SEISMIC DESIGN FOR REINFORCED CONCRETE OFFICE BUILDING INFLUENCED BY CONCRETE GRADE AND LEVEL OF SEISMICITY

AZLINA BINTI NORDIN

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

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AZLINA BINTI NORDIN

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ABSTRAK

Gempa bumi adalah bencana alam yang boleh mengakibatkan runtuh bangunan. Bangunan pejabat adalah tempat pekerja melakukan kerja mereka, apabila gempa berlaku, bangunan itu tidak akan mampu menahan gempa bumi yang mungkin berbahaya kepada orang. Oleh itu, untuk menjadi tempat yang selamat, bangunan itu mesti menahan bencana seperti gempa bumi. Malaysia dianggap mempunyai profil seismicity yang rendah tetapi lebih banyak bukti menunjukkan bahawa anggapan awal Malaysia bebas daripada gempa bumi yang mengelirukan. Gempa bumi pada tahun 2004 gempa bumi India-India dengan magnitud 9.1 yang membunuh 68 nyawa di Malaysia dan beribu-ribu orang lain di Indonesia, Sri Lanka dan Thailand. Oleh itu, kerja-kerja ini akan memberi tumpuan kepada mengkaji kesan reka bentuk seismik terhadap berat pengukuhan keluli dan jumlah konkrit yang digunakan untuk bangunan pejabat. Objektif pertama ialah mengkaji kesan pada magnitud PGA pada jumlah pengukuhan keluli. Objektif kedua ialah mengkaji kesan pada gred konkrit pada jumlah pengukuhan keluli. Dan objektif ketiga untuk kajian ini adalah untuk mengkaji pengaruh PGA dan gred konkrit pada anggaran kos. Dalam keseluruhan 16 model bangunan pejabat konkrit bertetulang dengan bilangan 3 dan 6 tingkat akan digunakan dalam analisis ini. Model-model ini akan direka bentuk untuk dua gred konkrit yang berbeza iaitu G25 dan G30. Nilai PGA akan ditetapkan sebagai 0.03g, 0.09g dan 0.15g. Kajian ini hanya menilai medium dan jenis tanah kelas kemuluran D. Perisian struktur Tekla akan digunakan untuk analisis dan direka berdasarkan Eurocode 8 (2004). Perbandingan akan dibuat dari segi jumlah keluli yang diperlukan sebagai 1m3 konkrit bagi setiap model. Untuk magnitud PGA yang berbeza, hasilnya menunjukkan bahawa perbezaan peratusan pengukuhan keluli yang diperlukan untuk model bukan seismik bangunan 3 tingkat dan 6 tingkat telah meningkat dari 2%, 14% dan 56% dan 7%, 49% dan 162% bagi pecutan puncak puncak rujukan, agR = 0.03g, 0.09g dan 0.15g masing-masing. Walaupun untuk nilai gred konkrit yang berlainan, hasilnya menunjukkan bahawa perbezaan peratusan pengukuhan keluli yang diperlukan untuk model bukan seismik bangunan 3 tingkat dan 6 tingkat telah berkurang dari 36% kepada 56% dan 162% kepada 139% mengikut gred konkrit yang berlainan. Oleh itu, magnitud PGA dan gred konkrit struktur memberikan kesan yang signifikan kepada jumlah keseluruhan pengukuhan keluli yang diperlukan. Oleh itu, ia perlu dipertimbangkan dalam merekabentuk bangunan seismik.

ABSTRACT

Earthquake is a natural disaster that may lead to collapsing of building. Office building is a place the employee do their work, when earthquake happened, the building will not be able to withstand the earthquake which may be dangerous to people. So, in order to be a safe place, the building must withstand the disaster such as earthquake. Malaysia is considered to have a low seismicity profile but more evidences are showing that early assumption Malaysia is free from earthquake are misleading. The earthquake on 2004 Indian-Ocean earthquake with magnitude 9.1 which killed 68 lives in Malaysia and thousands others in Indonesia, Sri Lanka and Thailand. Therefore, this work will focus on study the effect of seismic design on the weight of steel reinforcement and volume of concrete used for office building. The first objectives is to study the effect on magnitude of PGA on the amount of steel reinforcement. The second objectives is to study the effect on grade of concrete on the amount of steel reinforcement. And the third objectives for this research is to study the influence of PGA and grade of concrete on cost estimation. In the total of 16 models of reinforced concrete office building with number of 3 and 6 storeys will be used in this analysis. The models will be design for two different grade of concrete which are G25 and G30. The value of PGA will be fixed as 0.03g, 0.09g and 0.15g. This study only considered the ductility class medium and soil type D. Tekla structure software will be used for analysis and designed based on Eurocode 8 (2004). The comparison will be made in term of amount of steel required as 1m^3 of concrete for every model. For different magnitude of PGA, the result shows that the percentage difference of steel reinforcement required to non-seismic model of 3-storey and 6-storey office building had increased from 2%, 14% and 56% and 7%, 49% and 162% for reference peak ground acceleration, agR = 0.03g, 0.09g and 0.15g respectively. While for different value of grade of concrete, the result shows that the percentage difference of steel reinforcement required to non-seismic model of 3-storey and 6-storey office building had decrease from 36% to 56% and 162% to 139% respectively according to different grade of concrete. Thus, magnitude of PGA and concrete grade of structure give significant effect to overall amount of steel reinforcement required. Hence, it should be considered in designing a seismic building.

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LIST OF SYMBOLS

ag	Design ground acceleration
a_{gR}	Reference peak ground acceleration
$Asprov$	Total area of steel provided
$Asreq$	Total area of steel required
dbL	Diameter of longitudinal bar
d_{bw}	Diameter of shear or confinement bar
F_b	Base shear force
fcd	Design value of concrete compressive strength
fck	Characteristic cylinder strength of concrete
Fi	Lateral load on storey
Fy	Yield strength of reinforcement
g	Acceleration due to gravity, m/s2
Gk	Dead load
H	Storey height
M	Bending moment
m	mass of structure
MRb	Design moment resistance of beam
MRc	Design moment resistance of column
Mw	Magnitude of earthquake intensity
q	Behaviour factor
Qk	Live load
S	Soil factor
$Sd(T1)$	Ordinate of the design spectrum at period
$T1$	Fundamental period of vibration
TB	Lower limit of the period of the constant spectral acceleration
TC	Lower limit of the period of the constant spectral acceleration
TD	Beginning of the constant displacement response range of the spectrum
V	Beginning of the constant displacement response range of the spectrum

LIST OF ABBREVIATIONS

DCH	Ductility class high
DCL	Ductility class low
DCM	Ductility class medium
Kelastic	Elastic stiffness
PGA	Peak ground acceleration
RC	Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.1 Introduction

Earthquake is a natural disaster that shows a results of shifting plates in the crust of earth and resulting a sudden release of energy in the earth of lithosphere which creates seismic waves. Earthquake happens when the earth plate move with respect to one another which make stress build up due to friction and stored. After that, it releases in the form of seismic waves which induce ground shaking. The shaking and the ground rupture are the main effects that created by earthquakes which can bring damage to building and rigid structures. According to (Martín-gonzález, 2018) damage in architectonic elements of buildings as shown in Figure 1.1 are one of the effects observed after earthquakes, and they can remain in historical buildings and archaeological sites for years and even centuries as a witness of the earthquake. Such earthquake damage can be used to complete historical seismic catalogue and give information about earth- quake parameters.

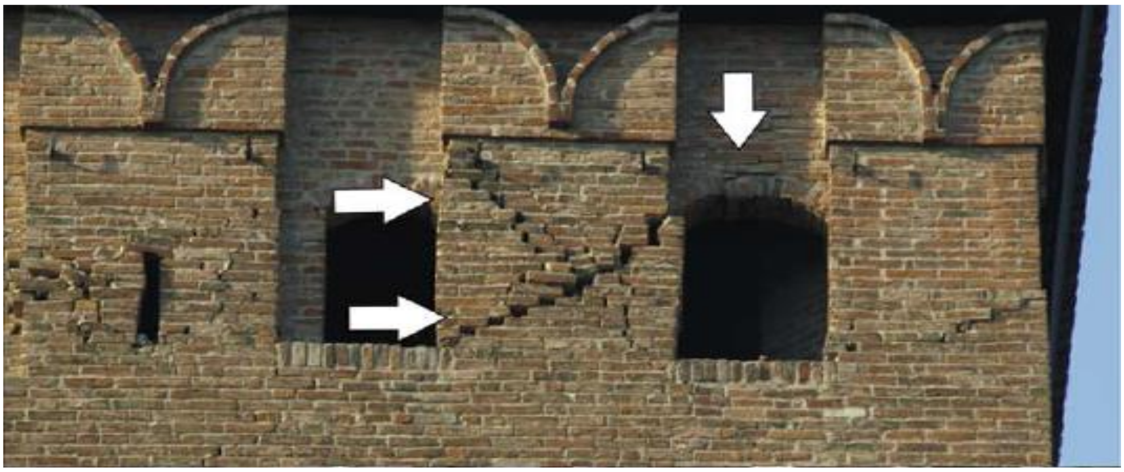


Figure 1.1: Conjugated fracture sets and dropped keystones in windows

Most earthquakes occur along the edge of the oceanic and continental plates. The earth's crust is made up of several pieces, called plates. The plates under the oceans are called oceanic plates and the rest are continental plates. The plates are moved around by the motion of a deeper part of the earth (the mantle) that lies underneath the crust. These plates are always bumping into each other, pulling away from each other, or past each other. The plates usually move at about the same speed that your fingernails grow. Earthquakes usually occur where two plates are running into each other or sliding past each other. Earthquakes can also occur far from the edges of plates, along faults. Faults are cracks in the earth where sections of a plate (or two plates) are moving in different directions. Faults are caused by all that bumping and sliding the plates do. Figure 1.2 shows the different types of faults which is normal, reverse and strike-slip.

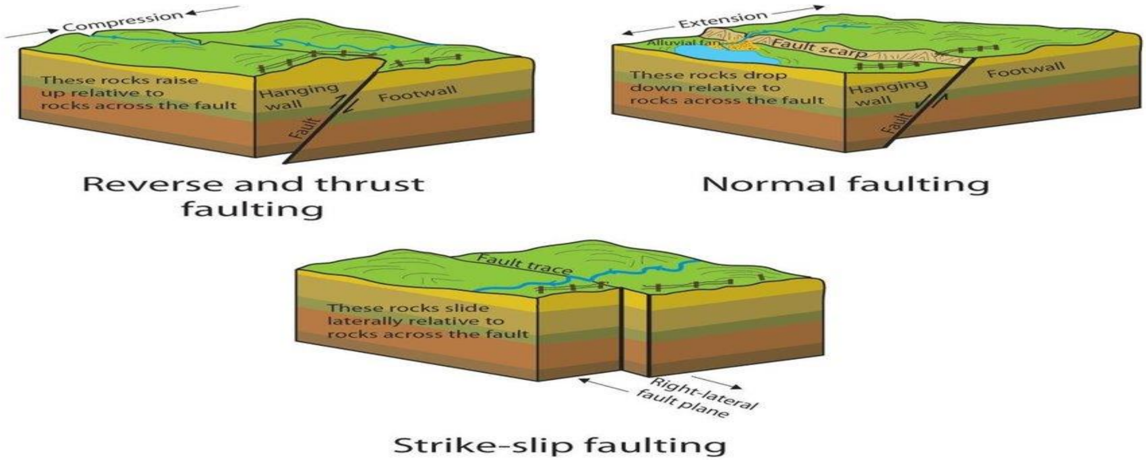


Figure 1.2: Types of faults (Normal, Reverse and Strike-Slip)

Malaysia is considered to have a low seismicity profile but more evidences are showing that early assumption Malaysia is free from earthquake are misleading. This is because, as the previous recorded earthquake that occurred in the neighboured countries such as Thailand and Indonesia, Malaysia is occasionally subjected to tremors. In accordance to the geological map of Peninsular Malaysia published by the Mineral and Geoscience Department of Malaysia (JMG), three prominent set of fault systems trending in N-S, E-W, and NW-SE directions were recognized. Seven major faults with strike-slip mechanism were listed within the region, including Bukit Tinggi fault, Kuala Lumpur fault, Bok Bak fault, Lebir fault, Terengganu fault, Lepar fault, and Mersing fault (Minerals and Geoscience Department Malaysia, 2014). The boundaries have been formed by the Hulu Kelang-Kongkoi fault zone and the Bukit Tinggi fault zone as shown in Figure 1.3.

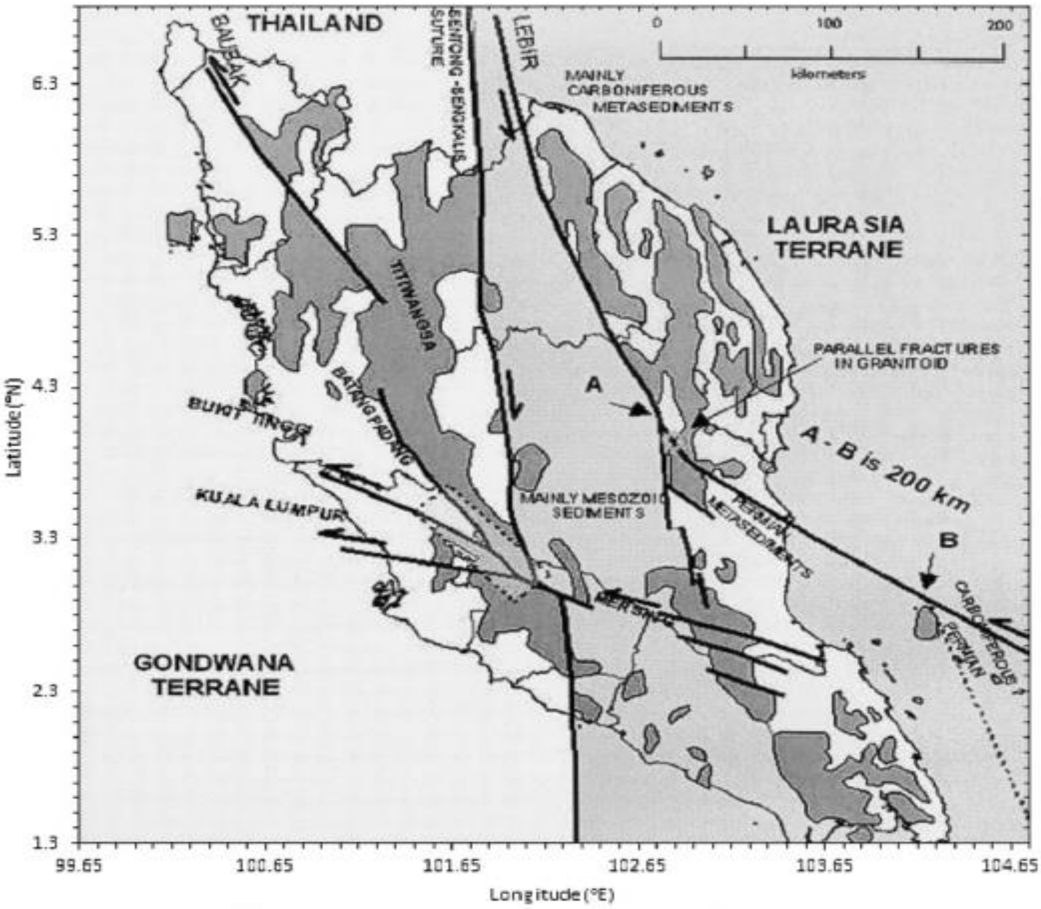


Figure 1.3: Local tectonic framework of Peninsular Malaysia (Minerals and Geoscience Department Malaysia, 2012).

1.2 Problem Statement

Earthquake had happened in Malaysia and also worldwide even though it is small or large magnitude. However, Malaysia has lack awareness about earthquake. Malaysia had experienced several local tremors from earthquakes which was occurred in Sabah, Peninsular Malaysia and also far field earthquakes from Indonesia and Philippine. In June 2015, Ranau was struck by a 6.0-magnitude earthquake. There were 18 people, including 9 Singaporeans, were killed when they were struck by falling rocks on Mount Kinabalu and also some 137 climbers were stranded on the mountain but were later rescued. Through the incidents, people starts to questioning that the building in Malaysia is strong enough to withstand or the resist earthquake.

Based on a study, a Malaysian Standards (MS) for earthquake-resistant building design code had been developed that involved two phases developed in collaboration with various stakeholders, acting as guidelines for local authorities on the design of earthquake-resistant structures in ensuring the lifespan, strength and safety of buildings in areas vulnerable to earthquakes (MOSTI, 2017). In order to be a safer place, the reinforced concrete (RC) office building must can withstand the load and force that produced by earthquake and also make the building structure can still survive during earthquake events. Hence, the office building shall be built to be able to resist earthquake and local authority also started to reconsider to implement seismic design in their practice.

It is important that RC office building to remain functioning even after gone through earthquake events. Therefore, this study is to investigate the performance of office building that subjected to seismic load towards the magnitude of Peak Ground Acceleration (PGA) and grade of concrete on the amount of steel reinforcement.

1.3 Objectives

Objectives of the study are:

i. To determine the effect on magnitude of PGA on the amount of steel reinforcement.

ii. To determine the effect of grade of concrete on the amount of steel reinforcement.

iii. To study the influence of PGA and grade of concrete on cost estimation.

1.4 Scope of Work

This study focused and covered the following aspects:

i. A 3 storey and 6 storey RC office building used as the basic model.

ii. Tekla software was used for analysis and design based on Eurocode 8 (2004).

iii. Three different magnitude of PGA equal to 0.03g to represent in Kapit, 0.09g to represent in Klang Valley and 0.15g to represent in Lahad Datu had been considered for design.

iv. Two different grade of concrete also had been considered for the design which is G25 and G30.

v. The model is assumed to be built on Soil Type D with Ductility Class Medium (DCM).

vi. The result are discussed in term of comparison of steel required as reinforcement influenced by magnitude of PGA and grade of concrete.

