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ESTIMATION MODEL OF WEIGHT OF STEEL IN REINFORCED CONCRETE BUILDING WITH SEISMIC DESIGN IN MALAYSIA

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ABSTRACT

Generally, reinforced concrete buildings in Malaysia were built and used widely compared to steel, timber, and masonry wall system. Majority reinforced concrete design practice in Malaysia had been conducted without seismic consideration by referring to BS 8110. On 5th June 2015, a moderate earthquake with magnitude Mw5.9 was occurred in Sabah. The epicentre was located at 16 km northwest from Ranau. The tremors were felt in Kundasang, Ranau, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud. A lot of damages had been reported on residential, school, mosque, temple, and commercial buildings. In medium – to – high risk earthquake zones, the Malaysian Public Work Department had suggested that it is worthwhile to consider seismic design input for new buildings. From economical view, it is interesting to study the effect of seismic design on cost of construction material and factors which influencing the cost. Hence, this research work investigated the effect of seismic design on the amount of steel used as reinforcement in reinforced concrete buildings. This research focused to low rise reinforced concrete buildings as models covering various function namely as hospital, office, school, and multipurpose hall. A total of four seismic design parameters namely as reference peak ground acceleration, α_{gR} soil type, concrete grade, and ductility class had been considered in analysis and design process. Based on results, it can be concluded that the total weight of steel reinforcement increases as the value of reference peak ground acceleration, α_{gR} increases. Soil type also influencing the total weight of steel reinforcement. Different soil type caused the total weight of steel reinforcement increased around 1.16 to 2.11 times higher compared to the nonseismic design. Besides, the concrete grade and ductility class also influencing the total weight of steel reinforcement. Lower concrete grade required higher amount of steel reinforcement. In regions with higher seismicity, ductility class medium is preferable for more economical design.

ABSTRAK

Secara umumnya, bangunan konkrit bertetulang di Malaysia telah dibina dan digunakan secara meluas berbanding besi, kayu, dan sistem dinding bata. Majoriti praktik rekabentuk konkrit bertetulang di Malaysia telah dijalankan tanpa pertimbangan beban seismik dengan merujuk kepada BS8110. Pada 5 Jun 2015, gempa bumi sederhana dengan magnitude Mw5.9 telah terjadi di Sabah. Pusat gempa terletak 16km ke arah Barat Laut dari Ranau. Gegaran telah dirasai di Kundasang, Ranau, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud. Kerosakan telah dilaporkan pada bangunan-bangunan kediaman, sekolah, masjid, tokong, dan komersial. Di kawasan risiko gempa bumi medium ke tinggi, Jabatan Kerja Raya Malaysia telah mencadangkan bahawa pertimbangan rekabentuk seismik adalah berbaloi bagi bangunan-bangunan baru. Dari pandangan ekonomi, adalah menarik untuk mengkaji kesan rekabentuk seismik ke atas kos bahan binaan dan faktor-faktor yang mempengaruhi kos. Maka, kerja penyelidikan ini telah menyiasat kesan rekabentuk seismic ke atas jumlah besi yang digunakan sebagai pengukuhan dalam bangunan konkrit bertetulang. Kajian ini telah memberikan fokus kepada bangunan-bangunan konkrit bertetulang aras rendah sebagai model merangkumi pelbagai fungsi iaitu hospital, pejabat, sekolah, dan dewan serbaguna. Sejumlah empat parameter rekabentuk seismic iaitu rujukan pecutan tanah puncak, jenis tanah, gred konkrit, dan kelas kemuluran telah dipertimbangkan di dalam proses analisis dan rekabentuk. Berdasarkan keputusan, boleh disimpulkan bahawa jumlah berat besi pengukuhan adalah meningkat apabila nilai rujukan pecutan tanah puncak meningkat. Jenis tanah juga mempengaruhi jumlah berat besi pengukuhan. Jenis tanah yang berbeza telah menyebabkan jumlah berat besi pengukuhan meningkat sekitar 1.16 hingga 2.11 kali lebih tinggi berbanding tanpa rekabentuk seismik. Selain itu, gred konkrit dan kelas kemuluran juga mempengaruhi jumlah berat besi pengukuhan. Gred konkrit yang lebih rendah memerlukan jumlah besi pengukuhan yang lebih tinggi. Dalam kawasan seismik lebih tinggi, kemuluran kelas medium lebih baik untuk rekabentuk yang lebih ekonomi.

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LIST OF SYMBOLS

α_g	Design ground acceleration
α_{gR}	Reference peak ground acceleration
As_{prov}	Total area of steel provided
As_{req}	Total area of steel required
d_{bL}	Diameter of longitudinal bar
d_{bw}	Diameter of shear or confinement bar
F_{b}	Base shear force
f_{cd}	Design value of concrete compressive strength
f_{ck}	Characteristic cylinder strength of concrete
$F\mathrm{i}$	Lateral load on storey
f_{y}	Yield strength of reinforcement
g	Acceleration due to gravity, m/s^2
G_{k}	Dead load
H	Storey height
M	Bending moment
m_{i}	Mass of storey *i*
M_{Rb}	Design moment resistance of beam
M_{Rc}	Design moment resistance of column
M_{w}	Magnitude of earthquake intensity
N	Number of storey
q	Behaviour factor
Q_{k}	Live load
S	Soil factor
$S_{\mathrm{d}}(T_1)$	Ordinate of the design spectrum at period
T_1	Fundamental period of vibration
T_{B}	Lower limit of the period of the constant spectral acceleration
T_{C}	Lower limit of the period of the constant spectral acceleration
T_{D}	Beginning of the constant displacement response range of the spectrum
V	Beginning of the constant displacement response range of the spectrum
λ	Correction factor
γ_1	Importance factor

LIST OF ABBREVIATIONS

DCH	Ductility class high
DCL	Ductility class low
DCM	Ductility class medium
JKR	Jabatan Kerja Raya
MMD	Malaysian Meteorological Department
PGA	Peak ground acceleration
RC	Reinforced concrete

LIST OF PUBLICATIONS

1. M.I. Adiyanto, F. Ahmad Jani, S.A.H.S. Mustafa and S.W. Ahmad (2019), Estimation on Amount of Steel Reinforcement for Six Storey Hospital Building with Seismic Design Consideration in Malaysia, *IOP Conference Series: Earth and Environmental Science*, 244, pp. 012015 **(Scopus Index)**

2. S.A.H.S. Mustafa, M.I. Adiyanto, T.A. Majid, M.I. Ali (2019), Influence of Soil Type on Steel Reinforcement of Four Storey Reinforced Concrete Building with Seismic Design, *Malaysian Construction Research Journal*, 7 (2), pp. 81-87 **(Scopus Index)**

3. H.A. Roslan, M.I. Adiyanto, S.A.H.S. Mustafa, T.A. Majid, S.M. Noor (2019), Increment of Steel Tonnage for Reinforced Concrete School Building Considering Seismic Design, *International Journal of Recent Technology and Engineering*, 8 (3S3), pp. 351-355 **(Indexed Journal)**

4. N.I.A Azman, M.I. Adiyanto, S.A.H.S. Mustafa, A. Adnan, A. Rashidi (2019), Steel Reinforcement and Concrete for Multipurpose Hall Building with Seismic Design, *International Journal of Recent Technology and Engineering*, 8 (3S3), pp. 543-547 **(Indexed Journal)**

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CHAPTER 1

INTRODUCTION

1.1 State of the Art

Malaysia is surrounded by high seismicity regions at the east, west, and south parts. This is strongly associated with the subduction zones between the Eurasian and Philippines plates at the east part (Pappin et al., 2011). At the west and south parts, high seismicity region is formed by the subduction zones between the Indo-Australian and Eurasian plates. On 26th December 2004 a large earthquake was occurred with magnitude M_w9.0 originated from West Aceh, Sumatra, Indonesia. The event had become a wakeup call to Malaysian as they felt the tremor in their own home ground. The earthquake also triggered a disastrous Indian Ocean tsunami with high tidal wave which struck the coastal area of several countries in Asian region. After that event, several other tremors were felt in Malaysia due to regional earthquakes especially from Indonesia and Philippine. Local earthquakes also occurred in Bukit Tinggi with magnitude M_w up to 3.5 (MOSTI, 2009).

On 5th June 2015, a moderate earthquake with magnitude Mw5.9 as reported by Malaysian Meteorological Department (MMD) was occurred in Sabah around 7:15 am local time. According to the MMD, the epicentre was located at 16 km northwest from Ranau and the depth is 54 km beneath the earth. The tremors were felt in Kundasang, Ranau, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud. A lot of damages had been reported on residential, school, mosque, temple, and commercial buildings. Prior to that event, the question on capacity of Malaysian buildings to survive during earthquake arises again.

