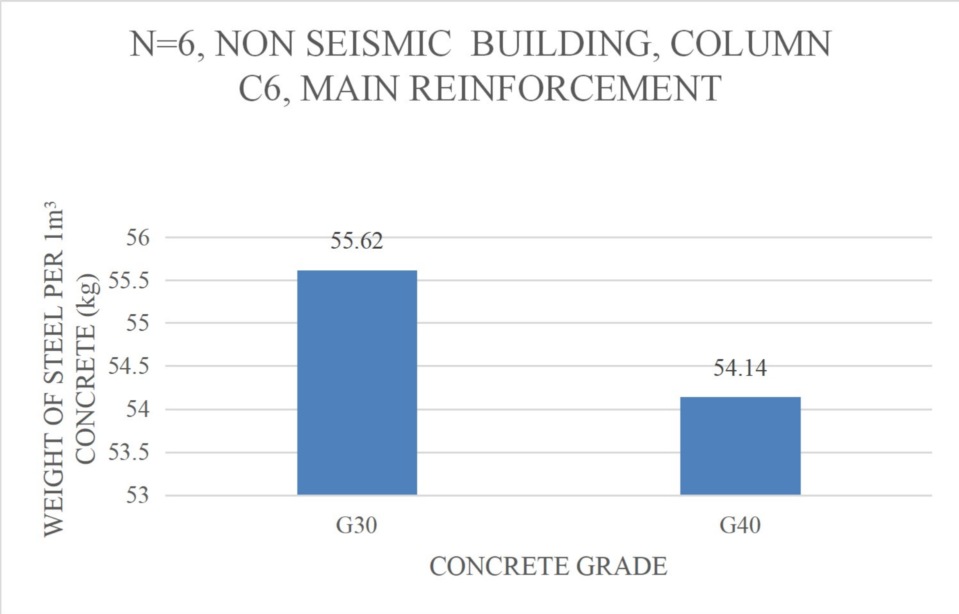

Figure B4c Total amount of steel reinforcement for 1m3 of concrete of Column C6 for main reinforcement influenced by concrete grade

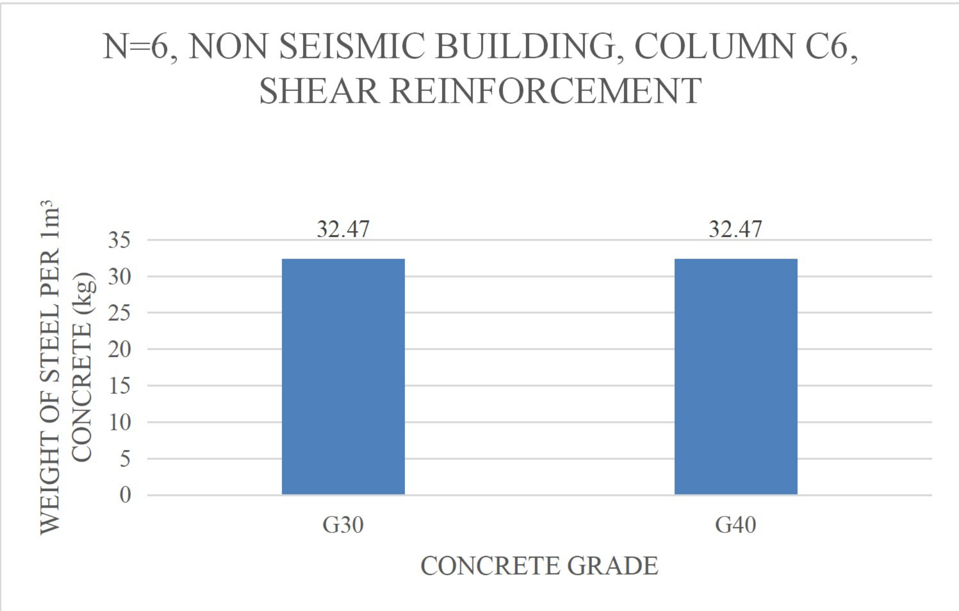

Figure B4d Total amount of steel reinforcement for 1m3 of concrete of Column C6 for shear reinforcement influenced by concrete grade

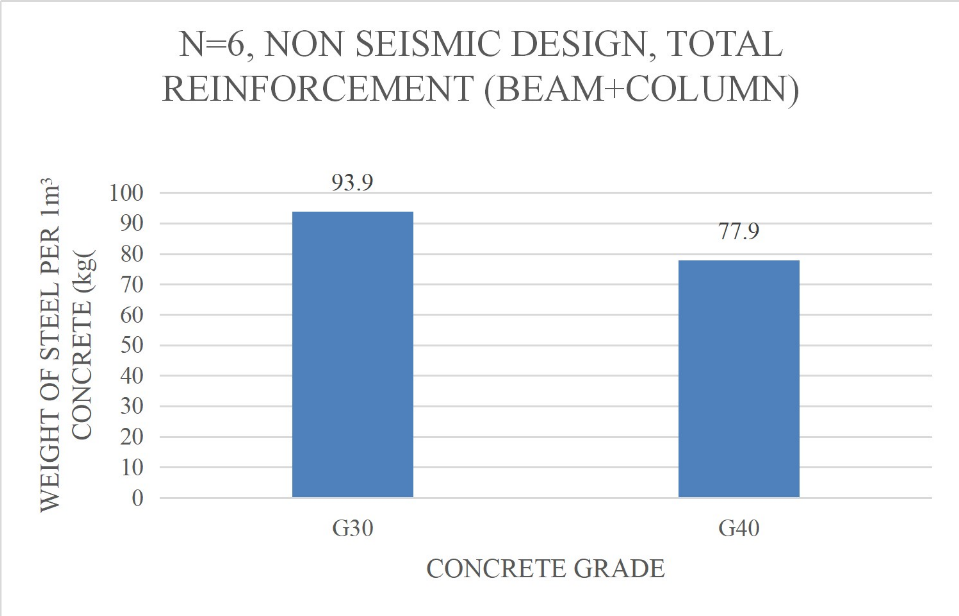

Figure B4e Total amount of steel reinforcement for 1m^3 of concrete of overall beam and column element in the whole building influenced by concrete grade