CHAPTER 2

LITERATURE REVIEW

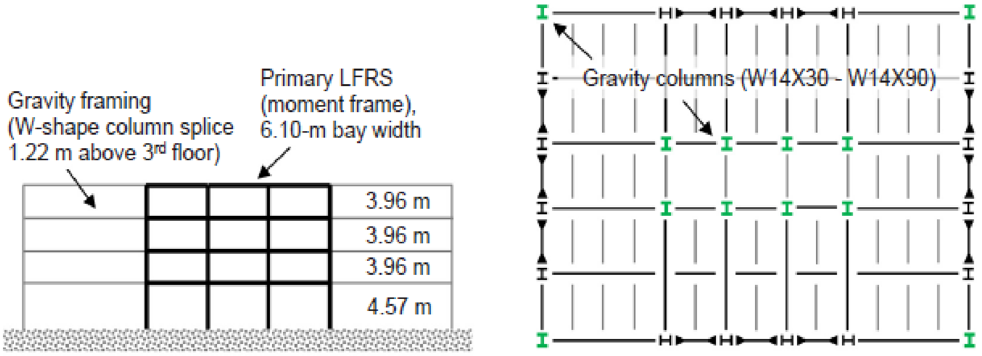
2.1 Introduction

Implemented seismic design on building structures required several number of important factors that should be analyse. This study will used Eurocode 8 as a guideline in overall design analysis. These code provide on the basis of seismic design which include general rules, seismic actions and rules for buildings which can minimising damage on building structures, protect human life and also ensuring the structures can be used after earthquake events. The main things that people concerned are the limitations of damage on building and safety issues of people even though it is just a small movement of building that creates by earthquake vibration. In order to get better understanding about the study, this chapter will discussed the literature review from previous study that related and relevant to this current study.

2.2 Earthquake Disaster

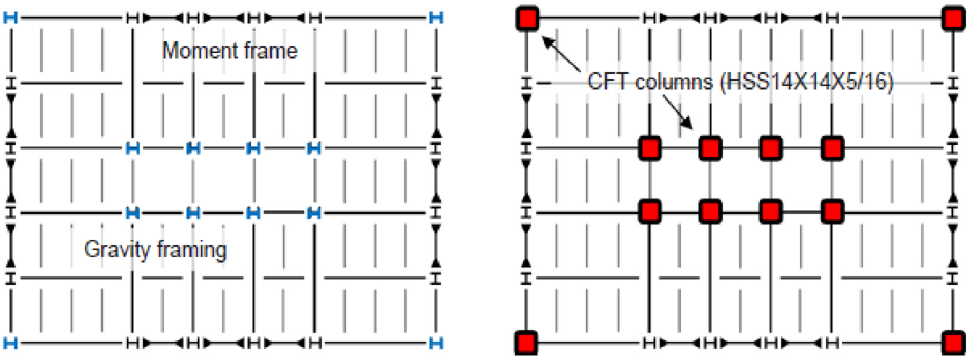
Mantawy (2018) has conducted a research that earthquakes induce loading cycles on structures based on the dynamic properties of their structural systems and the ground motion parameters. Due to the cyclic nature of the earthquake loading, deterioration of both strength and stiffness is expected to happen for different structural members resulting in a cumulative reduction in the service life. The occurrence of long-duration earthquakes increases the total number of loading cycles which the building might experience during its lifetime. The accumulation of seismic damage within the elements of a structure due to long-duration earthquakes can lead to increased vulnerability to failure. Long-duration earthquake can be more damaging than short-duration earthquakes due to the increased number of response cycles associated with the longer shaking which can lead to more significant damage.

Judd & Pakwan (2018) has studied about the seismic performance of steel moment frame office buildings with square concrete-filled steel tube gravity columns. And in his studies, he stated that buildings with the dual concrete-filled steel tube (CFT) system generally had improved seismic performance, depending on the moment frame design, the number of stories, and the intensity of the ground shaking. Buildings with the dual CFT system had up 45% lower repair costs, up to 64% shorter repair time, and a lower probability that the building would be deemed unsafe.



a) Elevation view of building frame

b) W-shape gravity columns weak orientation



c) W-shape gravity columns strong orientation

d) CFT columns

Figure 2.1: Building Configuration that used by (Judd & Pakwan, 2018)

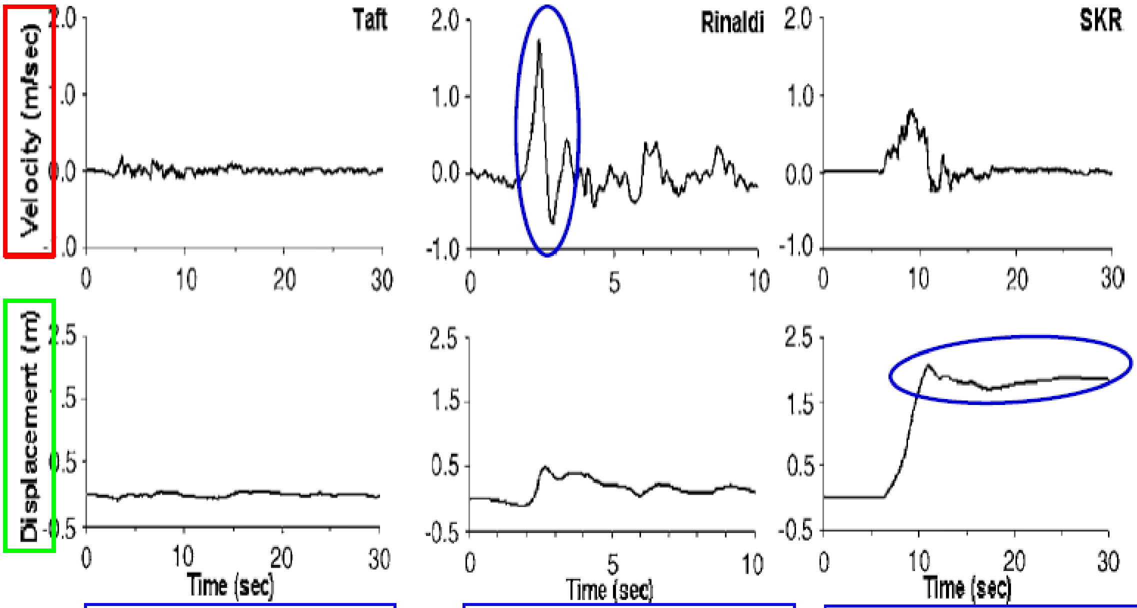
2.3 Seismic Design

Li et al (2018) studies about optimum seismic design of multi-story buildings for increasing collapse resistant capacity. In this study, a new design method for multi-story buildings that uses an optimum lateral force pattern is proposed based on the concept of uniform damage distribution at the collapse state of these buildings. To reduce the computational cost of statistical analyses for deriving the optimum lateral force pattern, the non-linear story behaviours are represented by a story shear-deformation model with tri-linear relationships. Systematic parametric analyses are performed to study the influences of various ground motion parameters and structural parameters on the optimum lateral force pattern. Formulas for the optimum lateral force pattern that are applicable for practical seismic designs are provided. The collapse resistant capacities of structures designed using the proposed and conventional methods are compared by fragility analyses. Results show that the proposed method increases the seismic collapse resistant capacity of structures under the same construction cost.

Adiyanto & Majid (2014) studies about the seismic design of two storey reinforced concrete building in Malaysia with low class ductility. The study was investigated the difference of steel reinforcement and concrete volume required when seismic provision is considered in reinforced concrete design of 2 storey general office building. The regular office building which designed based on BS8110 had been redesigned according to Eurocode 2 with various level of reference peak ground acceleration, agR reflecting Malaysian seismic hazard for ductility class low. It is observed that the level of reference peak ground acceleration, agR and behaviour factor, q strongly influence the increment of total cost. For 2 storey RC buildings built on Soil Type D with seismic consideration, the total cost of material is expected to increase around 6 to 270%, depend on seismic region. In term of seismic performance, the repeated earthquake tends to cause increasing in interstorey drift ratio around 8 to 29% higher compared to single earthquake.

2.4 Ground Motion

Ground motion is the movement of the earth surface that can cause vibration which will produced critical damaged on structure. This ground motion can cause permanent displacement of ground surface that is classifies as fling-step. Forward directivity effect is where the fault of rupture propagates toward the site with a velocity which closes to shear wave velocity and for backward directivity effect is the ground motions where the wave propagates away from the site with longer duration and lower amplitude.



A) Far Field Earthquake

B) Near Field Earthquake (Forward-directivity effect)

C) Near Field Earthquake (Fling-Step)

Figure 2.2: Typical ground motion records from real earthquake

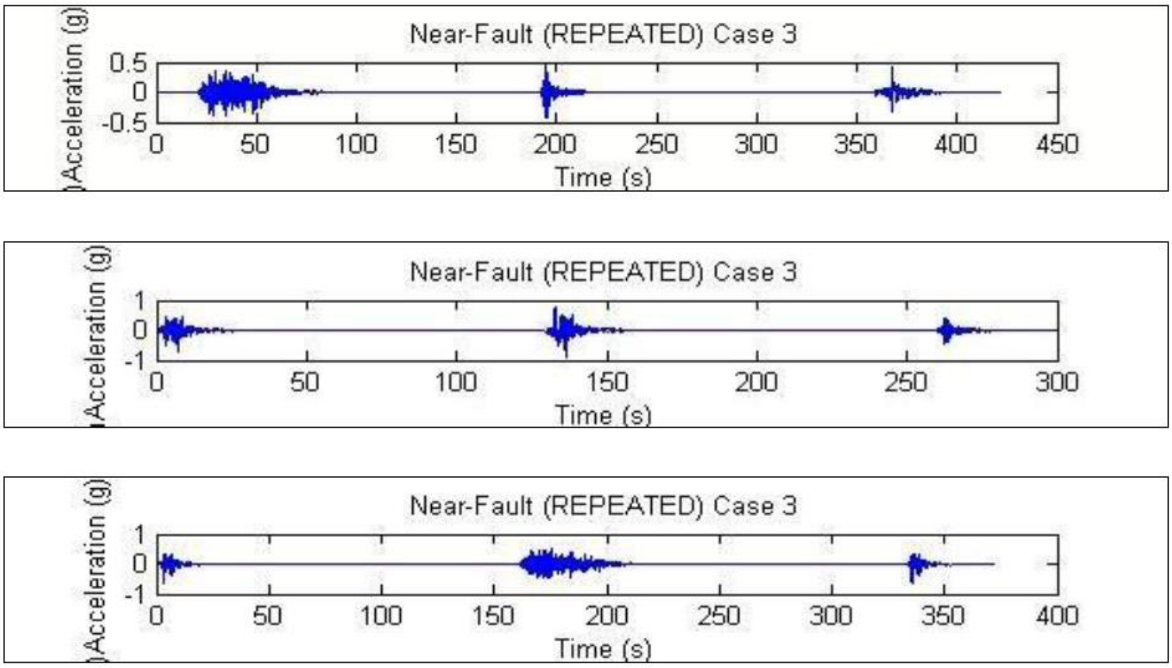


Figure 2.3: Examples of ground motion records (Multiple earthquakes)

For designing a seismic resistant building, the value of peak ground acceleration (PGA) is most important. PGA is calculated using attenuation function that describes the correlation between the local ground movement intensity the earthquake magnitude and the distance from the earthquake's epicenter (Irwansyah et al., 2013). This value of PGA is take from the seismic hazard map. The result from a research project to develop the macrozonation map for Malaysia that was conducted by University Teknologi Malaysia, Universiti Sains Malaysia and Universiti Teknologi Mara had produce the value of PGA for all region in Malaysia. The PGA map for Penisular Malaysia and East Malaysia is shown in Figure 2.4 and Figure 2.5. The latest version of seismic hazard map for peninsular Malaysia, Sabah and Sarawak is shown in appendix A as proposed by National Annex (2017).

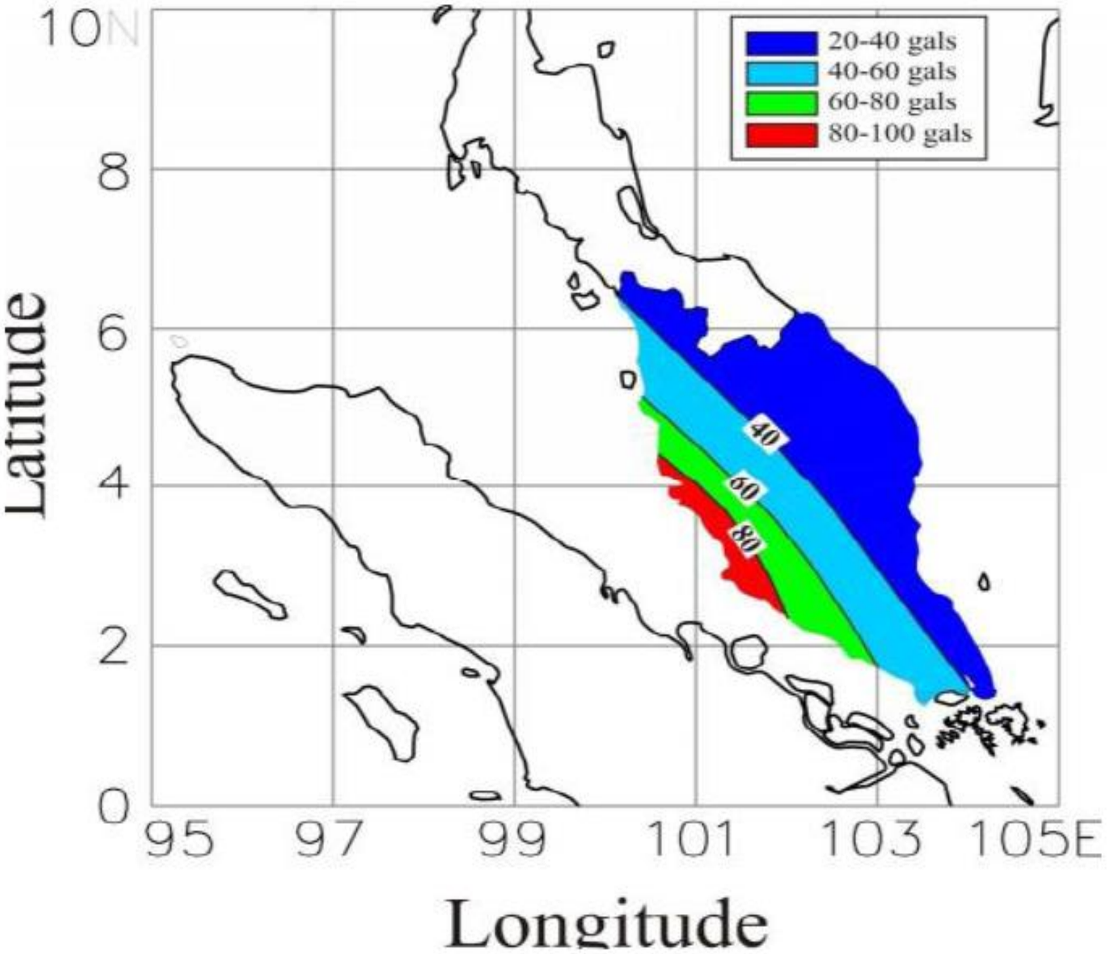


Figure 2.4: Malaysia Seismic Hazard Map (Peninsular Malaysia), Mosti (2009)

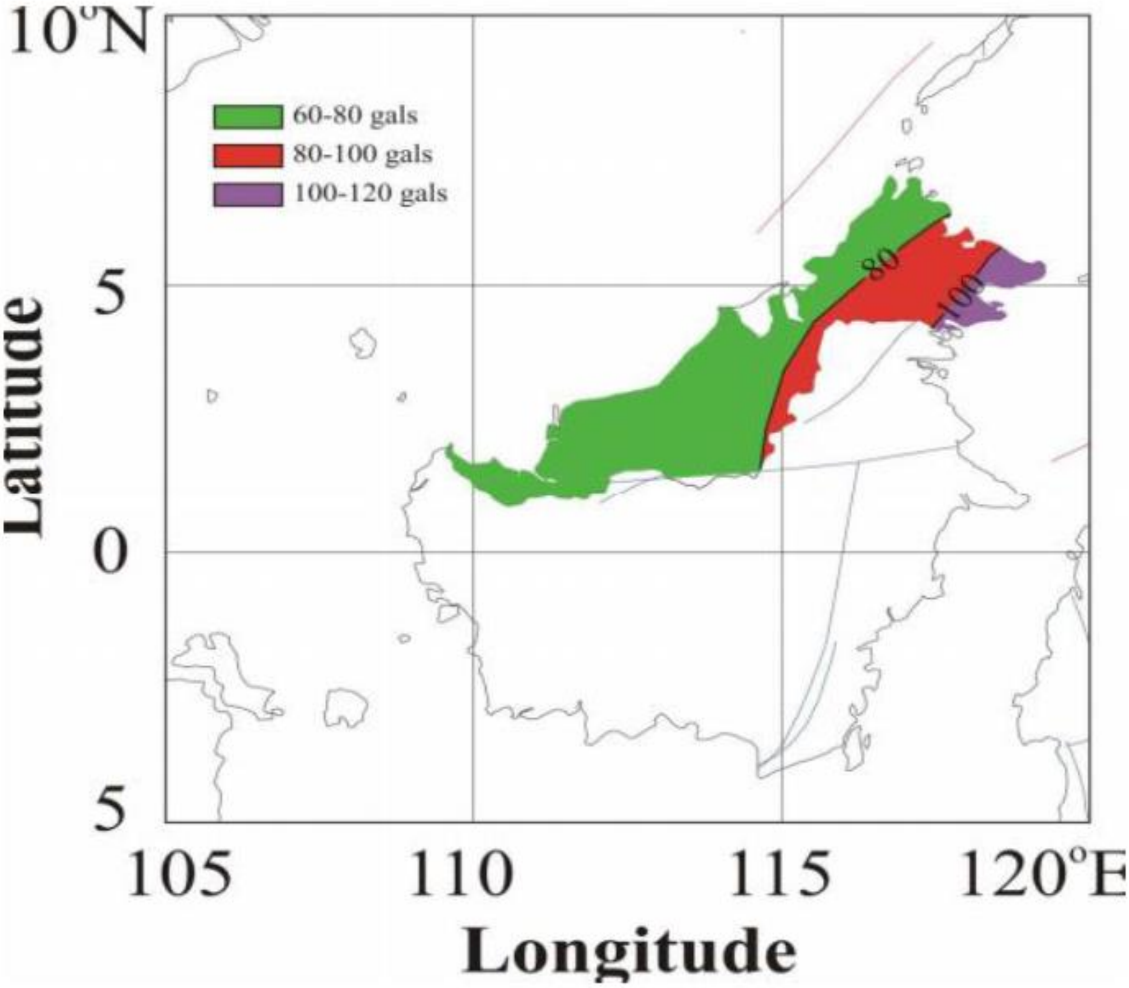


Figure 2.5: Malaysia Seismic Hazard Map (East Malaysia), Mosti (2009)

2.5 Ductility

Ductility is one of the important parameter when design loads for earthquakes. Ahmad Jani (2018), studies about the seismic design for reinforced concrete hospital building influenced by level of peak ground acceleration and class of ductility which give a result that total amount of reinforcement required in a building is higher when it is subjected to low class of ductility. The percentage of difference compared to non-seismic model is 6% to 145% for DCM and DCL respectively. This is because the lower class of ductility, or lower the behaviour factor, q will resulted in higher value of response spectrum, S_d (T_1) which will increase the value of base shear force, F_b. When base shear force increase, the amount of steel required also will increase.