Generally, reinforced concrete (RC) moment resisting frame buildings in Malaysia were built and used widely 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. Majority RC design practice in Malaysia had been conducted without seismic consideration by referring to BS 8110.

As reported by MOSTI (2009), most of the buildings in Peninsular Malaysia were in good condition and at least 50% of selected buildings were found to experience concrete deterioration problems due to vibration during earthquake. From the same report, it was found that the vertical element design provision were inadequate for at least 50% of the evaluated buildings. Hence, in medium – to – high risk earthquake zones, the Malaysian Public Work Department had suggested that it is worthwhile to consider seismic design input for new buildings. From economical view, it is interesting to study the effect of seismic consideration on cost of material and factors which influencing the cost.

There are a few factors which influencing the seismic design such as the site location, soil type, peak ground acceleration (PGA), materials, type of structures, ductility, stiffness, and behaviour factor, q. The latter was introduced for seismic design in order to reduce the forces obtained from a linear analysis in order to take into account for the nonlinear response of a structure (Eurocode 8, 2004). The value of behaviour factor, q is associated with the materials, structural system, and the class of ductility.

According to Eurocode 8 (2004) there are three classes of ductility namely as ductility class low (DCL), ductility class medium (DCM), and ductility class high (DCH). Different value of behaviour factor, q was proposed for every class of ductility. For multi-storey and multi-bay RC buildings with moment resisting frame system, the value of behaviour factor, q for DCL, DCM, and DCH is equal to 1.5, 3.9, and 5.85, respectively (Eurocode 8, 2004).The level of ductility to be used for seismic design in Malaysia also has become a discussion. According to Pappin et al. (2011), for low rise buildings with lower fundamental period of vibration, T_1 ductile detailing could be ignored but at the expense of using a lower behaviour factor, q. As a result, higher seismic forces have to be considered in design. Therefore, the designer may still wish to use ductile detailing to take advantage of the lower seismic design forces. The latter can be obtained by using a higher value of behaviour factor, q. Therefore, a research work had been conducted in order to investigate the effect of seismic design on costing. This research work focused to determine the approximate weight of steel in every 1m^3 of concrete.

1.2 Objectives

The main objectives of the study are:

1. To investigate the effect of class of ductility, soil type, concrete grade and magnitude of reference peak ground acceleration, α_{gR} on weight of steel in RC building in Malaysia.
2. To develop guideline model to estimate the weight of steel used as reinforcement in every 1m^3 of concrete for building in Malaysia

1.3 Scope of Work

This study is covered for the following aspect:

1. Four buildings layout representing hospital, office, school, and multipurpose hall in Malaysia had been used as models
2. The reference peak ground acceleration, α_{gR} in range from 0.04g to 0.16g had been considered to represent seismicity in Malaysia
3. Five soil types had been considered which is Soil Type A, Soil Type B, Soil Type C, Soil Type D and Soil Type E.
4. The concrete grade C25, C30, and C35 had been utilised for member design
5. The DCL and DCM had been considered to study the effect of ductility class
6. The process of structural analysis and member design had been conducted by using Tekla Structural Design Software and referred to Eurocode 8 (2004) for seismic provision.
7. Comparison is made in term of amount of steel required as reinforcement per 1m^3 of concrete for every model.

CHAPTER 2

ESTIMATION AMOUNT OF STEEL REINFORCEMENT FOR SIX STOREY HOSPITAL BUILDING WITH SEISMIC DESIGN CONSIDERATION IN MALAYSIA

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Abstract. A series of earthquakes such as Sumatra-Andaman earthquake on 26 December 2004, Nias earthquake on 28 March 2005, and Bengkulu earthquake on 12 December 2007 had influences to a series of subsequence local earthquake in Peninsular Malaysia. Recently, East Malaysia especially Sabah has become earthquake prone region due to local fault. Hence, Malaysia is not totally free from seismic activities. Therefore, in 2009 Malaysian Public Work Department had concluded that it was worthwhile to consider seismic design input in new building which are located in medium to high risk earthquake zone. The effect of seismic design implementation on cost of materials has become an interesting topic to discuss. This study presents the estimation of steel reinforcement required for six storey hospital building in Malaysia with seismic design consideration. Two parameters namely as reference peak ground acceleration and class of ductility has been considered as variable. The result shows that the total amount of steel reinforcement is increased from 6%, 116%, 257%, and 290% for peak ground acceleration equal to 0.04g, 0.08g, 0.12g, and 0.16g, respectively compared to the non-seismic design counterpart. Beside, total amount of steel reinforcement is increase around 6% and 145% for ductility class medium and ductility class low, respectively compared to its non-seismic design counterpart.

2.1 Introduction

According to Department of Mineral and Geoscience Malaysia, the nation is considered as a country that has relatively low seismicity except for the state of Sabah where earthquake is locally known to occur [1]. For a few decades Malaysia had not consider seismic load in structural design. This is due to our geographical location which are situated on the stable part and far from active seismic fault region. For reinforced concrete (RC) structures, current design practice in Malaysia are referring to BS8110 which has no seismic provision [2]. However, the low seismic hazard in

Malaysia cannot be taken lightly as Malaysia is surrounded by high seismicity regions from neighbouring countries such as Indonesia and Philippine. Therefore, Malaysia will have a certain risk of earthquake coming from the regions especially in the west coast of peninsular Malaysia and Sabah. This is supported by previous study [3] which mentioned that the statistics for an updated earthquake recorded from 1884 through 2016 represented by magnitude indicates a large increment of earthquake events for the last 140 years as shown in Figure 2.1

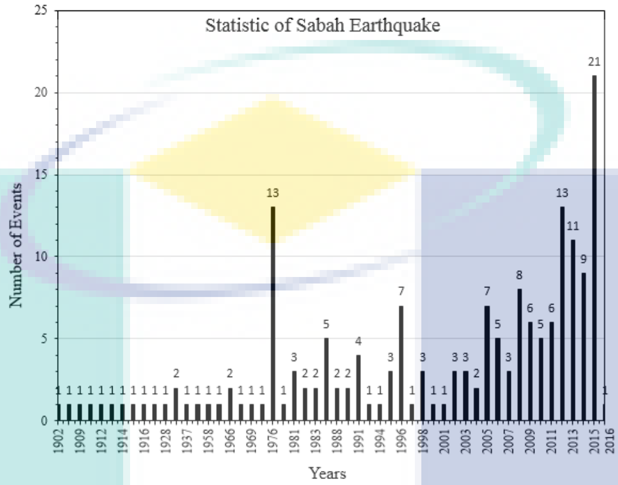

Figure 2.1 Number of local earthquakes reported (1900-2016) around Sabah [3]

On 5th June 2015, a moderate local earthquake with magnitude M_w6.1 was occurred in Sabah. According to the Malaysian Meteorological Department, the epicentre located at 16 km northwest from Ranau. It has been recorded as the strongest local earthquake to affect Malaysia for the last 45 years [4]. The earthquake had caused a lot of damages on structural and non-structural elements as reported based on in-situ investigation [5,6]. Malaysians started to worry and questioning the ability of existing structures to withstand the future earthquakes. Seismic design might be considered as solution for new buildings. This matter had been raised almost a decade ago by Malaysian Public Work Department which concluded that it was worthwhile to consider seismic design input in new building which are located in medium to high risk earthquake zone [1]. However, from economical view the implementation of seismic design has triggered a question either the cost of material for construction will increase and is it affordable? [7]. Therefore, this study investigated the six storey RC building with seismic and non-seismic design consideration. The level of reference peak ground acceleration, α_{gR} and class of ductility has been considered as variable for seismic design. The comparison has been made in term of total amount of steel reinforcement.

2.2 Model and Methodology

This study has been conducted based on three phases started by model generation, followed by structural analysis and seismic design, before final process namely as taking off. In model generation part, a six storey regular in plan and elevation RC building has been generated by using Tekla Structural Designer computer software as shown in Figure 2.2. The RC building has been generated based on hospital building for patient wards purpose. The floor to floor height is equal to 3.6m. The column to column span is equal to 3.0 m and 6.0 m. Table 2.1 presents the dimension of all beams and columns for the generated hospital RC building.