2.6 Concrete Grade

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). Saka (2018), studies about 6-storey RC hospital building with different of soil type and concrete grade and the Peak Ground Acceleration value used is fixed as $\alpha gR = 0.10g$. The author concluded that 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.

According to Yaakup (2018) also concluded that the total amount of steel reinforcement required for RC school building with higher concrete grade is lower. The decrement shows of around 3.24% to 13.16% according to different concrete grade. This is because as the concrete grade higher, it possessed higher compressive strength which resulted in lower amount of steel reinforcement required.

2.7 Summary

In summary, Malaysia need to considered seismic design approach for future construction of the buildings. This is due to distant ground motion from previous record that occurred in the neighbouring countries. From the literature review, the selection of the characteristic of seismic design is noted to be very important in analysis and design which includes the PGA and concrete grade. This is because difference value of them will cause an influence to the cost of a project. Therefore, this study will be conducted to understand on the effect of different grade of concrete and different value of PGA in seismic design along with its building cost referring to Eurocode 8 as seismic provision.

CHAPTER 3

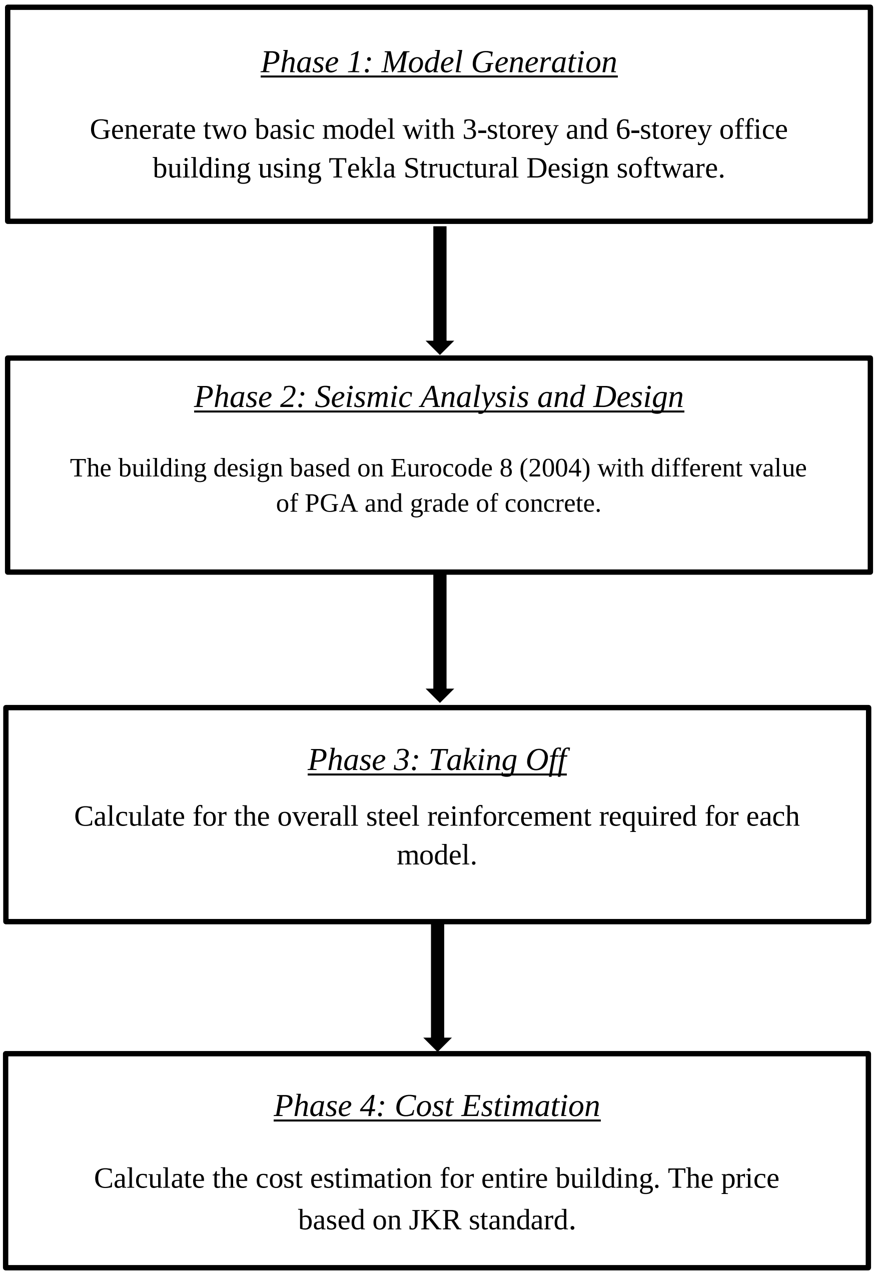
METHODOLOGY

3.1 Introduction

In this chapter, it will describes the steps carried out for the research study. Building structure that used as the model for this study is reinforced concrete (RC) office building. Besides that, this study had used Eurocode 8 (2004) as it basic reference when do the modelling of RC office building and used Tekla Structural Designer software for the analysis. Thus, in this chapter will discuss on the steps carried out to determine the influence of both magnitude of peak ground acceleration (PGA) and grade of concrete on the amount of steel reinforcement. Generally, there are three major phases that contribute in this overall design process. The summary of research methodology is shown in Figure 3.1.

3.2 Summary of Research Methodology

This research is carried out on three phases. On the first phase is the model generation by using Tekla structural software. Second phase is seismic design based on Eurocode 8 (2004) for earthquake resistance. The design is carried out with different value of PGA and grade of concrete. On the final phase is seismic analysis and taking off that were perform after getting the flexural and shear reinforcement design requirement at phase 2. Taking off process were perform on the beam and column member to get the value of overall total steel reinforcement for seismic design building.



Phase 1: Model Generation

Generate two basic model with 3-storey and 6-storey office building using Tekla Structural Design software.

Phase 2: Seismic Analysis and Design

The building design based on Eurocode 8 (2004) with different value of PGA and grade of concrete.

Phase 3: Taking Off

Calculate for the overall steel reinforcement required for each model.

Phase 4: Cost Estimation

Calculate the cost estimation for entire building. The price based on JKR standard.

Figure 3.1: Flow Chart of Seismic Design and Analysis

3.3 Phase 1 – Model Generation

A 3-storey and 6-storey office building were selected as the main basic model for this study. This model will design based on Eurocode 8 (2004) by using Tekla structural software. The section of the structural member for roof beam and floor beam measured (250x550) and (350x600) mm^2 respectively. Table 3.1 shows the summary of the member of the section. The frame featured five bays and 3.5 m column height for each floor. Figure 3.2 and Figure 3.3 shows the side and plan view of office building model that generated in Tekla structural software.

Table 3.1: Section of the member

Member	Section (mm)
Roof Beam (RB)	250 x 550
Floor Beam (FB)	350 x 600
Column	350 x 350

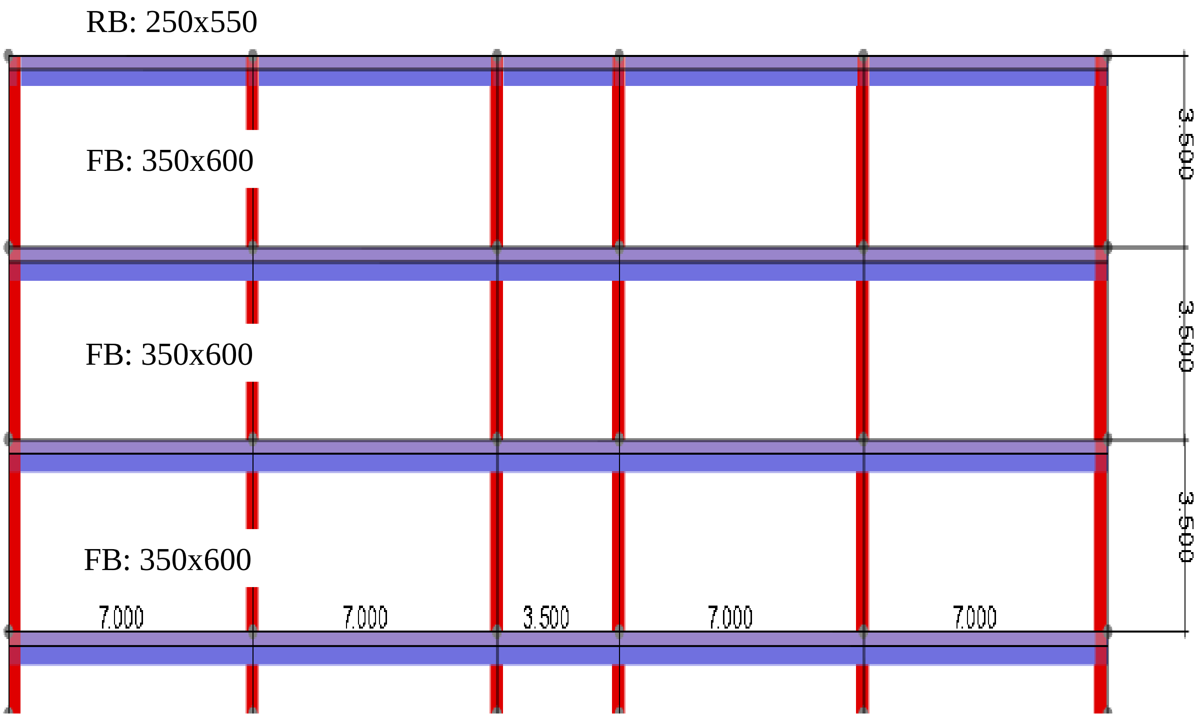


Figure 3.2: Side View of Office Building Model

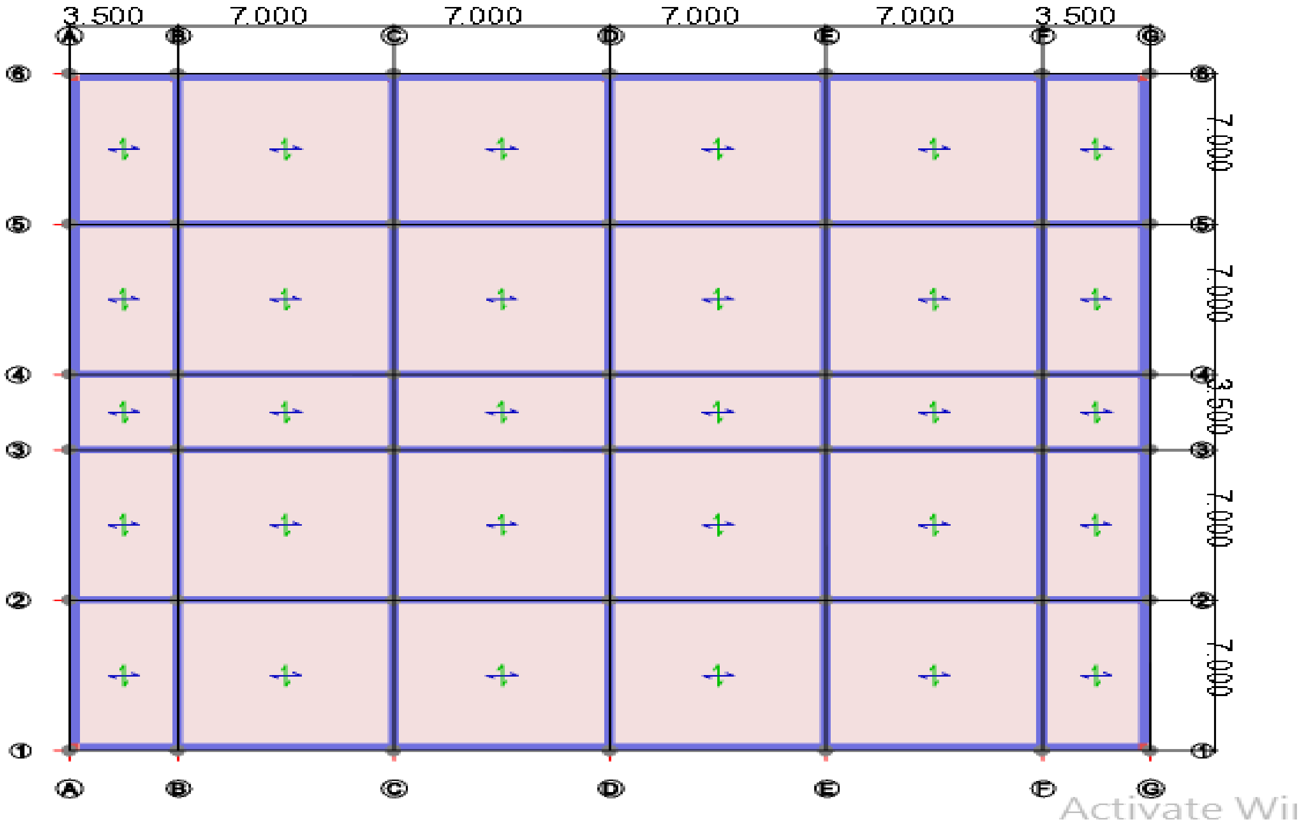


Figure 3.3: Plan View of Office Building Model

3.4 Phase 2 – Seismic Design

In phase 2, the office building is designed based on Eurocode 8 using Tekla software. Beams and columns were design in order to get the total reinforcement required for each model. The various parameter that had been used are complying with the current condition of our country. This study will consider on Soil Type D only which represents the soft soil based on Eurocode 8 (2004) and with Ductility Class Medium (DCM). The material properties for the hospital building is shown in Table 3.2 in accordance to Mc Kenzie (2004).

Table 3.2: Weight of Materials (Mc Kenzie, 2004)

Material	Weight	Unit
Concrete	24.0	kN/m^3
Finishing	1.0	kN/m^2
Water Proofing	0.5	kN/m^2
Suspended Ceiling	0.15	kN/m^2
Mechanical & Electrical	0.30	kN/m^2
Brick wall	3.0	kN/m^2/m height

In this study, office building were used and categorized in Category B for load distribution as stated in Eurocode 1 (2002) shown in Figure 3.4. Therefore, the imposed load, qk on the floor and roof of this category will be 3.0kN/m^2 and 0.4kN/m^2 respectively. Table 3.3, Table 3.4, and Table 3.5 shows the imposed load on floor, roof categorization and imposed load on roof as stated in Eurocode 1 (2002).

Table 3.3 Categories of building use (Eurocode 1, 2002)

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

Table 3.4: Imposed loads on floors, balconies and stairs in buildings (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
- C3	3.0 to 5.0	4.0 to 7.0
- C4	4.5 to 5.0	3.5 to 7.0
- C5	5.0 to 7.5	3.5 to 4.5
Category D		
- D1	4.0 to 5.0	3.5 to 7.0
- D2	4.0 to 5.0	3.5 to 7.0

Table 3.5: Categorization of roofs (Eurocode 1, 2002)

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

Table 3.6: Imposed loads on roofs of category H (Eurocode 1, 2002)

<table>
<tr><th>Roof</th><th>qk
[kN/m2]</th><th>Qk
[kN]</th></tr>
<tr><td>Category H</td><td>qk</td><td>Qk</td></tr>
<tr><td colspan="3">NOTE 1 For category H qk may be selected within 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 give the values may be set by the National Annex. The recommended values are:

$qk = 0.4kN/m^2$, $Qk = 1.0kN$

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

NOTE 3 qk may be assumed to act 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 See also 3.3.2 (1)</td></tr>
</table>

3.4.1 Grade of Concrete

Concrete grade can be defined by the strength and composition of the concrete and the minimum strength the concrete should have following 28 days of initial construction. This grade of concrete also influence the quantity of steel needed to support the load of the building. In this study, the grade of concrete used is G25 and G30.

3.4.2 Base Shear Force, F_b

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

$$Fb = Sd\,(T1).m.\lambda \qquad 3.1$$

Where;

Sd(T1) = The ordinate of the design spectrum at period T1;

T1 = 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 T1 $\leq$ 2Tc and the building has more than two storey, or λ=1.0

Sd(T_1), m, and λ correspond to the ordinate of the design spectrum at period T1, the total mass of the building above the foundation or above the top of a rigid basement, and the correction factor, respectively. The value of T1 can be defined by using following equation.

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

Where;

Ct = 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 rigid basement.

3.4.3 Design Response Spectrum

From equation 3.1 stated in section 3.4.2 above, the ordinate of the design spectrum at period, T_1, in Sd(T_1) is required to determine the base shear force, Fb 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. As for this study, it used Soil Type D for all the model. Table 3.7 below shows the value parameters that describing the recommended Type 1 elastic response spectra. Equation (3.3) to (3.6) had been referred to develop the design response spectrum.

Table 3.7: Values of the parameters describing the recommended Type 1 elastic response spectra for Soil Type D

Ground Type	**S**	**T_B (s)**	**T_C (s)**	**T_D (s)**
D	1.35	0.20	0.80	2.0

According to Eurocode 8 (2004), design spectrum for elastic analysis is as following expression:

$$0 \leq T \leq T_B.\ S_d\,(T) = \ .\,S\,.\,\frac{2}{3} + \frac{T}{T_B}\,.\,(\frac{2.5}{q} + \frac{2}{3}) \qquad 3.3$$

$$T_B \leq T \leq T_C.\ S_d\,(T) = a_g\,.S\,.\,\frac{2.5}{q} \qquad 3.4$$

$$T_C \leq T \leq T_D.\ S_d\,(T) = \begin{cases} = a_g\,.\,S\,.\,\frac{2.5}{q}\,(\frac{T_C}{T}) \\ \geq\ .\ a_g \end{cases} \qquad 3.5$$

$$T_D \leq T \leq \quad S_d\,(T) = \begin{cases} = a_g\,.\,S\,.\,\frac{2.5}{q}\,(\frac{T_C}{T}) \\ \geq\ .\ a_g \end{cases} \qquad 3.6$$

Where;

T	is vibration period of a linear single-degree-of-freedom system
a_g	is the design ground acceleration
T_B	is the lower limit of the period of the constant spectral acceleration branch
T_C	is the upper limit of the period of the constant spectral acceleration branch
T_D	is the value defining the beginning of the constant displacement response range of the spectrum

S is the soil factor

η is the damping correction with a reference value of $\eta = 1$ for 5% viscous damping

3.4.4 Design Ground Acceleration

By referring to Eurocode 8 (2004), design ground acceleration, ag can be expressed as following expression:

$$ag = \gamma_1 \cdot a_{gR} \tag{3.7}$$

Where γ_1 is correspond to importance factor and a_{gR} is the reference of peak ground acceleration.

The value of the importance factor can be determined by referring to the importance classes for building classification as shown as Table 3.8. In this study, the value of γ_1 for importance class of II are equal to 1.0.