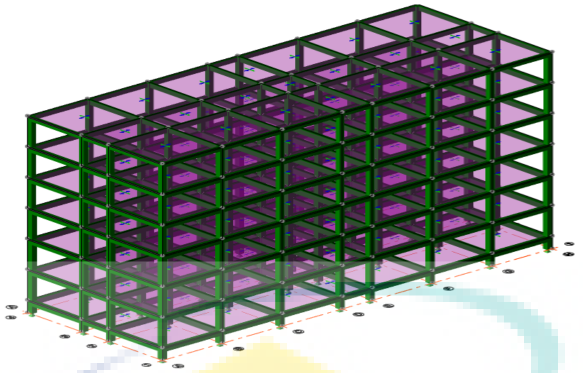

Figure 2.2 3D view of six storey hospital RC building

Table 2.1 Size of structural members of the model

Member	Size (mm)
Roof beam	250 x 500
Floor beam	350 x 600
Column A (floor 4 to 6)	450 x 450
Column B (Floor 1 to 3)	500 x 500

The structural analysis and seismic design took part in Phase 2. Since the model has been generated based on patient ward for hospital, it was classified as importance class IV as recommended by Eurocode 8 [8]. Therefore, the value of importance factor, γ_I is equal to 1.4. The recommended value is to offer better protection of life for such buildings due to its importance after disaster [9]. The model is categorized as Category A for load distribution as stated in Eurocode 1 [10].Therefore, the imposed load, Q_k used on the floor and roof of this category is equal to 2.0 kN/m^2 and 0.4 kN/m^2, respectively.

As mentioned in previous section, the level of reference peak ground acceleration, α_{gR} and class of ductility has been considered as variable for seismic design. In order to investigate the effect of different level of reference peak ground acceleration, α_{gR} on total amount of steel reinforcement, four reference peak ground acceleration, α_{gR} equal to 0.04g, 0.08g, 0.12g, and 0.16g has been considered for structural analysis and design. These values representing the level of seismicity in Malaysia. The structural members of RC hospital model has been designed repeatedly based on the aforementioned level of reference peak ground acceleration, α_{gR} for ductility class medium (DCM).

In order to investigate the effect of class of ductility on total amount of steel reinforcement, two class of ductility namely as ductility class low (DCL) and DCM has been considered in this study. Ductility class high is not taken into account because it only suitable for high seismic region such as Italy, Greece, and Turkey in Europe. The RC hospital model with DCL has been analysed and designed based on reference peak ground acceleration, α_{gR} equal to 0.04g. In addition, one RC hospital model has been analysed and designed without any seismic consideration for control purpose. Table 2.2 summarized all RC hospital models used in this study and its design consideration.

Table 2.2 RC hospital models and design consideration

No	Model Code	Reference peak ground acceleration, α_{gR} (g)	Class of ductility	Behaviour factor, q
1	NS	-	-	-
2	DCL – 0.04	0.04	Low	1.5
3	DCM – 0.04	0.04	Medium	3.9
4	DCM – 0.08	0.08	Medium	3.9
5	DCM – 0.12	0.12	Medium	3.9
6	DCM – 0.16	0.16	Medium	3.9

The structural analysis has been conducted based on Lateral Force Method. The latter mentioned that the action of earthquake on building can be represented by lateral load acting on each storey joints [8]. The magnitude of lateral load is distributed from the base shear force, F_b. The latter is derived based on the following equation:

$$F_b = S_d(T_1).m.\lambda. \tag{1}$$

where $S_d(T_1)$ is the ordinate of design response spectrum at the fundamental period of vibration of the building, m is the total mass of the building, and λ is the correction factor where $\lambda = 0.85$ if $T_1 < 2T_c$ and the building has more than two storey, or $\lambda = 1.0$ [8]. The ordinate of design response spectrum, $S_d(T_1)$ is determined based on the design response spectrum. The latter has been developed for all reference peak ground acceleration, α_{gR} and class of ductility as mentioned before. This study only consider Type I design response spectrum and Soil Type D [8]. All models has been designed based on concrete compressive strength, f_{cu} and yield strength of steel, f_y equal to 30 N/mm^2 and 500 N/mm^2, respectively.

The final phase is the taking off process. The latter is a process to measure all the steel reinforcement used for all RC hospital models. The data has been collected and analysed in form of weight of steel reinforcement per 1m^3 of concrete. In this study, the density of steel reinforcement is equal to 7850 kg/m^3.

2.3 Result and Discussion

2.3.1 Spectral Design Acceleration, $S_d(T_1)$

In RC design, the number of steel reinforcement and its size are directly depend on the magnitude of internal reactions namely as bending moment, m shear force, v and axial load, P. All these internal reactions are strongly influenced by the magnitude of load. The higher magnitude of load will result in higher magnitude of internal reactions, vice versa. In this study, all models has been assigned to similar magnitude of dead load, G_k and imposed load, Q_k. Therefore, different magnitude of internal reactions for all models are influenced by the magnitude of earthquake load, E. The latter is expressed in form of base shear force, F_b. By referring to Equation 1, the magnitude of based shear force is depends on ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$ the total mass of the building, m and the correction factor, λ. In this study, the last two parameters are similar for all models. Therefore, the magnitude of based shear force, F_b is directly influenced by the ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$. Figure 2.3 presents the design response spectrum developed for reference peak ground acceleration, α_{gR} equal to 0.04g, 0.08g, 0.12g, and 0.16g with DCM.

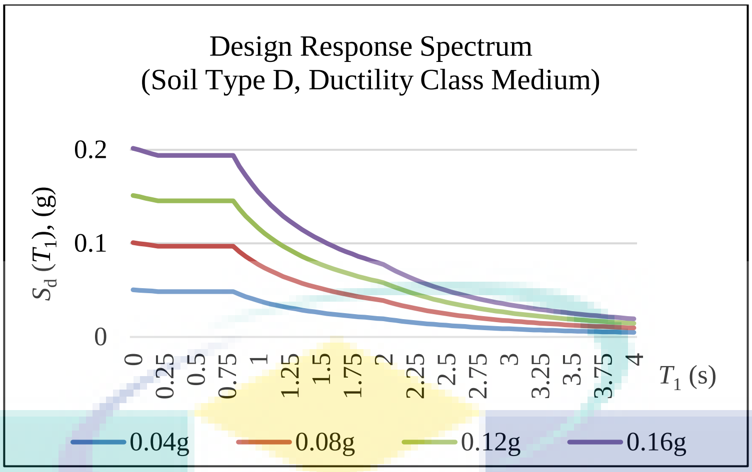

Figure 2.3 Design response spectrum for different value of reference peak ground acceleration

Based on the equation proposed by Eurocode 8 [8], the fundamental period of vibration, T_1 for all models is equal to 0.75 sec. Therefore, by referring to Figure 3, the ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$ is equal to 0.048g, 0.097g, 0.145g, and 0.194g for reference peak ground acceleration, α_{gR} equal to 0.04g, 0.08g, 0.12g, and 0.16g, respectively. It means that higher value of reference peak ground acceleration, α_{gR} will give higher value of the ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$ as well as higher value of base shear force, F_b. Therefore, the DCM – 0.16 model has been subjected to the highest magnitude of base shear force, F_b compared to other models.

Figure 2.4 presents the design response spectrum developed for both DCL and DCM based on reference peak ground acceleration, α_{gR} equal to 0.04g. It shows that the ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$ is equal to 0.048g and 0.126g for DCM and DCL, respectively. This means that higher class of ductility will reduce the value of the ordinate of design response spectrum at the fundamental period of vibration of the building, $S_d(T_1)$. As a result, the magnitude of base shear force, F_b also reduced. Therefore, in this study the DCL – 0.04 model has been subjected to higher magnitude of base shear force, F_b compared to DCM – 0.04 and NS models. This is in good agreement with previous study [11].

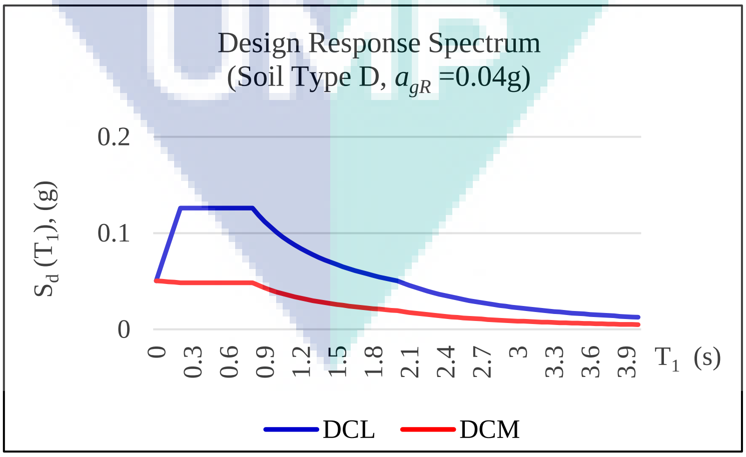

Figure 2.4 Design response spectrum for different class of ductility

2.3.2 *Effect of reference peak ground acceleration, α_{gR} on total weight of steel reinforcement*

Figure 2.5 presents the comparison of the total weight of steel reinforcement per $1m^3$ concrete influenced by the value of reference peak ground acceleration, α_{gR} for DCM. It is clear that the increasing of reference peak ground acceleration, α_{gR} tends to increase the total weight of steel reinforcement per $1m^3$ concrete.

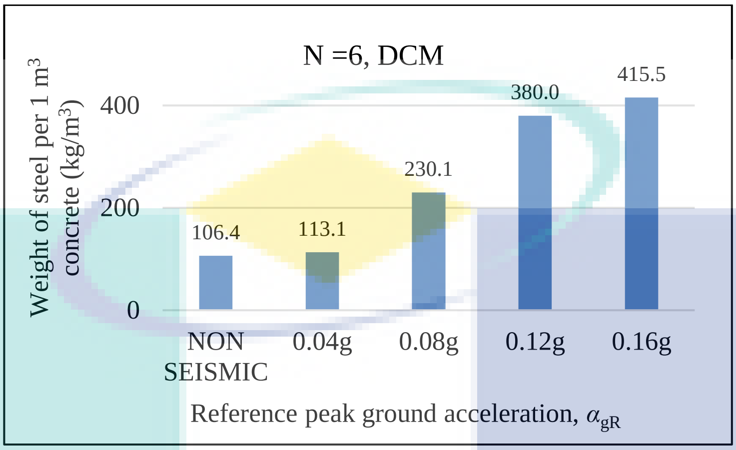

Figure 2.5 Total weight of steel reinforcement for $1m^3$ concrete for different value of reference peak ground acceleration, α_{gR}

Based on Figure 2.5, the total weight of steel reinforcement per $1m^3$ concrete are equal to 113.1kg, 230.1kg, 380.0kg, and 415.5kg when subjected to reference peak ground acceleration, α_{gR} equal to 0.04g, 0.08g, 0.12g, and 0.16g, respectively. This result is strongly associated with the magnitude of based shear force, F_b and internal reactions as discussed in previous subsection. Higher value of reference peak ground acceleration, α_{gR} will gives higher value of base shear force, F_b and internal reactions. As a result, higher amount of steel reinforcement has to be provided in the RC elements. This result is strongly in line with previous study by Ramli et al. [12]. Based on this study, the cost of steel reinforcement tends to increase around 6% to 290% compared to similar model without seismic design consideration, depend on the level of seismicity of the corresponding site. In order words, a similar building will have different cost of steel reinforcement due to different value of reference peak ground acceleration, α_{gR}.

2.3.3 *Effect of class of ductility on total weight of steel reinforcement*

The effect of class of ductility on the total weight of steel reinforcement is presented by Figure 2.6. It shows that the total weight of steel reinforcement per $1m^3$ concrete for models designed based on DCL and DCM are equal to 260.2kg and 113.1kg, respectively. For NS model which has been designed without any seismic consideration, total weight of steel reinforcement per $1m^3$ concrete is equal to 106.4kg. This means that the class of ductility is strongly influencing the total weight of steel reinforcement. In this study, the cost of steel reinforcement is increasing up to 145% when considering DCL in design. For DCM, the increasing is only about 6%. The magnitude of base shear force, F_b and internal reactions are strongly influencing this result as explained in previous subsection. By considering DCM for seismic design, the model is subjected to lower magnitude of base shear force, F_b resulting in lower internal reactions. As example, the beam design for DCM – 0.04 model has been conducted based on lower bending moment, m compared to the similar beam of DCL – 0.04 model resulting in lower amount of steel reinforcement. The details can be referred to Ahmad Jani [13] which is in good agreement with previous study [11].

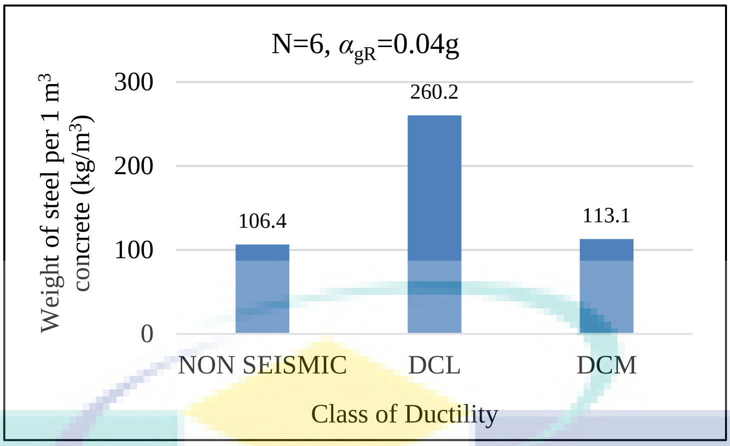

Figure 2.6 Total weight of steel reinforcement for 1m^3 concrete for different class of ductility

2.4 Conclusion

This study investigates the effect of value of reference peak ground acceleration, α_{gR} and class of ductility on the total weight of steel reinforcement. A typical six storey RC hospital building has been generated as model. A total of 6 models has been designed separately based on reference peak ground acceleration, α_{gR} equal to 0.04g, 0.08g, 0.12g, and 0.16g to represent seismicity in Malaysian region. DCL and DCM has been considered in design to investigate the effect of class of ductility. The following conclusions has been obtained from this study:

- The value of reference peak ground acceleration, α_{gR} is strongly influencing the total weight of steel reinforcement. The latter is increase as the former increase, vice versa. Based on this study, the cost of steel reinforcement for a six storey RC hospital building tends to increase around 6% to 290% compared to similar building without seismic design consideration.

- The class of ductility also influencing the total weight of steel reinforcement. Higher class of ductility tends to reduce the amount of steel reinforcement used in design. In this study, the cost of steel reinforcement tends to increase around 6% to 145% when considering DCM and DCL, respectively in seismic design. It can be concluded that DCM is preferable for more economical design. However, the seismic performance has to be evaluated to ensure it pass the desired performance level.

CHAPTER 3

INFLUENCE OF SOIL TYPE ON STEEL REINFORCEMENT OF FOUR STOREY REINFORCED CONCRETE BUILDING WITH SEISMIC DESIGN

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Abstract

For a few decades before December 2004, Malaysia is known as a country which free from earthquake hazard, unlike Japan and Indonesia. However, the fact has changed after the great Mw9.1 Aceh earthquake in December 2004. The tremor was felt in several places in Peninsular Malaysia. Since that moment, Malaysia was affected by ground tremors from Indonesia and Philippines earthquakes. The local earthquake with small magnitude occurred in Bukit Tinggi, Pahang in 2007 before M_w6.1 Ranau earthquake in June 2015. The latter had caused minor to severe damage on reinforced concrete building around Ranau town. Recently, the government has decided to implement seismic design on new buildings. Soil Type is one of parameters that influencing the seismic design and structural performance. This study presents the influence of different Soil Type on the total weight of steel reinforcement of four storey reinforced concrete building. The building has been simplified and modelled as building in important class IV. The reference peak ground acceleration, α_{gR} was assumed as equal to 0.07g. The building had been repeatedly designed on five different type of soil namely as Soil Type A, B, C, D, and E by referring to Eurocode 8. Based on result, the Soil Type is strongly influencing the total weight of steel reinforcement. The latter is higher for softer type of soil. In this study, the buildings with seismic design require around 1.16 to 2.11 times higher amount of steel reinforcement compared to the nonseismic building. Therefore, the Soil Type will influencing the cost of steel reinforcement.

Keywords: *Cost comparison; Seismic design; Soil type; Steel reinforcement; Reinforced concrete*

3.1 INTRODUCTION

Unlike Japan and Indonesia, Malaysia is geologically situated far away from active seismic fault zones. The nation is considered to be located in low seismicity region (MOSTI, 2009). Therefore, no seismic consideration has been taken into account in construction industry in Malaysia, except for a few special buildings. Existing reinforced concrete buildings in Malaysia had been designed by referring to BS8110 without any seismic provision (Tukiar et al., 2016). According to Majid (2009), less than one percent of buildings in Malaysia are seismic resistant. However, Malaysia still has a certain risk of earthquake hazard due to high seismicity region in neighbouring countries. West coast of Peninsular Malaysia is exposed to Sumatra Andaman and Java earthquakes from Indonesia while Sabah is exposed to Philippines earthquake. In fact, Sabah has its own local earthquakes. According to Harith et al., (2017) large increment of earthquake events has been recorded in Sabah for the last 140 years ago. This trend depicts that earthquake hazard cannot be ignored anymore.