Table 3.8: Importance classes for buildings (Eurocode 8, 2004)

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

The value of reference peak ground acceleration, a_{gR} is based on PGA for Malaysia. In this study, the value of reference peak ground acceleration, a_{gR} is taken as 0.03g, 0.09g and 0.15g which covers for both at Peninsular and eastern Malaysia. The concrete grade is G25 and G30. Table 3.9 shows all the model of the office building that had been considered in this study. Figure 3.4 shows the 3D model of the building that generated by using Tekla structural software for 3-storey office building. As for 6-storey refer Appendix A.

Table 3.9: List of All models of office building

No	Model	Code	PGA (g)	Concrete Grade
1	Non Seismic (3-Storey)	3-NS-25	-	G25
2		3-NS-30		G30
3	Non Seismic (6-Storey)	6-NS-25	-	G25
4		6-NS-30		G30
5	3-Storey	3-0.03-25	0.03	G25
6		3-0.03-30		G30
7		3-0.09-25	0.09	G25
8		3-0.09-30		G30
9		3-0.15-25	0.15	G25
10		3-0.15-30		G30
11	6-Storey	6-0.03-25	0.03	G25
12		6-0.03-30		G30
13		6-0.09-25	0.09	G25
14		6-0.09-30		G30
15		6-0.15-25	0.15	G25
16		6-0.15-30		G30

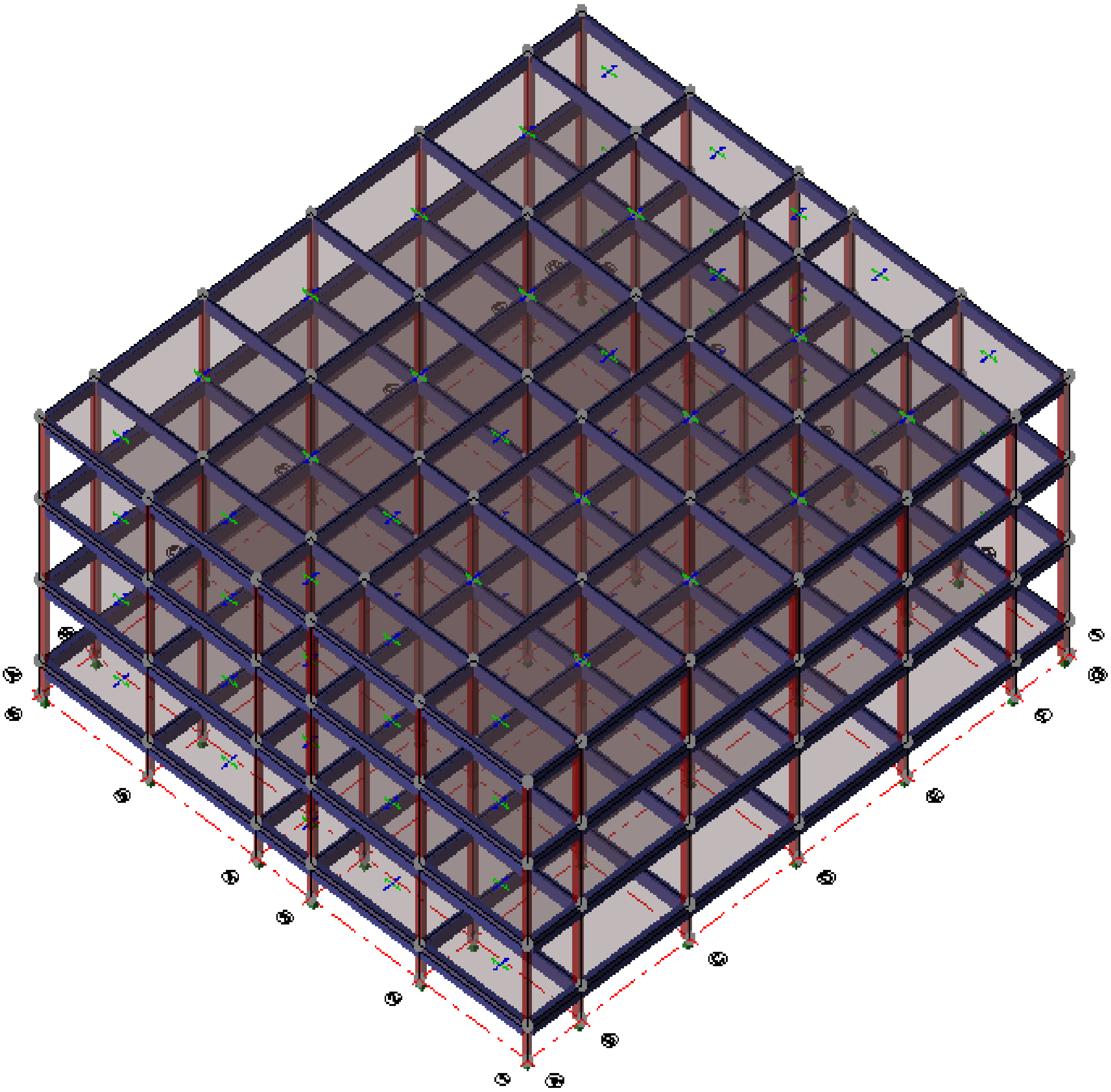


Figure 3.4: 3D model of the building generated from Tekla structural software (3-storey)

3.4.5 Distribution of Lateral Load

According to Eurocode 8, the seismic action effects shall be determined by applying to the two planer models, horizontal forces, *Fi* to every storey of the building.

$$Fi = Fb \, . \frac{\text{zi.mj}}{\Sigma \text{ zj.mj}} \qquad 3.8$$

Where;

F_i is the horizontal force acting on storey, i

F_b is the seismic base shear force

z_i , z_j are the height of masses mi ,mj above the level of application of the seismic action m_i, m_j are the storey masses computed

Once the magnitude of base shear force, *Fb* had been determined, bending moment, shear force and axial load will be obtained from structural analysis. These output will be used for beam and column design.

3.4.6 Beam Design

Beam design was carried out according to Eurocode 8. In this study, the maximum bending moment is chosen as design moment for the analysis. The amount of steel reinforcement proposed will be depending on the maximum bending moment at the section. The higher the bending moment, the higher amount of steel reinforcement required. Figure 3.5 shows the flow chart of beam design to Eurocode 8 (2004).

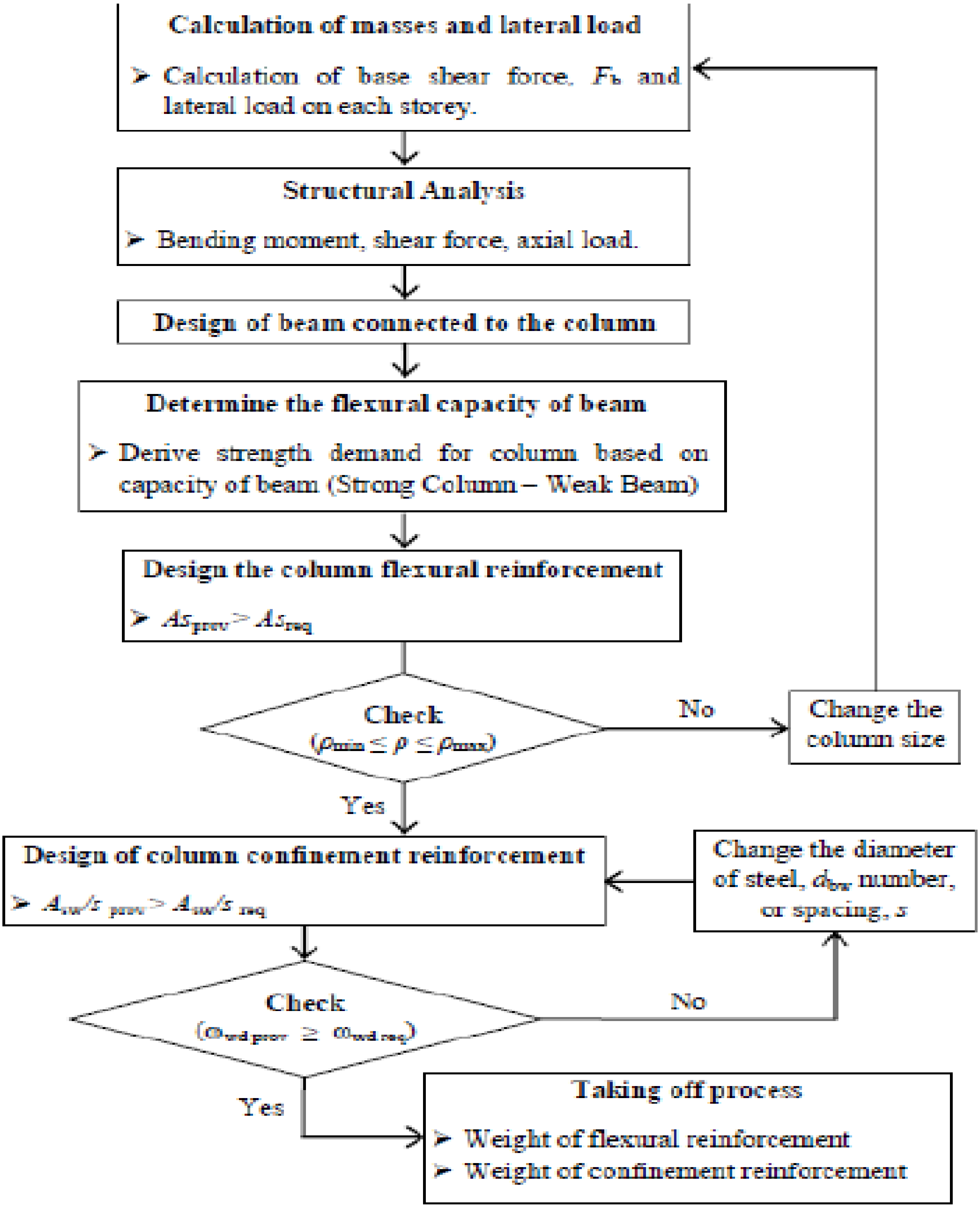


Figure 3.5: Flow Chart of beam design according to Eurocode 8 (Adiyanto, 2016)

3.4.7 Column Design

Column design was carried out according to Eurocode 8. Maximum bending moment was used to determine the column size and amount of steel reinforcement needed. Figure 3.6 shows the flow chart of column design to Eurocode 8 (2004).

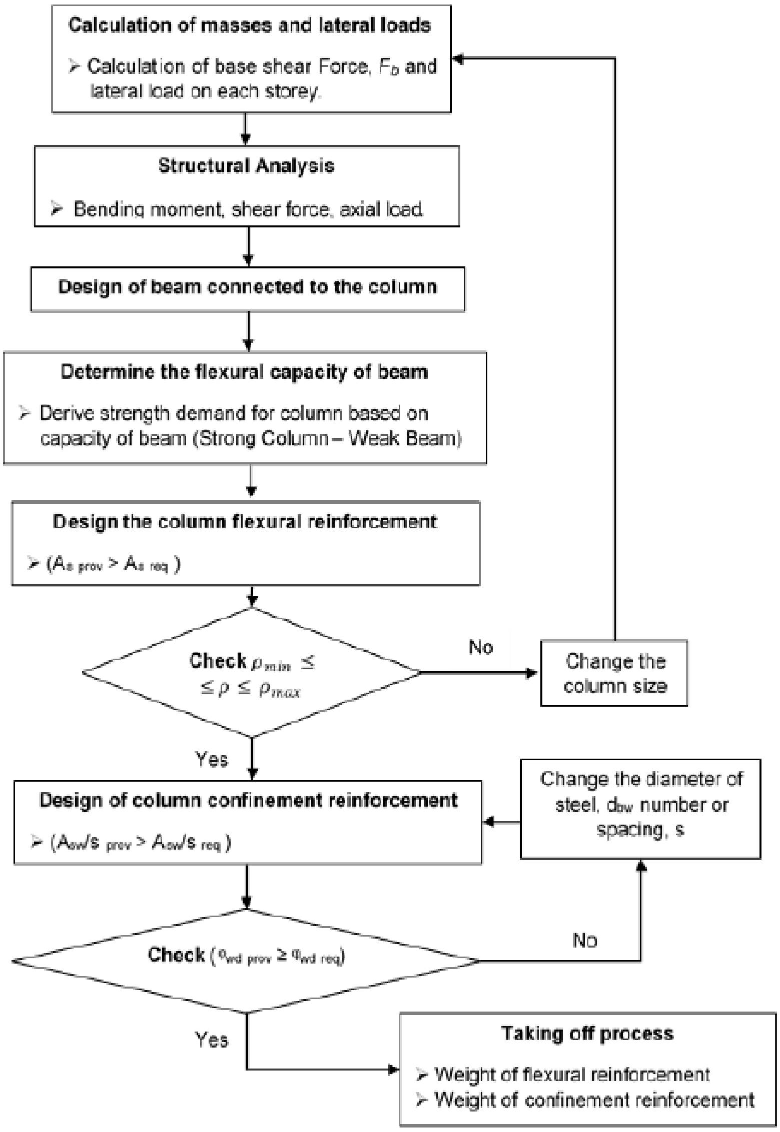


Figure 3.6: Flow Chart column design to Eurocode 8 (Adiyanto, 2016)

3.5 Phase 3 – Seismic Analysis and Taking Off

In this phase, seismic design on the building frames designed based on various value of reference peak ground acceleration and grade of concrete was carried out using Tekla structural software. Total mass of the frames was calculated based on the size of the structural member (beam and column) determined in Phase 2. Taking off process will be performed once the flexural and shear reinforcement had satisfied all the design process. Total amount of steel reinforcement required for 1 m^3 of concrete for main and link reinforcement for both beam and column of the buildings will be calculated.

3.6 Phase 4 – Cost Estimation

In the last phase of this research, cost estimation is the phase where the price of entire building is estimated based on Jabatan Kerja Raya. According to JKR (2017), the price of concrete for concrete grade 30 is RM372.10/m^3 and concrete grade 25 is RM325.30/m^3 and the price for steel is RM3.50/kg. The sum of beam and column for steel reinforcement and volume of concrete required for entire building can estimated the cost of the 3-storey and 6-storey office building.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the effect of peak ground acceleration and concrete grade on amount of steel discussed based on the result obtained. The discussion are discussed in term of comparison of steel used as reinforcement which influenced by magnitude of peak ground acceleration and grade of concrete. The total weight of steel reinforcement per $1m^3$ of concrete normalised to non-seismic model also will be discussed based on grade of concrete for all beam and column. In the other hand, the cost will be estimated in this discussion on material for entire building.

4.2 Design Response Spectrum

The design response spectrum is developed to avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behavior of its elements and other mechanisms. The parameters such as importance factor, $\gamma 1$ and reference peak ground acceleration, αgR are required to produce design response spectrum. However, as the model is assumed to be built on Soil Type D, the other parameter that should be considered is Type 1 of response spectrum. The seismic action of the design spectrum, $S_d(T1)$, which is defined using the equations that are previously mentioned in Chapter 3 also considered.

Based on equation 3.1 that discussed in the previous chapter, the equation will be used to determine the base shear force of the building which comprises of ordinate of design response spectrum $S_d(T1)$, and the fundamental period of vibration $T_{1.}$ According to Eurocode 8 (2004), Clause 4.3.3.2.2, the following equation can be used for building with height of up to 40m to determine the value of $T1$ (s).

$$T_1 = C_T.H^{3/4} \qquad 4.1$$

Where Ct is 0.075 for moment resistance space concrete frames and H is 12.3 and 23.1 meters for 3-storey and 6-storey building respectively which is the height of the building, in m, from the foundation or from the top of a rigid basement. Hence, the fundamental period of vibration, T_1 for 3-storey and 6-storey are 0.5 and 0.8 respectively.

As mention before, all models in this study will be using the same gravitational load such as dead load and imposed load. However, the model will be subjected to different lateral load due to the parameter in this study are varies which is magnitude of peak ground acceleration. In addition, the design response spectrum for 3-storey and 6-storey buildings will the same due to the magnitude of the peak ground acceleration are the same. The value of design response spectrum graph will be different for each magnitude of peak ground acceleration which will affect the base shear force, F_b that acting on the building.

On the first objectives which is to determine the effect on magnitude of Peak Ground Acceleration (PGA) on the amount of steel reinforcement with the fix value of behavior factor, q. Type 1 of response spectra has been develop for this study and consider soil type D which is soft soil which is tend to have greater effect on tremor compared to the other soil type.

Figure 4.1 shows the design response spectrum graph for the discussion both 3-storey and 6-storey building. The design response spectrum is develop for behavior factor, q=3.9 for ductility class medium. Importance factor that used is importance factor class II with the value of λ = 1.0 for office building and the reference peak ground acceleration, αgR used are 0.03g, 0.09g and 0.15g.

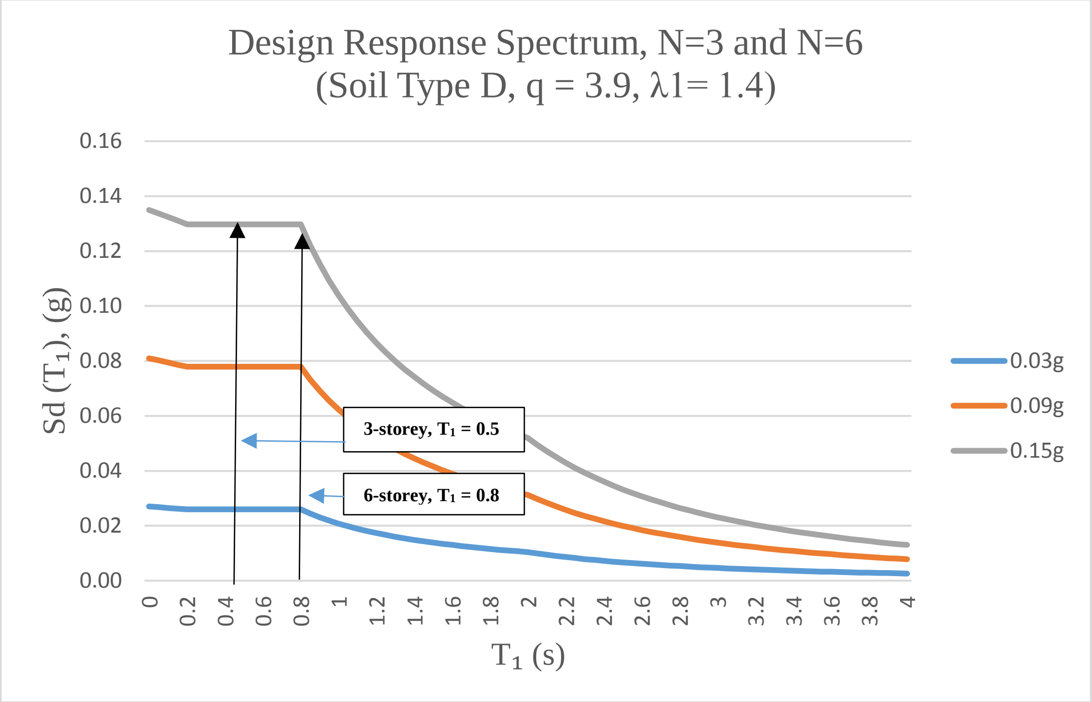


Figure 4.1: Design Response Spectrum for Soil Type D, *q* = 3.9, N=3 and N=6

Table 4.1: $S_d(T_1)$, Mass and Base Shear Force

Model code (G25 & G30)	PGA (g)	Spectral Acceleration at the fundamental period of vibration, $S_d(T_1)$, m/s^2	Mass, t	Base Shear Force, kN
3-0.03	0.03	0.255	4472.35	967.8
3-0.09	0.09	0.764	4472.35	2903.5
3-0.15	0.15	1.273	4472.35	4839.2
6-0.03	0.03	0.255	8409.56	1819.9
6-0.09	0.09	0.764	8409.56	5459.6
6-0.15	0.15	1.273	8409.56	9099.4

From Figure 4.1 and Table 4.1 it can be seen that, the fundamental period of vibration, T_1 for 3-storey and 6-storey are 0.5 and 0.8 respectively, the value of design response spectrum for increasing magnitude of PGA has become higher. Therefore, it can be concluded that when magnitude of PGA higher, the value of design response spectrum also become higher. Thus, when the magnitude of PGA higher the base shear also increase.

4.3 Influence of Level of Peak Ground Acceleration and Concrete Grade on Concrete Volume

In this discussion, the amount of concrete volume is being compared for different value of peak ground acceleration and grade of concrete. The concrete volume will be compared for all model both 3-storey and 6-storey building. The amount of concrete volume that used for beam, column and overall volume are discussed in the following graph comparison.

Figure 4.2 and figure 4.3 shows the comparisons of total volume of concrete that used for beam and column. This two graph represent for 3-storey office building which shows for two different value of concrete grade G25 and G30. It can be concluded that the graph shares the same values with 451.40 m^3 due to the size of beam and column are not varies for all the models including for non-seismic model.

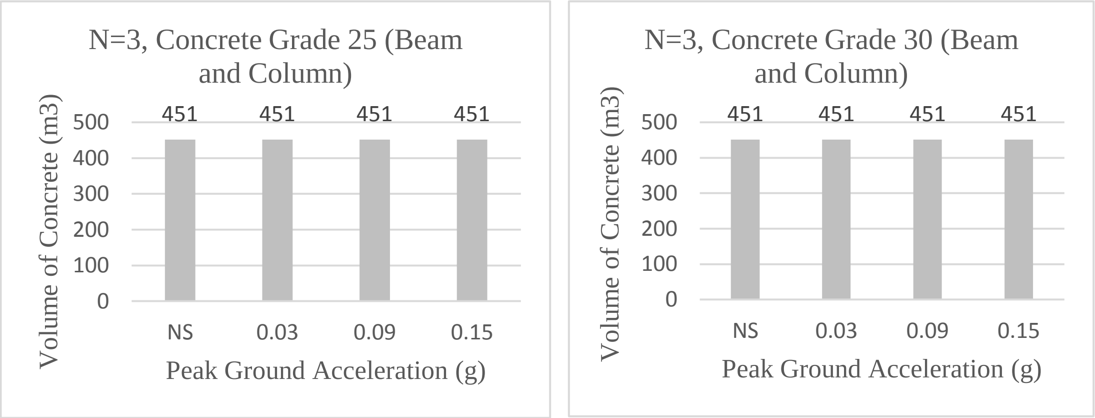


Figure 4.2 and Figure 4.3: Total Volume of Concrete for 3-storey Office Building with G25 and G30

Figure 4.4 and figure 4.5 shows the comparisons of total volume of concrete that used for beam and column. This two graph represent for 6-storey office building which shows for two different value of concrete grade G25 and G30. It can be concluded that the graph shares the same values with 789.29 m^3 due to the size of beam and column are not varies for all the models including for non-seismic model. The value for total volume of concrete for this 6-storey office building is two times of the 3-storey office building and also the size of column and beam that being used for 6-storey is bigger than 3-storey office building. Hence, it can be concluded that the total volume of concrete for 6-storey is higher than 3-storey office building which the higher size of column and beam is used the higher the total volume of concrete.

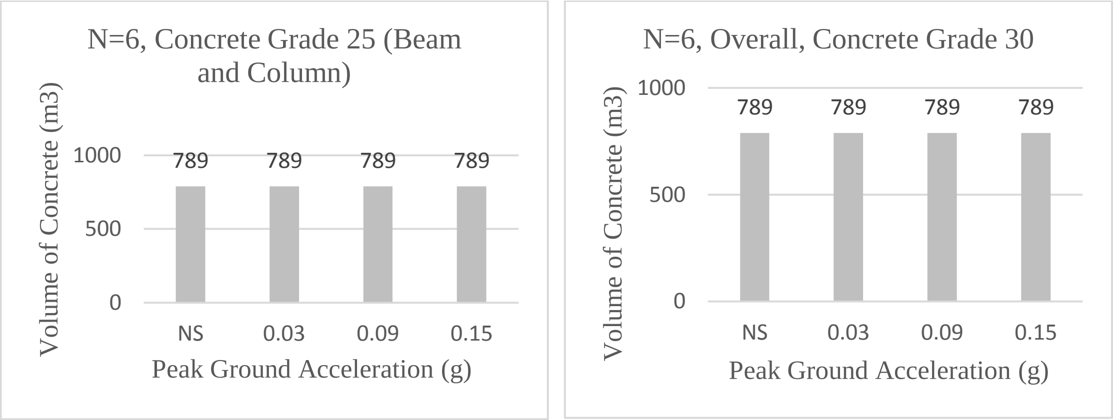


Figure 4.4 and Figure 4.5: Total Volume of Concrete for 6-storey Office Building with G25 and G30

4.4 Influence of Level of Peak Ground Acceleration on Amount of Steel Reinforcement Required

In this discussion, the amount of steel reinforcement used is being compared for different magnitude of PGA to non-seismic model. DCM is considered where the behaviour factor, q = 3.9 and considering on Soil Type D. The amount of steel reinforcement used for beam, column and overall reinforcement are discussed in the following section.

4.4.1 Influence of Level of Peak Ground Acceleration on Amount of Steel Reinforcement Used for Beam

Figure 4.6 and figure 4.7 shown the comparison of weight of steel per 1m^3 of concrete for beam for both 3-storey and 6-storey office building with different type magnitude of peak ground acceleration which 0.03g, 0.09g and 0.15g for grade of concrete 30 and also compared with the non-seismic model. As for concrete grade 25 the graph comparison can be refer at appendix C. The different type of PGA gives the different result on the amount of steel weight per 1m^3 of concrete required for the beam. Form the graph, the lowest is the non-seismic and the highest is on the PGA of 0.15g. This is due to the magnitude of the peak ground acceleration is high which required high force to resist the seismic load compared to the non-seismic which not applied any seismic load on it. Both 3-storey and 6-storey office building experienced the same trend which the non-seismic the lowest and the PGA of 0.15g is the highest that shown on the graph. For main reinforcement for 3-storey and 6-storey, the percentage rises from 3% to 19% and 10% to 145% respectively. For more detail, the 3-storey office building it rises from 3%, 7% and 19% for PGA 0.03g, 0.09g and 0.15g respectively. As for 6-storey office building it rises from 10%, 50% and 145% for PGA 0.03g, 0.09g and 0.15g respectively. To be compared both 3-storey and 6-storey office building, the 6-storey office building required higher amount of steel reinforcement than 3-storey office building due to the storey is required a lot more amount of steel reinforcement due to additional 3 more storey the building.

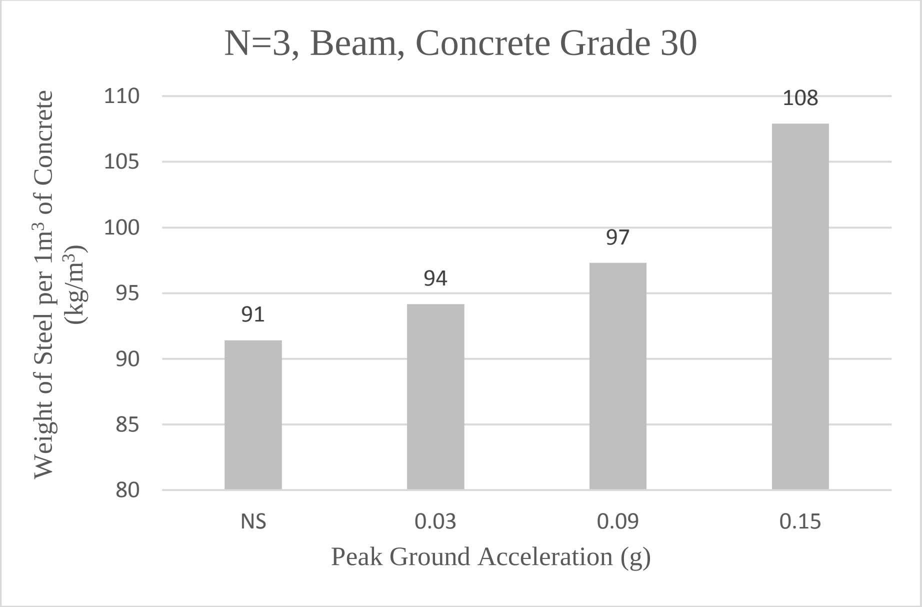


Figure 4.6: Weight of steel per 1m^3 of concrete for beam (3-storey)

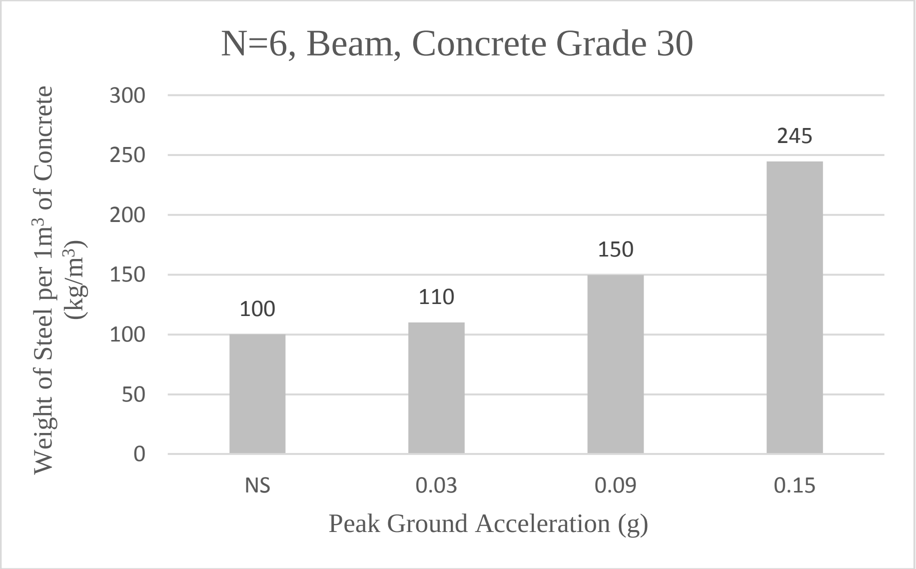


Figure 4.7: Weight of steel per 1m^3 of concrete for beam (6-storey)

For the main reinforcement, it can be said that the increasing of total weight of steel from the lowest magnitude of PGA is strongly related to design response spectrum as discussed in Figure 4.1. It is shows that the value of response spectrum, *Sd (T1)* for larger magnitude of PGA is higher compared to smaller magnitude of PGA. This is because the higher the magnitude of PGA, the higher the value of response spectrum. Hence, the higher value of response spectrum, *Sd (T1)* resulted in higher value of base shear force, *Fb*. When base shear force increase, with fix value of total mass, *m* and correction factor, λ the bending moment and shear force will be increase and resulting in higher amount of steel reinforcement required for beam. The increment of bending moment for 3-storey and 6-storey office building can be seen in Table 4.1. The consistencies of the graph shows that the effect of different magnitude of PGA gives significant effect to the amount of steel reinforcement required for beam.

Table 4.2: The increment of bending moment for 3-storey and 6-storey office building (beam)

Model	Longitudinal Bars							
	3-Storey				6-Storey			
	Med	A_s, min	A_s, req	A_s, prov	Med	A_s, min	A_s, req	A_s, prov
Non Seismic	16	323	68	339	9	323	37	339
0.03g	69	323	298	339	144	316	630	942
0.09g	185	316	812	942	374	308	1794	2101
0.15g	302	308	1413	2101	604	301	3326	3888

4.4.2 Influence of Level of Peak Ground Acceleration on Amount of Steel Reinforcement Used for Column

Figure 4.8 and figure 4.9 shown the comparison of weight of steel per 1m^3 of concrete for column for both 3-storey and 6-storey office building with different type magnitude of peak ground acceleration which 0.03g, 0.09g and 0.15g for concrete grade 30 and also compared with the non-seismic model. As for concrete grade 25 the graph comparison can be refer at appendix C. The different type of PGA gives the different result on the amount of steel weight per 1m^3 of concrete required for the column. Form the graph, the lowest is the non-seismic and the highest is on the PGA of 0.15g. This is due to the magnitude of the peak ground acceleration is high which required high force to resist the seismic load compared to the non-seismic which not applied any seismic load on it. Both 3-storey and 6-storey office building experienced the same trend which the non-seismic the lowest and the PGA of 0.15g is the highest that shown on the graph. For main reinforcement for 3-storey and 6-storey, the percentage rises from 0% to 177% and 0% to 200% respectively. For more detail, the 3-storey office building it rises from 0%, 36% and 177% for PGA 0.03g, 0.09g and 0.15g respectively. As for 6-storey office building it rises from 0%, 48% and 200% for PGA 0.03g, 0.09g and 0.15g respectively. To be compared both 3-storey and 6-storey office building, the 6-storey office building required higher amount of steel reinforcement than 3-storey office building due to the storey is required a lot more amount of steel reinforcement due to additional 3 more storey the building.

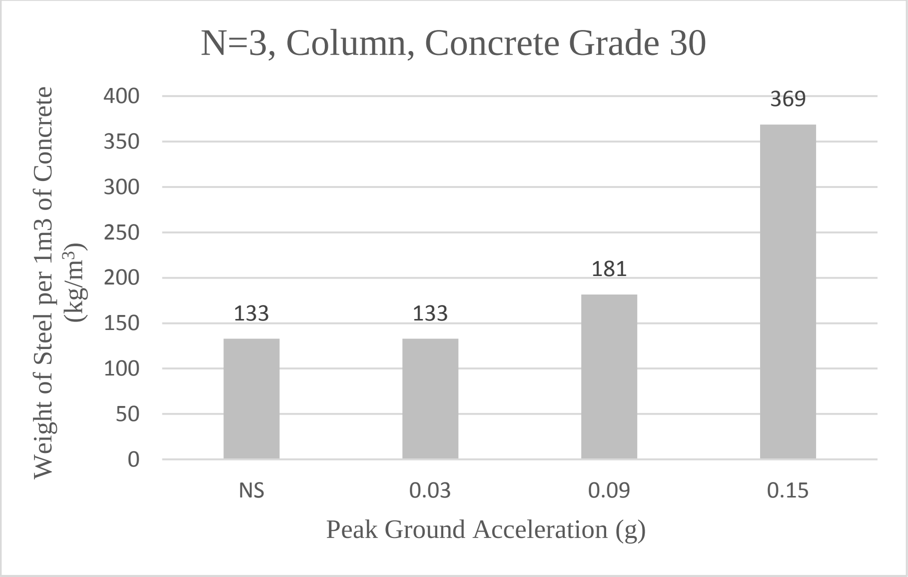


Figure 4.8: Weight of steel per 1m^3 of concrete for column (3-storey)

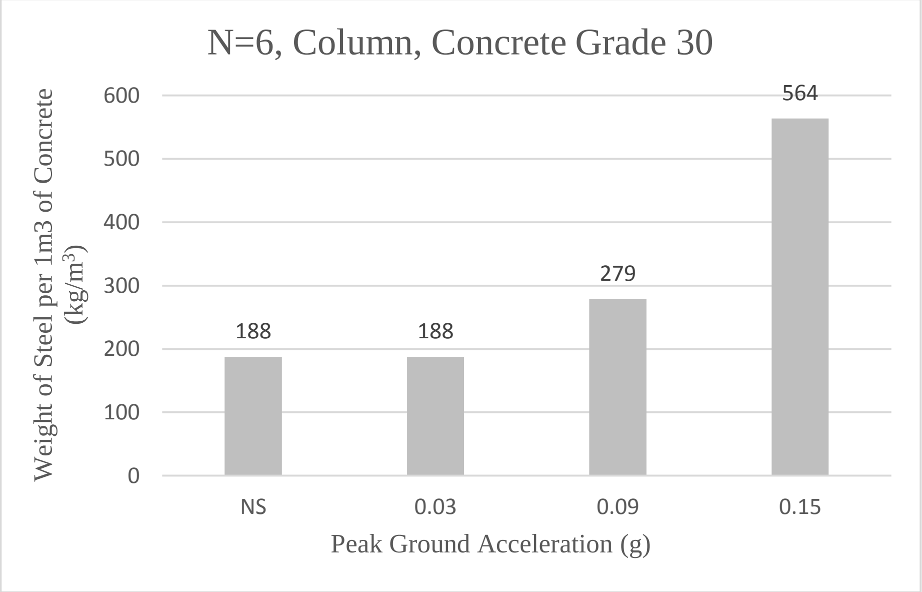


Figure 4.9: Weight of steel per 1m^3 of concrete for column (6-storey)

The increasing of the total weight of steel for the main reinforcement from the lowest magnitude of PGA is directly influenced to the base shear force, F_b. This is because the higher the magnitude of PGA, the higher the value of the base shear force. Hence, base shear force increase, with fix value of total mass, m and correction factor, λ the bending moment will also be increase and resulting in higher amount of steel reinforcement required for column. The increment of bending moment for 3-storey and 6-storey office building can be seen in Table 4.2. The consistencies of the graph shows that the effect of different magnitude of PGA gives significant effect to the amount of steel reinforcement required for the column.