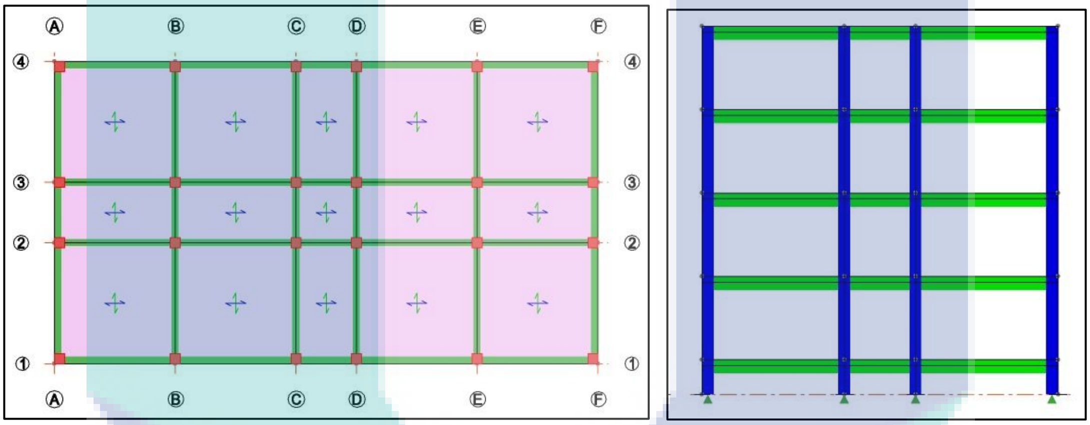
One of the memorable earthquake occurred in Sabah is the M_w6.1 Ranau earthquake which occurred on 5th June 2015. The epicentre was located around 16 km to the northwest of Ranau city. Based on preliminary in-situ observation by Majid et al., (2017) the earthquake had caused damages to reinforced concrete buildings especially on beam, column, and beam-column joint. The damages on column were severe than the beam due to Weak Column – Strong Beam design concept of nonseismic building. Besides, the damages also occurred on the non-structural elements such as ceiling and brickwall (Adiyanto et al., 2017). According to Hamid et al., (2018) seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage of buildings.

Seismic design on new buildings is one of the initiative taken by the government for the sake of public safety. According to MOSTI (2009) it is worth to consider seismic design for new buildings in medium to high risk earthquake zone in Malaysia. The implementation of seismic design also has pro and con. The consideration of earthquake load tends to change the detailing of structural element which will be differ compared to nonseismic design. From economical view, it is interesting to know the effect of seismic design on cost of material for construction. According to Ramli et al., (2017) seismic design tends to cause increment in total steel reinforcement which will directly increase the cost. However, the cost for repair and maintenance in the future will be reduced by implementation of seismic design. A few studies had been conducted to study the effect of reference peak ground acceleration, α_{gR} on seismic design. According to Adiyanto and Majid (2014) and Adiyanto et al., (2019) the increment of total steel used as reinforcement for reinforced concrete building is strongly influenced by the level of reference peak ground acceleration, α_{gR}. In both studies the authors only considered Soil Type D and hospital building in their study. For Malaysian regions, ductile detailing can be ignored for lower rise and shorter period buildings (Pappin et al., 2011). Based on previous study (Adiyanto and Majid, 2014) considering ductility class low will result in increment to total cost of material around 6% to 270% depend on level of seismicity.

Soil Type also influencing the seismic performance of buildings when subjected to earthquake load. Buildings built on soft soil tends to have greater damage compared to harder soil. Therefore, it is expected that different design and detailing are required for buildings to be built on different Soil Type. This paper presents the study on the influence of Soil Type on the design and detailing of four storey reinforced concrete building with earthquake load consideration. The comparison is presented is form of total weight of steel used as reinforcement for beams and columns.

3.2 MATERIAL AND METHODOLOGY

This study utilised a four storey reinforced concrete buildings as model. The building was regular in both plan and elevation as shown in Figure 3.1. The model had been simplified and assumed to be used as safety center building like fire station. Due to its importance during and after disaster, it was categorized as importance class IV (Fardis et al., 2015) and the value of importance factor, γ_I is equal to 1.4 as proposed by Eurocode 8 (2004). The floor to floor height was set to be equal to 3.6 m. The longer and shorter beam span are equal to 6.0 m and 3.0 m, respectively. All beams have similar size of section which is equal to 350 mm width and 600 mm depth regardless the position. The size of section for all columns is typical which is 500 mm width and 500 mm depth. The modelling process had been conducted by using Tekla Structural Designer computer software. The model had been assigned to appropriate dead load, G_k like floor finishing, brickwall, suspended ceiling, as well as mechanical and electrical equipment as proposed by Mc Kenzie (2004). The imposed load, Q_k was assigned on the model based on Category B as proposed by Eurocode 1 (2002).



(a) Plan (b) Elevation

Figure 3.1 Model of the four storey reinforced concrete building

Consideration of earthquake load had been conducted by assigning appropriate seismic design parameter such as reference peak ground acceleration, α_{gR} behaviour factor, q and Soil Type. Since this study focused on the influence of Soil Type on seismic design, a total of five Soil Type namely as Soil Type A, Soil Type B, Soil Type C, Soil Type D, and Soil Type E had been taken into account. The value of reference peak ground acceleration, α_{gR} was fixed as equal to 0.07g. In Malaysia, the latter represents the seismicity of some area in Kuala Lumpur, Beluran, and Sandakan (National Annex, 2017). Since the building has more than one storey and multiple bay, the value of behaviour factor, q was fixed as 3.9 for ductility class medium as proposed in Eurocode 8 (2004).

The fundamental period if vibration of the building, T_1 was estimated to be around 0.6 sec. The typical model had been analysed and designed repeatedly for every Soil Type. One model had been designed without any seismic consideration for control and comparison purpose. Concrete grade C30 was considered for all models as summarized in Table 3.1. The analysis and designed had been conducted based on lateral force method as proposed by Eurocode 8 (2004) and also implemented in previous study by Adiyanto et al., (2019).

Table 3.1 Design consideration

Model Number	Design Consideration	Reference Code	Soil Type
1	Gravity load only	Eurocode 2	Non applicable
2	Gravity + Seismic load	Eurocode 8	A
3	Gravity + Seismic load	Eurocode 8	B
4	Gravity + Seismic load	Eurocode 8	C
5	Gravity + Seismic load	Eurocode 8	D
6	Gravity + Seismic load	Eurocode 8	E

3.3 RESULT AND DISCUSSION

Design response spectrum and base shear force

Based on lateral force method, the magnitude of horizontal seismic force acting on every story, F_i are directly proportional to the magnitude of its base shear force, F_b. According to Eurodoce 8 (2004), the magnitude of base shear force, F_b is strongly influenced by the total mass of the building, m and the spectral acceleration at the fundamental period of vibration, $S_d(T_1)$. In this study, the latter was determined based on the design response spectrum developed for reference peak ground acceleration, $\alpha_{gR} = 0.07g$ and importance factor, $\gamma_I = 1.4$ as shown in Figure 3.2.

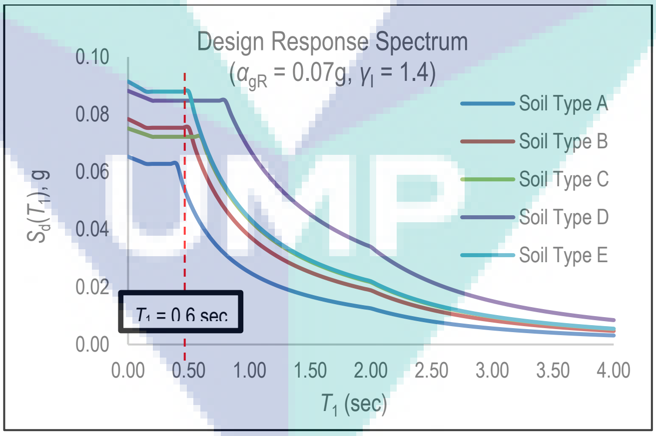


Figure 3.2 Design response spectrum for different Soil Type

As mentioned in previous section, the fundamental period of vibration of the building, T_1 was estimated to be around 0.6 sec. Therefore, based on design response spectrum shown in Figure 3.2, the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ for Soil Type A is equal to 0.042g which is the lowest compared to other Soil Type. Table 3.2 presents the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ and the base shear force, F_b of all models.

Table 3.2 Seismic load acting on every model

Model Number	Soil Type	Spectral acceleration at the fundamental period of vibration, Sd(T1), g	Base shear force, F_b (kN)
1	Non applicable	Non applicable	Non applicable
2	A	0.042	1050
3	B	0.063	1696
4	C	0.072	1869
5	D	0.085	2279
6	E	0.073	1979

In Table 3.2, it is clear that the magnitude of base shear force, F_b increases as the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ increases. The latter is strongly influenced by the value of soil factor, S. In this study, Model 5 which considering Soil Type D has the highest magnitude of base shear force, F_b which is equal to 2279 kN. This means Model 5 is exposed to the highest horizontal seismic force, F_i on every storey compared to other model. Due to different magnitude of seismic force, the design and detailing shall be differ for every models.

Comparison on total weight of steel reinforcement

According to Booth and Key (2006) it is hard to determine the cost increment due to seismic design. This is because every project has its own uniqueness such as function, layout, and requirement. However, it is worth to study the effect of seismic design on costing to give clear picture to every stakeholders in construction industry for better planning and management. Figure 3.3 presents the influence of Soil Type on the total weight of steel reinforcement for all beams. The total weight of steel reinforcement for models with seismic design are normalised to the total weight of steel reinforcement of beam for model 1 which is not considering seismic design.