Table 4.3: The increment of bending moment for 3-storey and 6-storey office building (column)

Model	Longitudinal Bars							
	3-Storey				6-Storey			
	Med	A_s, min	A_s, max	A_s, prov	Med	A_s, min	A_s, max	A_s, prov
Non Seismic	87	640	6400	2513	134	1000	10000	5890
0.03g	96	640	6400	2513	151	1004	10000	5890
0.09g	133	640	6400	2513	247	1004	10000	5890
0.15g	193	640	6400	5890	300	1004	10000	9651

4.4.3 Influence of Level of Peak Ground Acceleration on Amount of Steel Reinforcement Used for Beam and Column

The total weight of steel reinforcement for the entire building is obtained from the total amount of steel used both beam and column. The main reinforcement both 3-storey and 6-storey office building for the beam and column elements are combined together to produce the overall reinforcement of the building as shown in Figure 4.10 and Figure 4.11 for concrete grade 30 and as for concrete grade 25 the graph comparison can be refer at appendix C. The percentage difference for 3-storey and 6-storey office building obtained are from 2% to 56% and 7% to 162% respectively. For more detail, the increment percentage for 3-storey office building is 2%, 14% and 56% and the increment percentage for 6-storey office building is 7%, 49% and 162% for reference peak ground acceleration, agR = 0.03g, 0.09g and 0.15g respectively. Then, it can be concluded that the higher value of PGA resulted in higher amount of steel reinforcement required for the entire building. This result is in the same pattern with the previous study that conducted by Ahmad Jani (2018) and Adiyanto et al., (2019), the author stated that the magnitude of PGA gives significant effect to overall amount of steel required. The higher value of PGA, the higher amount of steel reinforcement required.

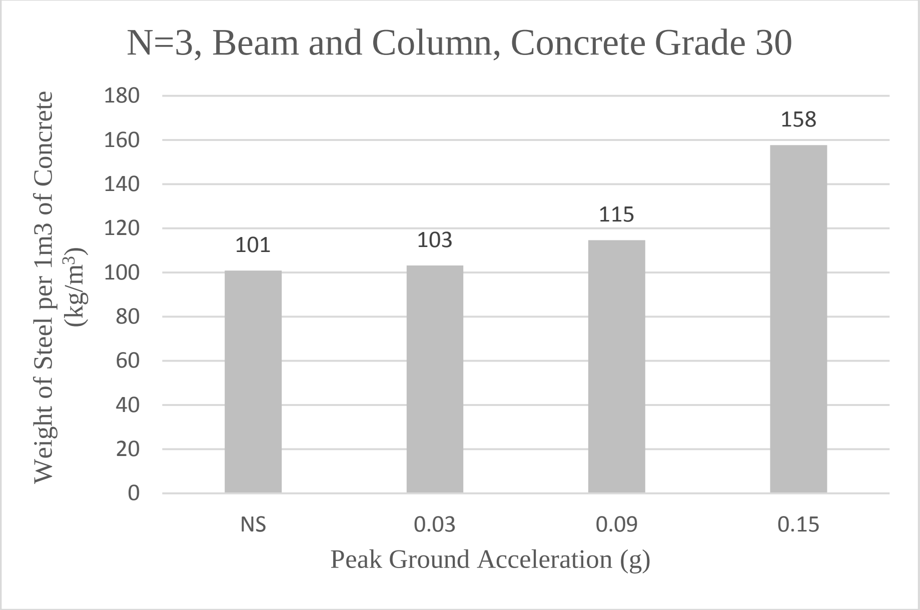


Figure 4.10: Weight of steel per 1m^3 of concrete for beam and column (3-storey)

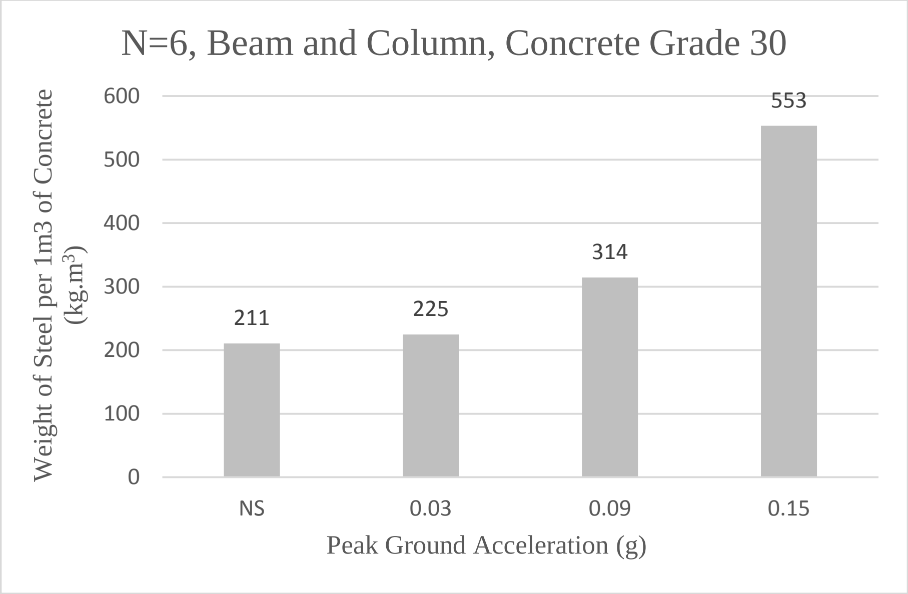


Figure 4.11: Weight of steel per 1m^3 of concrete for beam and column (6-storey)

4.5 Influence of Concrete Grade on Amount of Steel Reinforcement Required

In this discussion, the amount of steel reinforcement used is being compared in two different value of concrete grade which is G25 and G30. Different value of PGA 0.03g, 0.09g and 0.15g and considering on soil type D. The amount of steel reinforcement used for beam, column and overall reinforcement are discussed in the following section.

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

Figure 4.12 and 4.13 shows the result obtained from the analysis and design. Both figures are analysed in respect of PGA 0.15g which represented the critical value of PGA. The comparison of the total weight of steel reinforcement for concrete grade of G25 and G30. For main reinforcement of 3-storey and 6-storey office building, the percentage decrease from 16% to 18%and 147% to 145% respectively. For more detail, the decrement for both 3-storey and 6-storey are 16% to 18%and 147% to 145% is for G25 and G30 respectively.

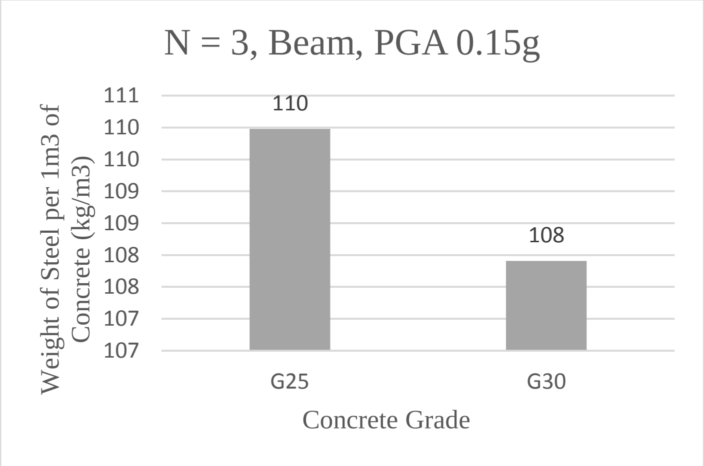


Figure 4.12: Main Reinforcement for beam (3-storey)

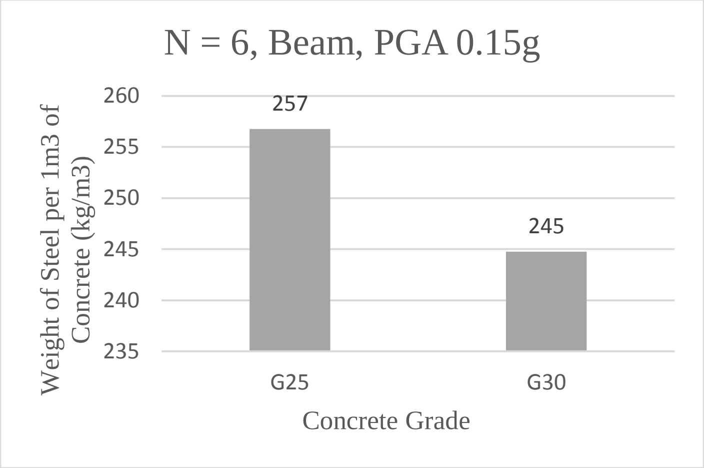


Figure 4.13: Main Reinforcement for beam (6-storey)

The decreasing of weight of steel reinforcement for the main reinforcement for the beam is highly related with the difference of concrete grade of G25 and G30. This will resulted in the decrement of base shear force, F_b. When the base shear force, *F*b decreased, the bending moment for beam will also decrease, where resulted in lower amount of the steel reinforcement required for beam. The decrement value for bending moment is shown in Table 4.3.

Table 4.4: Main reinforcement of bending moment for 3-storey and 6-storey office building (beam)

Model	Longitudinal Bars							
	PGA = 0.15g							
	3-Storey				6-Storey			
	Med	$A_{s,}$ min	A_s, req	A_s, prov	Med	$A_{s,}$ min	A_s, req	A_s, prov
NS-25	16	286	68	339	45	286	197	339
NS-30	14	323	62	339	9	323	37	339
G25	315	272	1513	2101	604	267	3326	3888
G30	302	308	1413	2101	604	301	3271	3571

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

Figure 4.14 and 4.15 shows the result obtained from the analysis and design. Both figures are analysed in respect of PGA 0.15g which represented the critical value of PGA. The comparison of the total weight of steel reinforcement for concrete grade of G25 and G30. For main reinforcement of 3-storey and 6-storey office building, the percentage decrease from 77% to 177% and 124% to 198% respectively. For more detail, the decrement for both 3-storey and 6-storey are 77% to 177% and 124% to 198% is for G25 and G30 respectively.

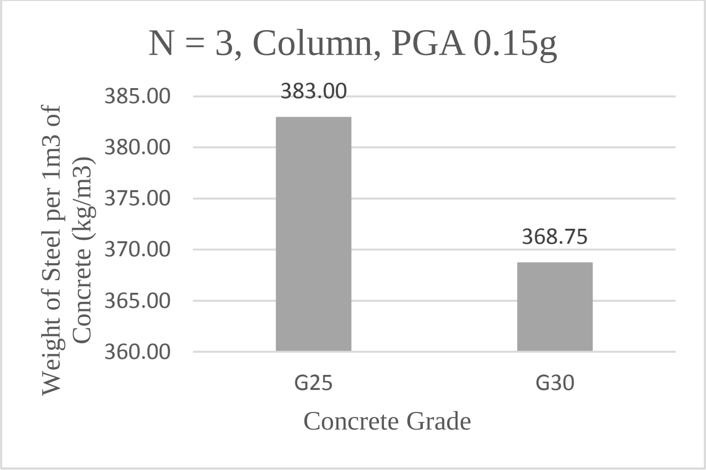


Figure 4.14: Main Reinforcement for column (3-storey)

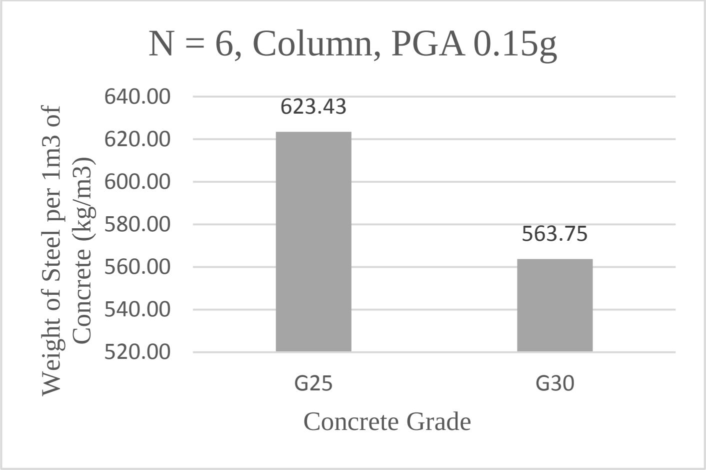


Figure 4.15: Main Reinforcement for column (6-storey)

The decrement of weight of steel reinforcement for main reinforcement for the column is strongly influenced with different concrete grade of G25 and G30.This resulted in the decreasing of base shear force, *F*b. When the base shear force, *F*b decreased, the bending moment for column will also decrease, which resulted in lower amount of the steel reinforcement required for column. The decrement value for bending moment is shown in Table 4.5.

Table 4.5: Main reinforcement of bending moment for 3-storey and 6-storey office building (column)

Model	Longitudinal Bars							
	PGA = 0.15g							
	3-Storey				6-Storey			
	Med	$A_{s,}$ min	A_s, req	A_s, prov	Med	$A_{s,}$ min	A_s, req	A_s, prov
NS-25	73	640	6400	4474	151	1004	10000	9651
NS-30	87	640	6400	2513	134	1000	10000	5890
G25	193	640	6400	5890	300	1004	10000	9651
G30	193	640	6400	5890	300	1004	10000	9651

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

The total weight of steel reinforcement for the entire office building is taken from the total amount of steel used for the main reinforcement. The main reinforcement for the beam and column elements are combined together to produce the overall reinforcement of the building as shown in Figure 4.16 and Figure 4.17. For main reinforcement of 3-storey and 6-storey office building, the percentage decrease from 36% to 56% and 162% to 137% respectively. For more detail, the decrement for both 3-storey and 6-storey are 36% to 56% and 162% to 137% is for G25 and G30 respectively. Then, it can be concluded that the higher the concrete grade, the lower the overall amount of steel required for the building. This result is in lined with the previous study that conducted by Yaakup (2018), she stated that the decrement of weight of steel reinforcement for main reinforcement for the column is strongly influenced with different concrete grade of G25, G30 and G35. This resulted in the decreasing of base shear force, Fb. When the base shear force, Fb decreased, the bending moment for column will also decrease, which resulted in lower amount of the steel reinforcement required.

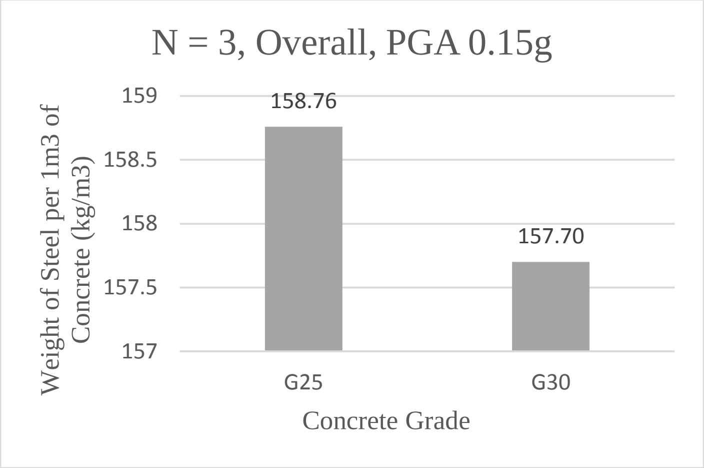


Figure 4.16: Main Reinforcement for beam and column (3-storey)

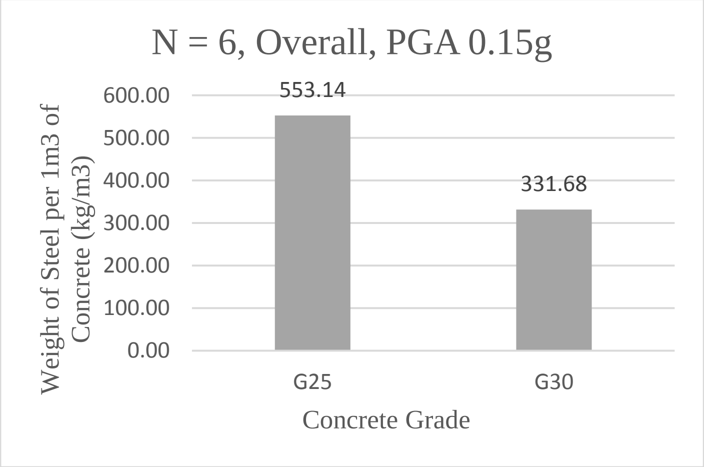


Figure 4.17: Main Reinforcement for beam and column (6-storey)

4.6 Total Weight of Steel Reinforcement per 1m^3 of Concrete Normalised to Non-Seismic Model

In this discussion, the total weight of steel reinforcement per 1m^3 of concrete normalised to non-seismic model is being compared for three different magnitude of peak ground acceleration and two different value of grade of concrete. The graph comparison will be discussed on the following section.

4.6.1 Total Weight of Steel Reinforcement per 1m^3 of Concrete Normalised to Non-Seismic Model for Concrete Grade 2

Figure 4.18 and figure 4.19 shows the total of weight of steel reinforcement per 1m^3 of concrete normalised to non-seismic model for grade of concrete 25. The graph is compared with different magnitude of PGA. From the graph, it can be shows that the highest is on the PGA equal to 0.15g and the lowest on the PGA equal to 0.03g. For more detail, the ratio of weight of steel reinforcement to non-seismic model for both 3-storey and 6-storey office building are 1.0, 0.9, 1.0, and 1.4 and 1.0, 1.1, 1.4 and 2.4 with PGA 0.03g, 0.09g and 0.15g respectively.

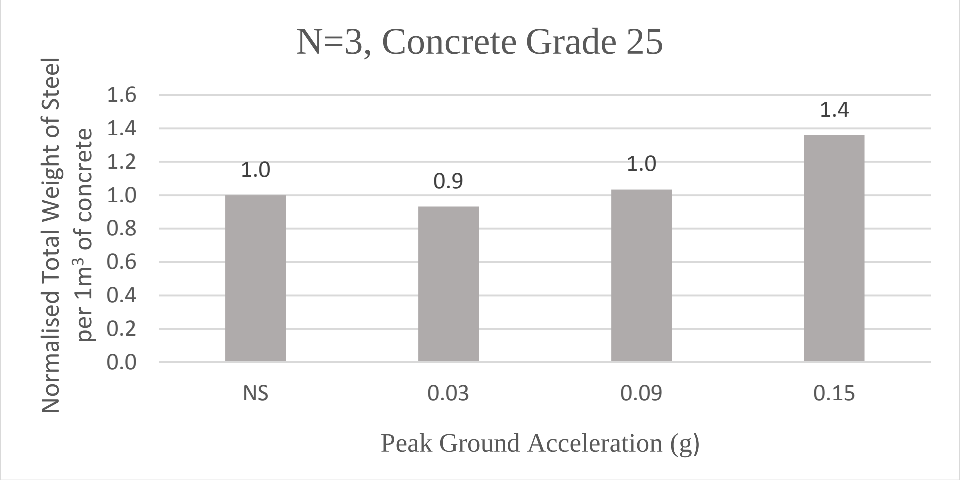


Figure 4.18: Normalised Total Weight of Steel per 1m^3 of concrete for G25 (3-storey)

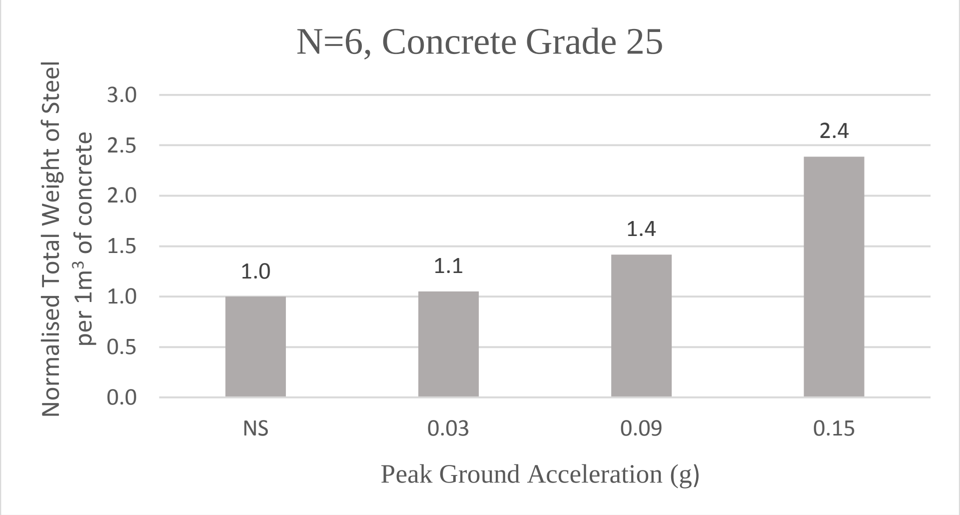


Figure 4.19: Normalised Total Weight of Steel per 1m^3 of concrete for G25 (6-storey

4.6.2 Total Weight of Steel Reinforcement per 1m^3 of Concrete Normalised to Non-Seismic Model for Concrete Grade 30

Figure 4.20 and figure 4.21 shows the ratio of weight of steel reinforcement per 1m^3 of concrete normalised to non-seismic model for grade of concrete 30. The graph is compared with different magnitude of PGA. From the graph, it can be shows that the highest is on the PGA equal to 0.15g and the lowest on the PGA equal to 0.03g. For more detail, the ratio of weight of steel reinforcement to non-seismic model for both 3-storey and 6-storey office building are 1.0, 1.0, 1.1, and 1.6 and 1.0, 1.1, 1.5 and 2.6 with PGA 0.03g, 0.09g and 0.15g respectively.

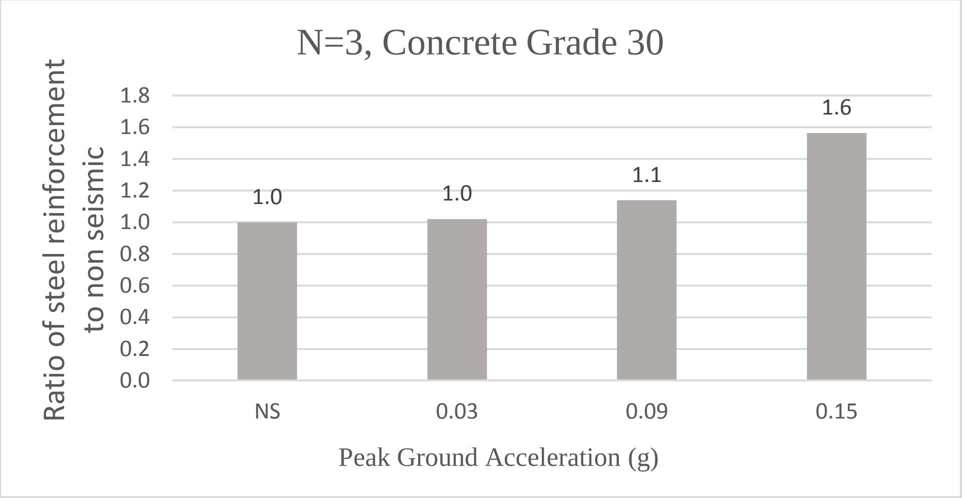


Figure 4.20: Normalised Total Weight of Steel per 1m^3 of concrete for G30 (3-storey)

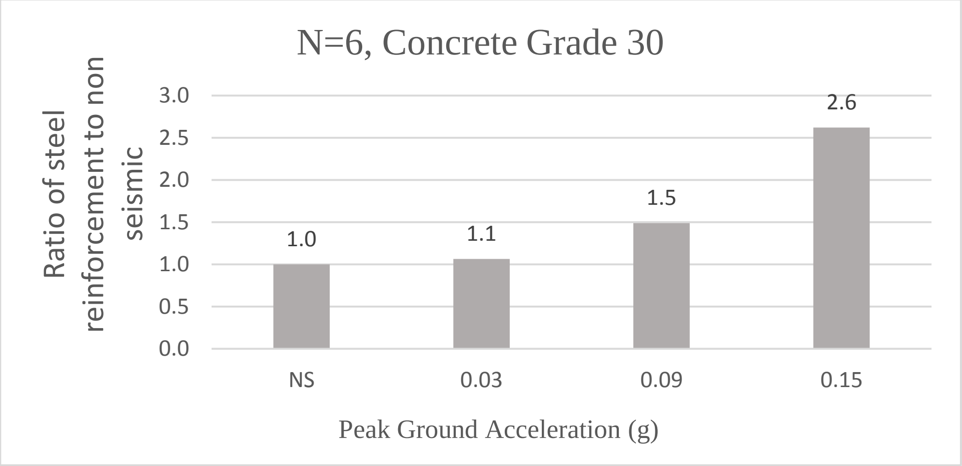


Figure 4.21: Normalised Total Weight of Steel per 1m^3 of concrete for G30 (6-storey)

4.7 Estimation of Total Cost on Material for Entire Building

In this discussion, the price on the material for whole building will be discussed based on the grade of concrete along with the three different type of peak ground acceleration which is 0.03g, 0.09g and 0.15g. The total cost of material used will be included the volume of concrete and steel weight that required for both beam and column for the entire building. The price will be based on JKR (2017) which the price for concrete grade G30 is RM372.10/m^3 and for concrete grade G25 is 325.30/m^3 and for steel is RM3.50/kg. The cost estimation for the whole building are discussed on the following section.

4.7.1 Estimation of Total Cost for Concrete Grade 25

The total cost estimation for grade of concrete G25 are obtained from the result that shown from previous part which included the total volume of concrete and the steel weight used for beam and column. The graph will be represented the price based on the magnitude of the PGA. The percentage different for 3-storey and 6-storey office building obtained are -4% to 20% and 3% to 83% respectively. For more detail the percentage obtained for both 3-storey and 6-storey office building is -4% to 20% and 3% to 83% for 0.03g, 0.09g and 0.15g respectively. From the graph, the higher cost for entire building is on the PGA equal to 0.15g and the lower is on the PGA 0.03g. Thus, it can be concluded that the higher the magnitude of PGA the higher the total cost for the whole building. This is because, when the building subjected to high magnitude of PGA, it will used high value of steel reinforcement. This result is in the same pattern with previous study that conducted by Ramli et al., (2017), the author stated that the higher value of peak ground acceleration will increase the total cost for the whole project.

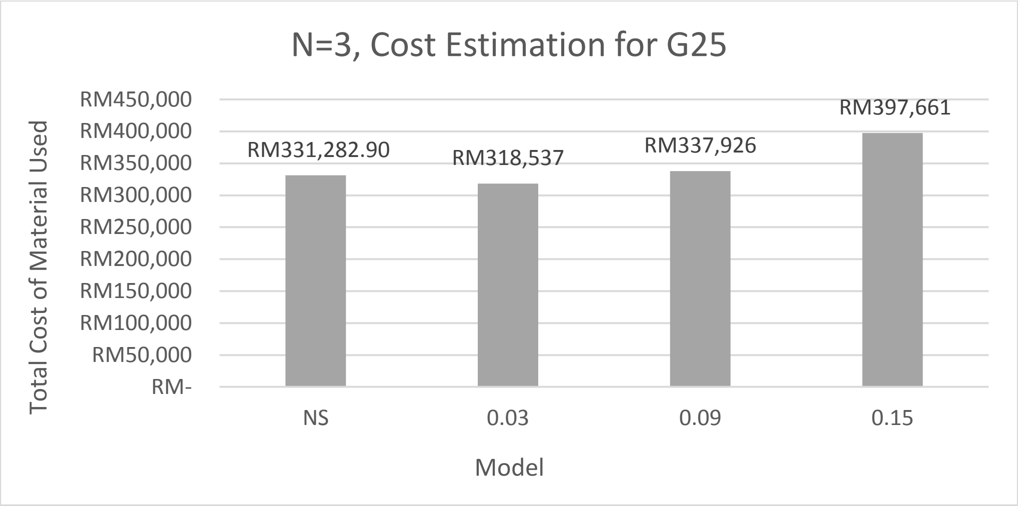


Figure 4.22: Cost Estimation for G25 (3-storey)

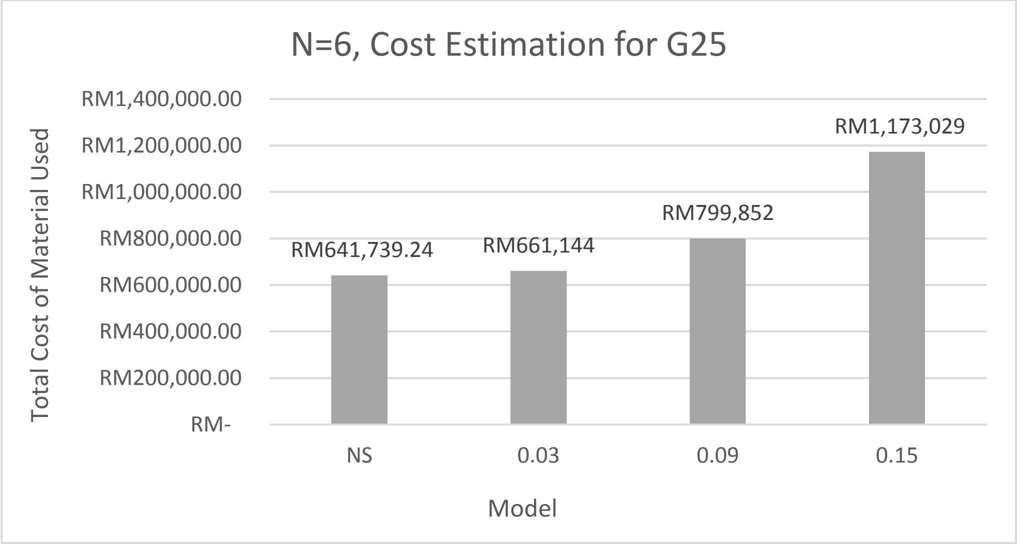


Figure 4.23: Cost Estimation for G25 (6-storey)

4.7.2 Estimation of Total Cost for Concrete Grade 30

The total cost estimation for grade of concrete G30 are obtained from the result that shown from previous part which included the total volume of concrete and the steel weight used for beam and column. The graph will be represented the price based on the magnitude of the PGA. The percentage different for 3-storey and 6-storey office building obtained are 1% to 27% and 3% to 85% respectively. For more detail the percentage obtained for both 3-storey and 6-storey office building is 1% to 27% and 3% to 85% for 0.03g, 0.09g and 0.15g respectively. From the graph, the higher cost for entire building is on the PGA equal to 0.15g and the lower is on the PGA 0.03g. Thus, it can be concluded that the higher the magnitude of PGA the higher the total cost for the whole building. This is because, when the building subjected to high magnitude of PGA, it will used high value of steel reinforcement. To be compared between this two concrete grade G25 and G30, the higher the concrete grade the higher the cost of the building.

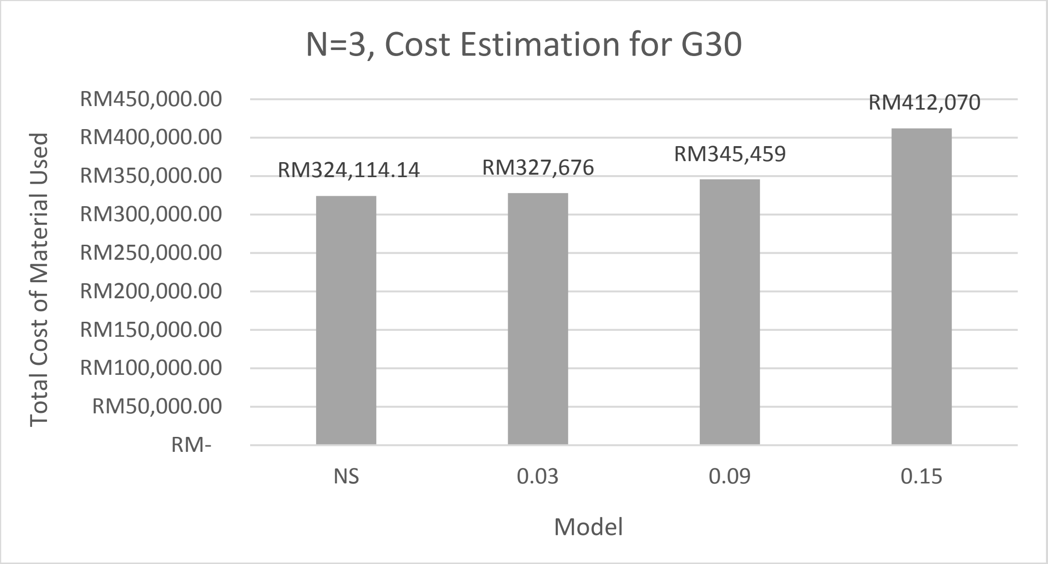


Figure 4.24: Cost Estimation for G30 (3-storey)

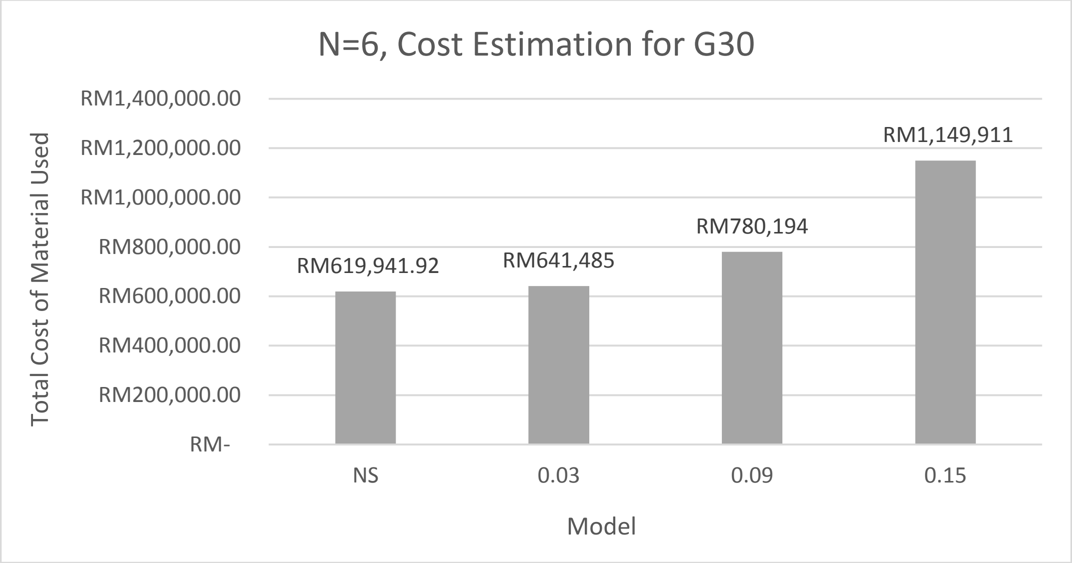


Figure 4.25: Cost Estimation for G30 (6-storey)

CHAPTER 5

CONCLUSION

5.1 Conclusion

The objectives of this study are to determine the effect on magnitude of Peak Ground Acceleration (PGA) and effect of grade of concrete of reinforced office building on the amount of steel reinforcement. The seismic performance was evaluated based on the amount of weight of steel per $1m^3$ of concrete for beam and column members for reinforced office building. The analysis is also done to get the design response spectrum graph where from the graph the results of $Sd(T_1)$ can be obtained. On the other hand, this study will also obtained the estimation cost for beam and column for entire building based on the market price in Malaysia. To achieve the above objectives, the analysis is done on 3-storey and 6-storey reinforced office building. The model is assumed to be built on Soil Type D and the ductility is Ductility Class Medium (DCM). The model was designed based on the Eurocode 8 (2004) to represent the reinforced office building. The analysis is also done by using Tekla Structural Designer software which use three different values of peak ground acceleration which are 0.03g, 0.09g and 0.15g on two different grade of concrete which are G25 and G30. The conclusions obtained from the analysis are listed as follows.

- Total amount of reinforcement required in a building is higher when it is subjected to higher magnitude of PGA. The percentage difference from non-seismic model of 3-storey and 6-storey office building are 2% to 56% and 7% to 162% respectively. For more detail, the increment percentage for 3-storey office building is 2%, 14% and 56% and the increment percentage for 6-storey office building is 7%, 49% and 162% for reference peak ground acceleration, agR = 0.03g, 0.09g and 0.15g respectively. This is because higher magnitude of PGA resulted in higher value of response spectrum, Sd (T_1) which will increase the value of base shear force, Fb.

When base shear force increase, the total amount of steel reinforcement required will increase.

- The higher total amount of steel reinforcement required for reinforced office building the lower concrete grade will be used. The decrement shows for 3-storey and 6-storey office building are around 36% to 56% and 162% to 139% respectively according to different grade of concrete. This is because as the concrete grade higher, it possessed higher compressive strength which resulted in lower amount of steel reinforcement required.

- The higher the amount of steel reinforcement and volume of concrete used, the higher the cost of the building. For G25, the percentage different for 3-storey and 6-storey office building obtained are -4% to 20% and 3% to 83% respectively. For more detail the percentage obtained for both 3-storey and 6-storey office building is -4% to 20% and 3% to 83% for 0.03g, 0.09g and 0.15g respectively. As for G30, the percentage different for 3-storey and 6-storey office building obtained are 1% to 27% and 3% to 85% respectively. For more detail the percentage obtained for both 3-storey and 6-storey office building is 1% to 27% and 3% to 85% for 0.03g, 0.09g and 0.15g respectively. To be compared between this two concrete grade G25 and G30, the higher the concrete grade the higher the cost of the building.

5.2 Future Recommendation

For future research for this study, some recommended studies are listed as follow:

i. Extend the studies using different type of building which can be categorized from importance factor. The earthquake will give different effect for the building when used different value of importance factor.

ii. The next study, considering the different types of Soil Type to investigate the effect of earthquake on the structural element of a building built in low and high seismicity regions then compare the difference.

iii. Research related to earthquake can be carried out in future by considering the foundation of the building.