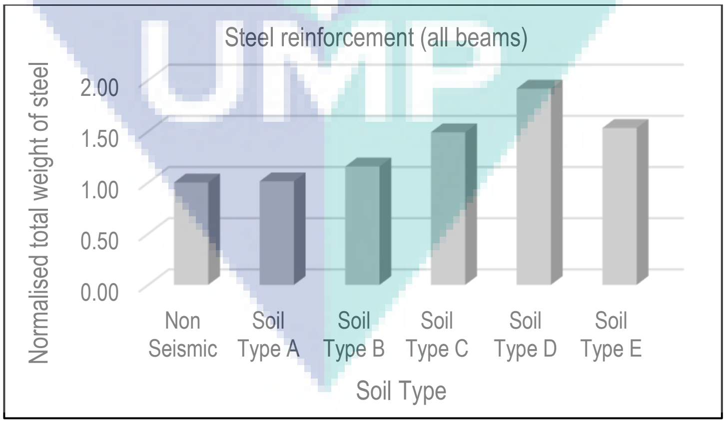


Figure 3.3 Normalised total weight of steel reinforcement for beam

From Figure 3.3, the total weight of steel used as reinforcement for beam varies for every model. It is clear that models with seismic design require higher amount of steel reinforcement. Beams with seismic design require around 1% to 92% higher amount of steel reinforcement compared to the beams without seismic design. The model considering Soil Type D has the highest amount of steel reinforcement for beams followed by models with Soil Type E, Soil Type C, Soil Type B, and Soil Type A. This result is strongly associated with the magnitude of base shear force, F_b acting on every models. As discussed in previous subsection, model 5 with Soil Type D has the highest magnitude of base shear force, F_b compared to other models. Therefore, based on structural analysis, Model 5 has the highest magnitude of bending moment, M as well as shear force, V which result in highest amount of steel to be provided as reinforcement. This result is in good agreement with previous finding by Ramli et al., (2017).

The influence of Soil Type on the total amount of steel used as reinforcement for column is presented by Figure 3.4. The result show similar pattern to the beam where columns with seismic design require higher amount of steel as reinforcement compared to the nonseismic column design. Model 2 which considering Soil Type A has similar amount of steel reinforcement for column with Model 1 which designed without any seismic consideration. This means the increasing of steel reinforcement due to seismic design is not significant for Soil Type A. However, the column for models on Soil Type B, Soil Type C, Soil Type D, and Soil Type E require around 1.29, 1.58, 2.11, and 1.72 times higher amount of steel reinforcement, respectively compared to the nonseismic column design. The pattern is similar to result for beam. This is because in seismic provision, the column design has to be stronger than its beam in order to achieve the Strong Column – Weak Beam design philosophy (Eurocode 8, 2004; Elghazouli, 2009; Elnashai and Sarno, 2008). Therefore, the design moment for column, M_c is directly derived from the moment resistance capacity of it beam, M_{RB}. In this study, the beams for Model 5 has the highest amount of steel reinforcement which result in the highest moment resistance capacity of beam, M_{RB}. Therefore, all columns for Model 5 were designed stronger which result in higher amount of steel as reinforcement.

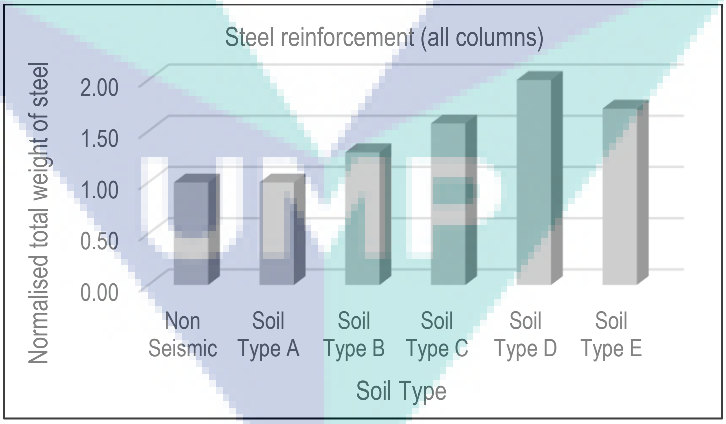


Figure 3.4 Normalised total weight of steel reinforcement for column

3.4 CONCLUSION

This paper presents the influence of Soil Type on the total amount of steel used as reinforcement by considering seismic design. A four storey reinforced concrete building in importance class IV has been utilised as typical model. The latter had been designed separately by considering five different Soil Type namely as Soil Type A, Soil Type B, Soil Type C, Soil Type D, and Soil Type E as defined by Eurocode 8 (2004). The reference peak ground acceleration, α_{gR} was fixed as equal to 0.07g while the behaviour factor, q was fixed as equal to 3.9 for ductility class medium. Based on the result, it can be concluded that the site condition, represented by Soil Type strongly influencing the design and detailing of beams and columns. Except for Soil Type A, models considering seismic design with Soil Type B to Soil Type E generally require higher amount of steel reinforcement compared to the nonseismic model. The increment of steel reinforcement is in range of 1.16 to 2.11 times higher compared to the nonseismic design. Therefore, the Soil Type will result in different cost of steel reinforcement even for similar building layout and configuration.

CHAPTER 4

INCREMENT OF STEEL TONNAGE FOR REINFORCED CONCRETE SCHOOL BUILDING CONSIDERING SEISMIC DESIGN

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Abstract. Within fifteen years after the 2004 Acheh Earthquake with $M_w9.3$, the number of tremors on Malaysian ground keep rising. This is due to either from Indonesian earthquakes, or local earthquakes in Bukit Tinggi and Sabah state. A series of Indonesian earthquakes, especially from Sumatra caused vibration on buildings in Peninsular Malaysia like Kuala Lumpur and Penang Island. In East Malaysia, Sabah state has been classified as a region with active local seismic fault. A moderate earthquake with $M_w6.1$ was occurred in Ranau on 5th June 2015 and caused a lot of damages on both structural and non-structural elements of buildings. Hence, the implementation of seismic design on new buildings is important to ensure public safety. However, such action has its own pro and contra especially when dealing with cost. Therefore, this paper presents the effect of seismic design consideration to the increment cost of steel reinforcement. For that purpose, a typical four storey reinforced concrete school building has been generated as basic model for analysis, design, and taking off. Based on result, the total steel tonnage for models considering seismic design is increase around 3% to 131% higher compared to model without seismic design.

4.1 Introduction

Geographically, Malaysia is formed by two main land namely as Peninsular Malaysia and East Malaysia. The Peninsular Malaysia is located at the south part of Asia continent. The East Malaysia is located in an island named Borneo. The East Malaysia consist of two states namely as Sabah and Sarawak. Both West and East Malaysia is relatively far away from Pacific-Ring of Fire regions. However, Malaysia is considered to have low seismicity profile [1]. Peninsular Malaysia is exposed to the Sumatra Andaman earthquakes. Due to the $M_w9.1$ Acheh earthquake in December 2004, Malaysia is undergoing long-term inter-seismic deformation toward south-east direction [2]. Local earthquakes also reported in Peninsular Malaysia especially Janda Baik and Bukit Tinggi which are located around 50km from Kuala Lumpur. The Bukit Tinggi fault line which triggered earthquakes in 2007-2009 is believed as a result from Paleo fault line reactivation [3]. In East Malaysia, a large number of increment of earthquake events has been detected based on updated records from 1884 to 2016 [4].

A moderate earthquake with M_w6.1 was occurred in Ranau on 5th June 2015. The event caused a lot of damages on both structural and non-structural elements of buildings [5-7]. Based on detail investigation, the highest damage recorded on brickwall with X-mark crack due to shear failure [8]. Hence, the implementation of seismic design on new buildings is important to ensure public safety. Seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage to buildings [9]. The 2015 Ranau earthquake can be seen as a motivating factor to implement seismic design in construction of structures in Malaysia [6]. However, such action has its own pro and contra especially when dealing with cost. The consideration of earthquake load in design will directly influencing the cost of material which should be adopted by construction industry [10]. Seismic design tends to cause increment in total steel reinforcement which will directly increase the cost. However, the cost for repair and maintenance in the future will be reduced by implementation of seismic design [11]. This paper presents the effect of seismic design consideration on the cost increment of steel reinforcement. For that purpose, a typical four storey reinforced concrete (RC) school building has been generated as basic model for analysis, design, and taking off. Different level of seismicity and soil type had been considered as variable in this study. The result is presented in term of normalised total steel tonnage used as reinforcement.

4.2 Model and Methodology

In this study, a total of three stages had been conducted namely as generate basic model, followed by structural analysis & seismic design, and then the taking off. Basic model generation took place in stage 1. As mentioned in previous section, a typical four storey RC school building has been generated as basic model as presented by Figure 4.1. The basic model has total height, H up to 15.5 m where the fundamental period of vibration, T_1 is estimated to be equal to 0.6 sec. A total three sizes of beam has been considered which is equal to 300 mm x 600 mm, 200 mm x 450 mm, and 200 mm x 225 mm depend on the position and span. The columns has been modelled based on two sizes which is equal to 350 mm x 350 mm and 450 mm x 450 mm.

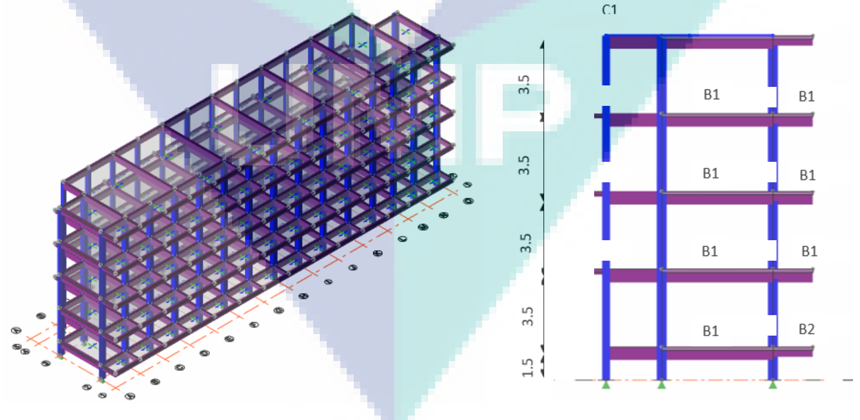

Figure 4.1 Four storey RC school building

Stage 2 involving the structural analysis following by seismic design on the basic models. As recommended by Eurocode 8 [12], the basic models was classified in importance class III. Hence, 1.2 has been assigned as value for importance factor, γ_I. Due to its importance after disaster, the recommended value of importance factor, $\gamma_I = 1.2$ is to offer better protection of life for such buildings [13]. This is because the RC school buildings always been converted to become a shelter for community after any disaster in Malaysia. Therefore, the RC school building must be stronger than any other ordinary buildings. The imposed load, Q_k was assigned on the basic model based on Category C1 as proposed by Eurocode 1 [14].

In this study, the level of seismicity and soil type has been considered as variable. The level of seismicity is represented by the value of reference peak ground acceleration, α_{gR} indicates the intensity of earthquake in a specific region. Three level of seismicity has been considered where the value of reference peak ground acceleration, α_{gR} = 0.04g, 0.07g, and 0.10g to represent the seismicity in Ipoh, Lumut, and Semporna, respectively as proposed by National Annex [15]. In addition, a total of three soil type has been considered namely as A, C, and E as proposed in Eurocode 8 [12]. In this study, ten models has been analysed and designed as shown in Table 4.1. One model without seismic consideration has been taken into account for control and result normalisation purpose. All models has been designed based on concrete grade C30/37 and yield strength of steel, f_y = 500 N/mm^2. Ductility class medium has been considered for models with seismic design. The structural analysis on models with seismic design has been conducted based on lateral force method by referring to Eurocode 8 [12].

Table 4.1 RC school models and design parameters

No	Model Code	Reference peak ground acceleration, α_{gR} (g)	Soil Type
1	NS	-	-
2	A – 0.04	0.04	A
3	A – 0.07	0.07	A
4	A – 0.10	0.10	A
5	C – 0.04	0.04	C
6	C – 0.07	0.07	C
7	C – 0.10	0.10	C
8	E – 0.04	0.04	E
9	E – 0.07	0.07	E
10	E – 0.10	0.10	E

The final stage is the process for taking off. During this process, the total concrete volume and steel tonnage for all models were measured for comparison. The total steel tonnage was normalised to total concrete volume in order to obtain the value of steel tonnage for every 1m^3 of concrete.

4.3 Result and Discussion

4.3.1 Earthquake Load on models

In this study, earthquake load, E acting on all models with seismic design was determined based on lateral force method. This method derives the total earthquake load, E which imposed laterally as the base shear force, F_b. The latter is then being distributed on every storey as explained by Elghazouli [16]. The magnitude of dead load, G_k and imposed load, Q_k were similar to all models. By referring to Eurocode 8 [12], the magnitude of base shear force, F_b is directly proportional to the value of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, effective mass of the building, m and correction factor, λ. In this study, the value of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ for all models were obtained from on the design response spectrum for every level of seismicity and soil type. The effective mass of the building, m and correction factor, λ are similar and fix for all models.

The magnitude of base shear force, F_b is presented in Table 4.2 which shows that the magnitude of base shear force, F_b are differ for every models. The results show that the magnitude of base shear force, F_b increases as the level of seismicity increases. It indicates that for similar soil type, a similar building tend to be imposed by different magnitude of lateral load depend on the level of seismicity of a region. Results in Table 4.2 also show that once the level of seismicity is similar, the magnitude of base shear force, F_b will be differ for different soil type. As an example, for seismicity with reference peak ground acceleration, α_{gR} = 0.10g the magnitude of base shear force, F_b are equal to 1074.6 kN, 1810.1 kN, and 1880.6 kN for models considering soil type A, soil type C, and soil type E, respectively. This result is contributed to different soil factor, S for every soil type as proposed by Eurocode 8 [12]. The seismicity on softer soil type tends to be amplified by higher factor which lead to severe damage compared to harder soil type. In Table 4.2, the highest magnitude of base shear force, F_b is model E-0.10 which considering reference peak ground acceleration, α_{gR} = 0.10g and soil type E. This means the model had been imposed to the highest magnitude of lateral force on every storey.

Table 4.2 Earthquake load, *E* acting on all models

No	Model Code	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ (m/s^2)	Base shear force, F_b (kN)
1	NS	Non applicable	Non applicable
2	A – 0.04	0.206	429.8
3	A – 0.07	0.361	752.2
4	A – 0.10	0.515	1074.6
5	C – 0.04	0.347	724.0
6	C – 0.07	0.607	1267.1
7	C – 0.10	0.868	1810.1
8	E – 0.04	0.361	752.2
9	E – 0.07	0.631	1316.4
10	E – 0.10	0.901	1880.6

4.3.2 *Total volume of concrete*

In this study, the size of beams and columns are similar for all models regardless the design consideration. Therefore, the volume of concrete for beams and columns is similar for all models which is equal to 245 m^3. Therefore, the cost for concrete is estimated to be similar for all models.

4.3.3 *Total steel tonnage*

The steel tonnage representing the total amount of steel bar as flexural and shear reinforcement. The number and size of steel reinforcement strongly influenced by the magnitude of bending moment, *M* shear force, *V* and axial load, *P* [17]. The steel tonnage in 1m^3 concrete of beams for all models is shown in Figure 4.2. The steel tonnage is normalised to the nonseismic model as a comparison to the current practice which not considering seismic design.

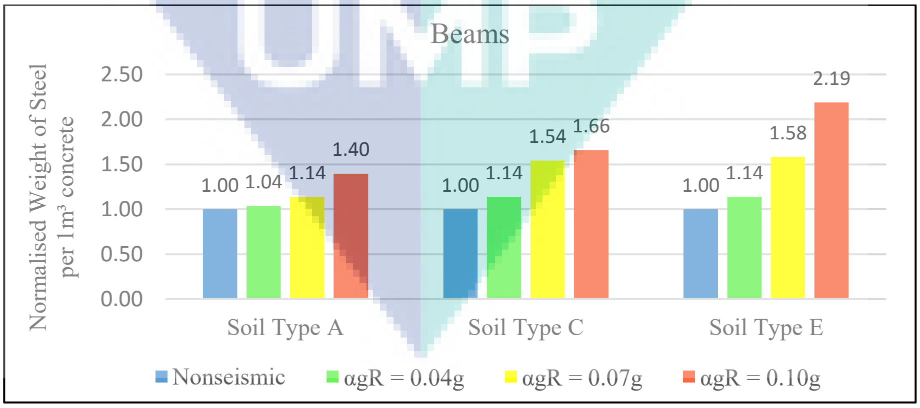

Figure 4.2 Total steel tonnage for all beams

In Figure 4.2, the steel tonnage used as reinforcement in beam increases when the seismic design has been taken into account. Regardless the soil type, the steel tonnage increased around 4% to 119%. The increment is higher for models considering higher value of peak ground acceleration, α_{gR}. This result mean regions with higher level of seismicity tend to require higher cost of steel reinforcement for beam. Previous study by Ramli et al., [11] also presented similar pattern. The soil type also influencing the increment of steel tonnage. For a similar level of seismicity, models considering soil type E have the highest steel tonnage. As discussed in previous subsection, model E-0.10g has the highest magnitude of base shear force, F_b result in highest lateral load acting on every storey. Based on structural analysis, the highest lateral force contributed to the highest magnitude of bending moment, M as well as shear force, V which result in highest amount of steel to be provided as reinforcement.