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APPENDIX A
SEISMIC HAZARD MAP

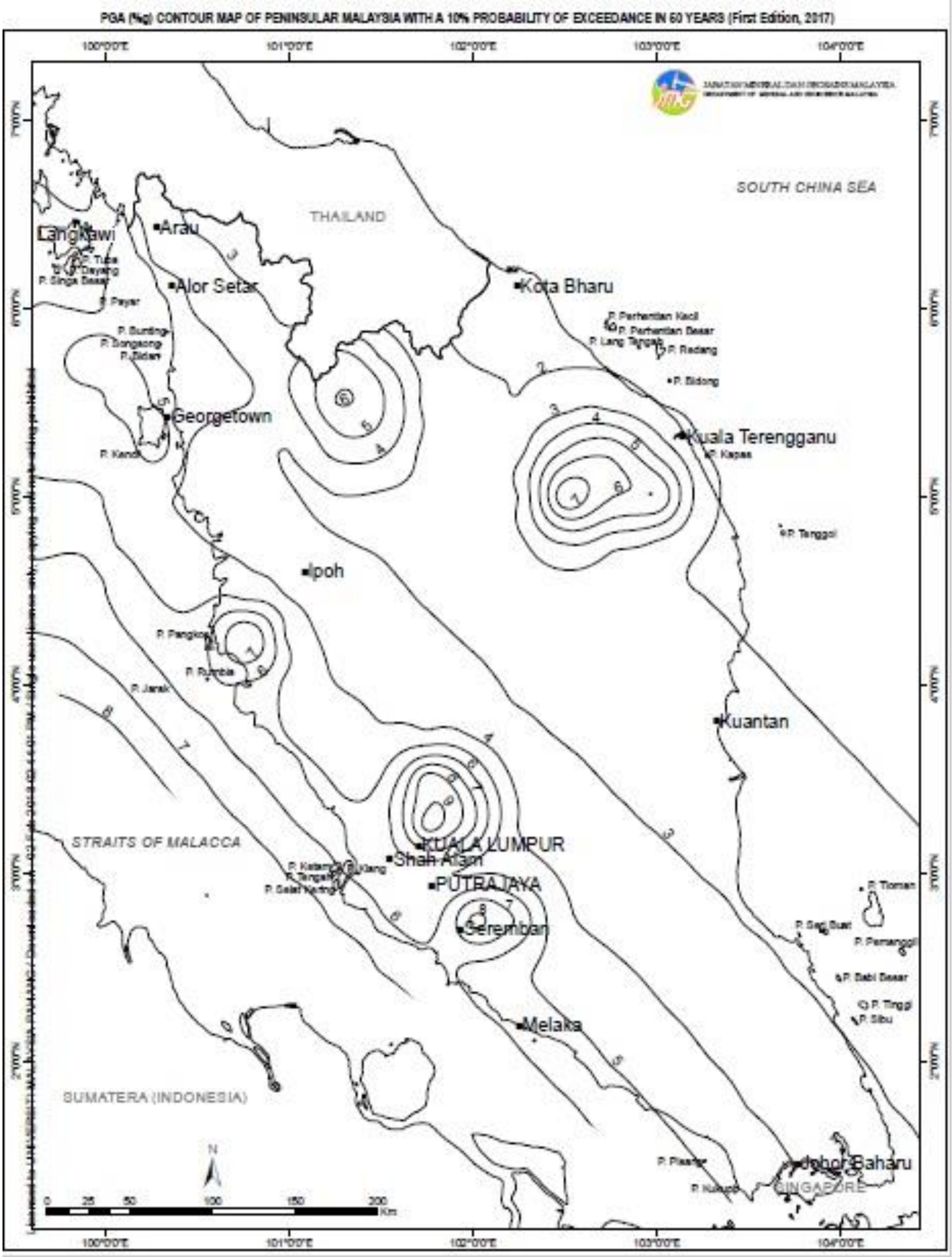

Figure A1: Seismic Hazard Map for Peninsular Malaysia

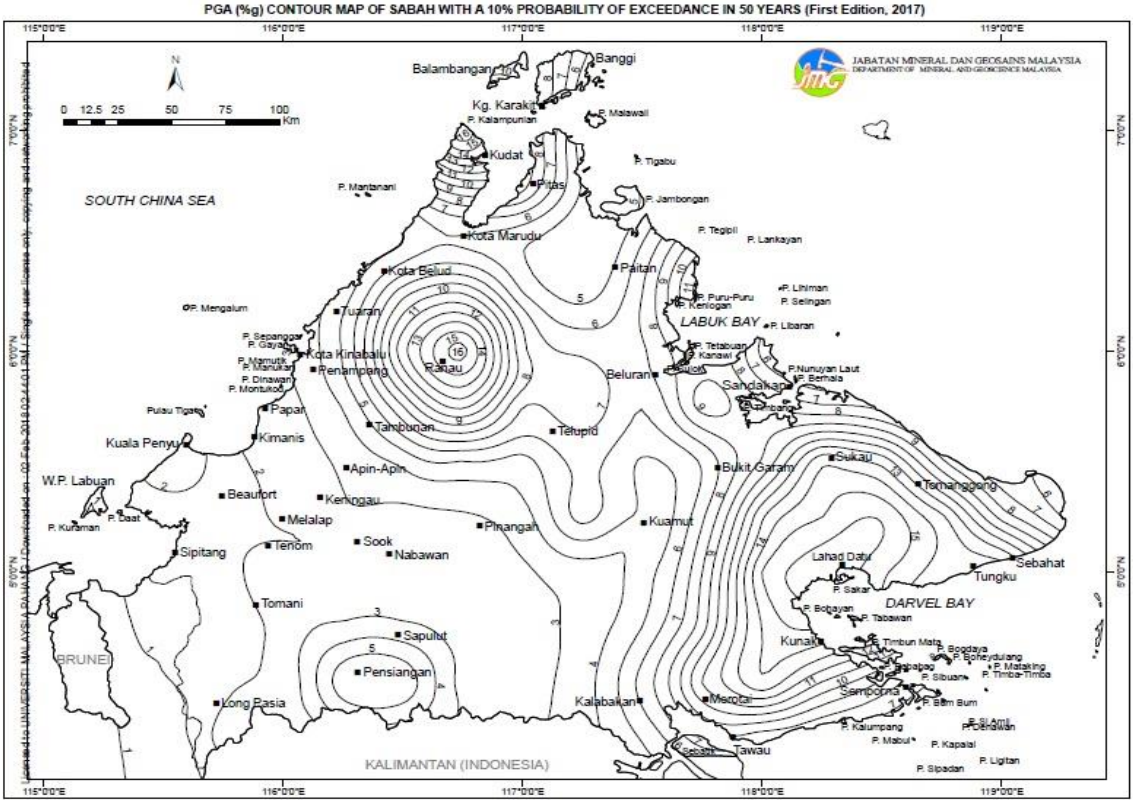

Figure A2: Seismic Hazard Map for Sabah

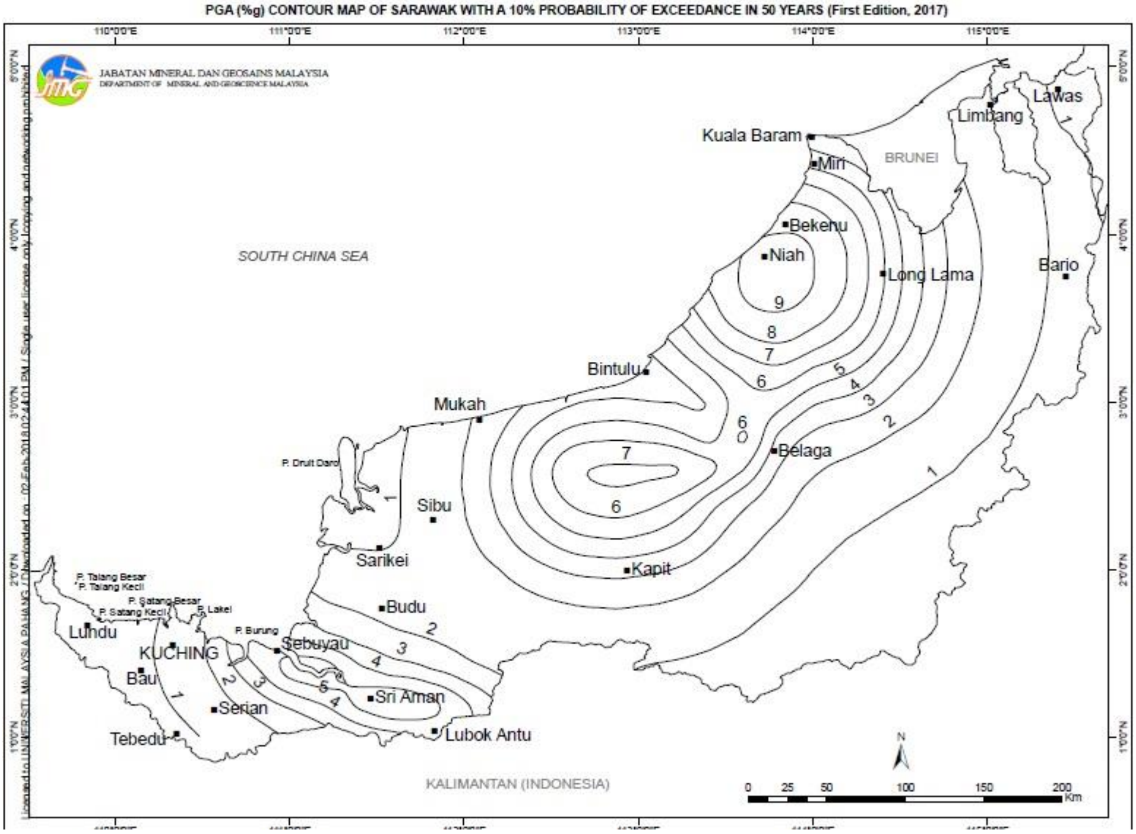

Figure A3: Seismic Hazard Map for Sarawak

APPENDIX B
6-STOREY OFFICE BUILDING

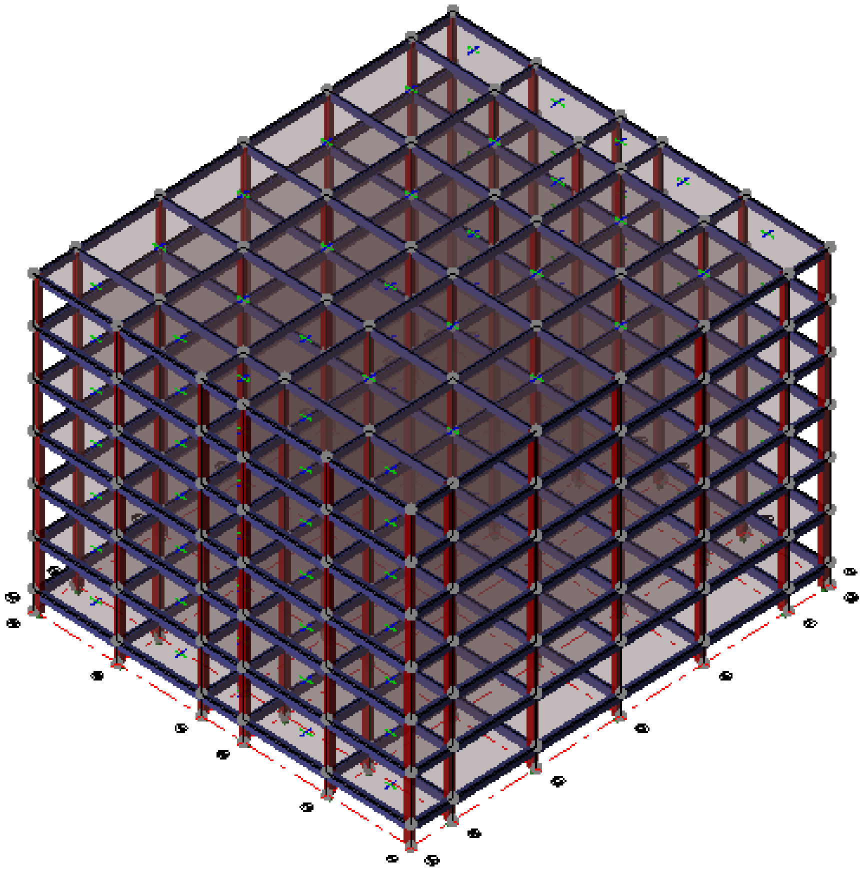

Figure B1: 3D model of the building generated from Tekla structural software (6-storey)

APPENDIX C
EFFECT OF PGA ON AMOUNT OF STEEL REINFORCEMENT

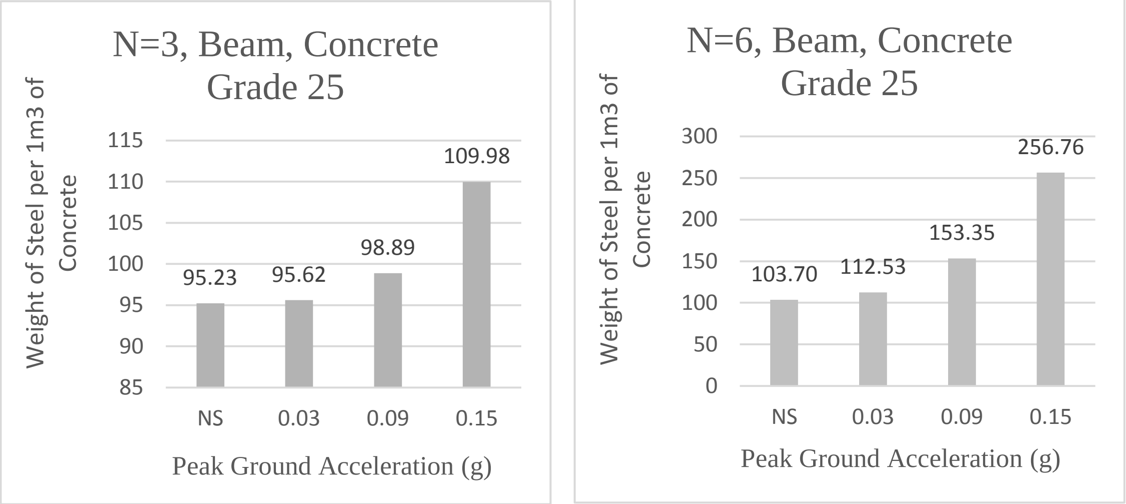

Figure C1 & C2: Weight of steel per 1m^3 of concrete for beam (3-storey & 6-storey)

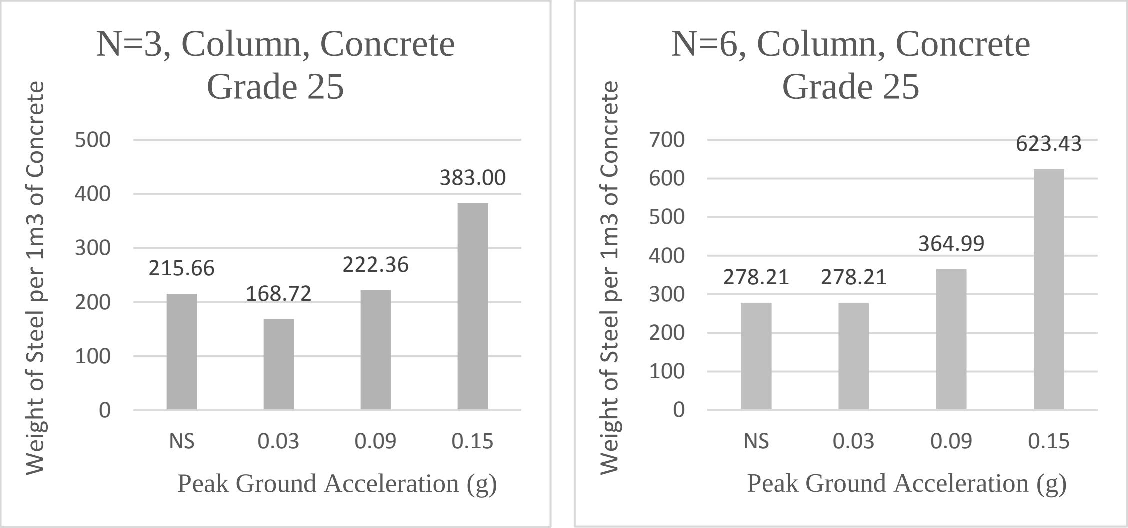

Figure C3 & C4: Weight of steel per 1m^3 of concrete for column (3-storey & 6-storey)

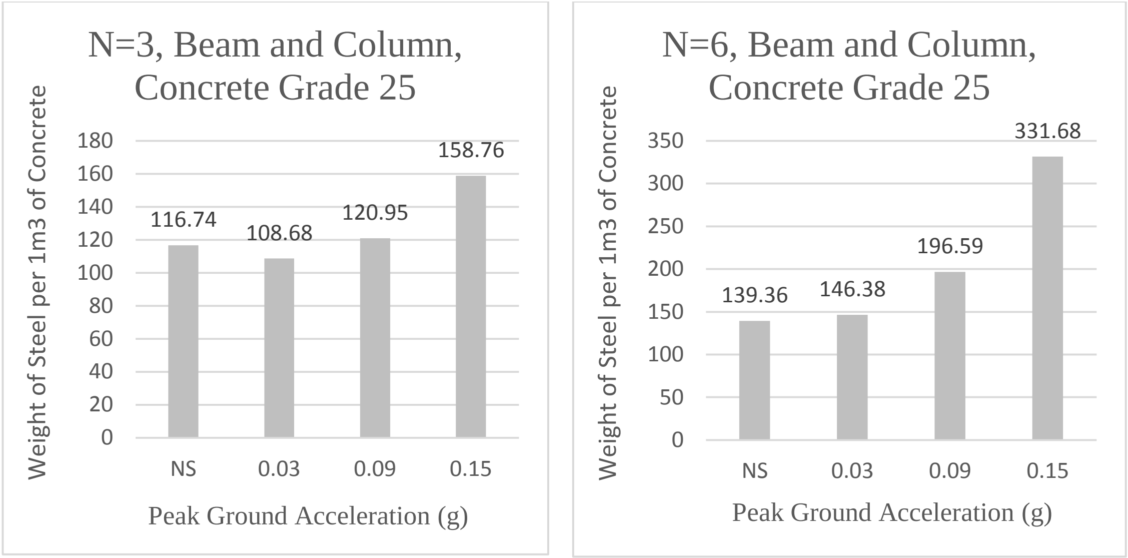

Figure C5 & C6: Weight of steel per 1m^3 of concrete for beam and column (3-storey & 6-storey)