Column plays important role for stability of structural system. During earthquake events, the columns will vibrate back and forth. The torsional effect tends to caused heavier damage on columns [18]. Therefore, special attention has to be given for column design in order to resist the earthquake load. By referring to Eurocode 8 [12] the seismic design approach must include the Strong Column – Weak Beam concept which means that the column shall be stronger than the beam. Figure 4.3 shows the steel tonnage in $1m^3$ concrete of columns for all models. The result shows similar pattern to the increment of steel tonnage in beams. The steel tonnage in columns for models with seismic design consideration increases around 2% to 155% higher compared to the control model without seismic design. This result is strongly relates to the requirement of Strong Column – Weak Beam concept as mentioned before. Through this approach, the strength of column shall be at least 1.3 times the strength of its beam. Hence, the result directly follow the pattern for beam where the steel tonnage increases as the level of seismicity increases.

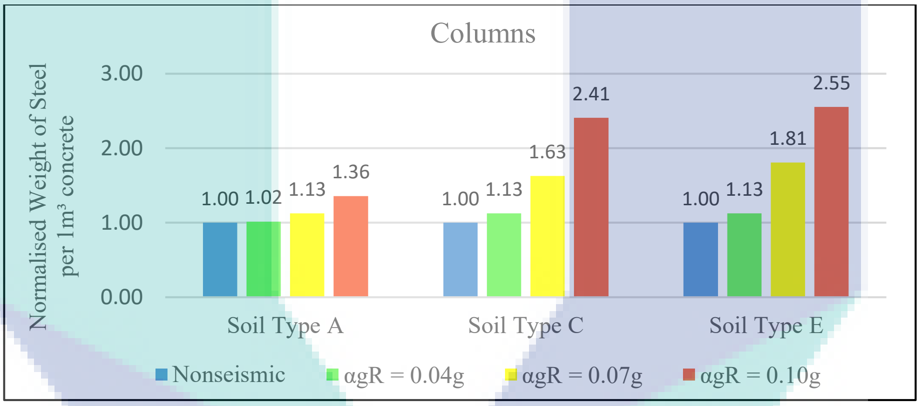

Figure 4.3 Total steel tonnage for all columns

4.3.4 Cost estimation for steel reinforcement

The normalised total cost of steel reinforcement for beams and columns of all models is shown in Figure 4.4. As referring to the results obtained for beams and columns, the cost of steel reinforcement increased when seismic consideration is taken into account in design. For models on soil type A, the cost of steel reinforcement increase up to 38%. The cost increment lies in range of 13% to 92% and 13% to 131% for models on soil type C and soil type E, respectively. This result indicates that the level of seismicity and soil type strongly influencing the cost of steel reinforcement. Proper selection of site for development also important in order to reduce the cost of steel reinforcement.

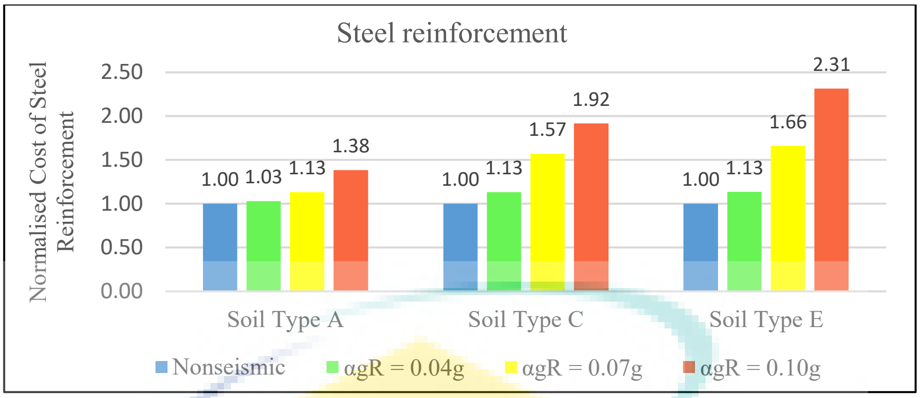

Figure 4.4 Normalised cost of steel reinforcement

4.4 Conclusion

The increment of steel tonnage due to seismic design consideration has been investigated in this study. For that purpose, a typical four storey RC school building has been generated as basic model. Two variables namely as level of seismicity and soil type has been considered for seismic design with ductility class medium. The level of seismicity was differentiated by the value of reference peak ground acceleration, α_{gR} which lies in range of 0.04g to 0.10g. Three types of soil namely as soil type A, soil type C, and soil type E has been taken into account to represent variability of site condition in Malaysia. A few conclusions are drawn as follow:

- The steel tonnage increases as the level of seismicity increases regardless the soil type. For beams, the increment is in range from 4% to 119% higher compared to nonseismic design. For columns, the increment is in range from 2% to 155%.

- The site condition which is represented by soil type also influencing the increment of steel tonnage. Models considering softer soil profile require higher increment of steel tonnage compared to models which considering harder soil profile.

- By considering seismic design, total cost of steel reinforcement for beams and columns tend to increase around 3% to 131% depend on level of seismicity and soil type.

At the moment this paper is written, a more comprehensive study is still ongoing considering various number of storey, function of buildings, soil type, level of seismicity, and concrete grade.

CHAPTER 5

COMPARISON STUDY ON COST OF CONCRETE AND STEEL REINFORCEMENT FOR MULTIPURPOSE HALL BUILDING WITH SEISMIC DESIGN

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Abstract. Multipurpose hall is a public building of people assembly for various function and activities. It can be converted to be a temporary shelter during disaster like flood and earthquake. After experiencing tremors from both local and distant earthquakes, the time has come to implement the seismic design to new buildings in Malaysia to ensure public safety. The implementation of seismic design also affecting the cost of construction, especially materials. Therefore, this paper presents the taking off results for reinforced concrete multipurpose hall building with seismic design. In this study two parameters namely as soil type and concrete grade had been considered as design variable. Result from design and taking off demonstrated that the amount of steel reinforcement is strongly influenced by both parameters. The usage of steel for reinforced concrete buildings with seismic design is estimated to increase around 3% to 59% depend on soil type and concrete grade. Results also demonstrated that higher concrete grade require lower amount of steel as reinforcement.

5.1 Introduction

Two main land has form a country named Malaysia. The one is located at the south part of Asia continent namely as Peninsular Malaysia. Another part known as East Malaysia is located in as island namely as Borneo. The East Malaysia is formed by two state namely as Sabah and Sarawak. Both Peninsular and East Malaysia is relatively far away from Pacific-Ring of Fire regions. The latter is a high seismicity regions affecting Indonesia and Philippines. However, according to Marto et al., [1] Malaysia is considered to have low seismicity profile. The M_w9.1 Acheh earthquake on December 2004 caused vibration to buildings in Peninsular Malaysia. In Peninsular Malaysia, local earthquakes were recorded in Manjung, Jerantut, Bukit Tinggi, and Janda Baik. The Paleo fault line reactivation is believed to be the main cause of Bukit Tinggi earthquakes from 2007 to 2009 [2]. In East Malaysia, around 70 local earthquake events with magnitude $M_w5.0$ and above were recorded since 1900 to 2014 [3].

An earthquake with $M_w6.1$ had struck Ranau, one of the districts in Sabah on early morning 5th June 2015. The moderate earthquake was the strongest recorded since the $M_w5.8$ earthquake which occurred in Lahad Datu in 1976. Minor to severe damages on buildings had been detected after the 2015 Ranau earthquake event. For reinforced concrete (RC) buildings, the earthquake action caused damages especially on beam, column, and beam-column joint [4]. The nonstructural elements such as brickwall and ceiling also affected and experience damage due to the event [5]. Based on detail survey, Khoiry et al., [6] reported that the 2015 Ranau earthquake had caused damages on wall, floor, column, and roof. In their report, the highest damage recorded on brickwall with X-mark crack due to shear failure. After experiencing the tremors from both local and regional earthquakes, Malaysian now aware on the importance of seismic design on buildings and structures. The 2015 Ranau earthquake can be seen as a motivating factor to implement seismic design in construction of structures in Malaysia [7]. Hence, seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage to buildings [8]. However, usage of construction materials due to seismic design consideration need to be investigated beforehand. Seismic design tends to cause increment in total steel reinforcement which will directly increase the cost. However, the cost for repair and maintenance in the future will be reduced by implementation of seismic design [9]. The increment of total steel used as reinforcement for RC building is strongly influenced by the level of reference peak ground acceleration, α_{gR} [10,11]. This paper presents the study on the influence of soil type and concrete grade on the design and detailing of RC multipurpose hall with earthquake load consideration. The comparison is presented is form of total weight of steel reinforcement used for beams and columns.

5.2 Model and Methodology

In order to achieve the objective, a total of three stages had been conducted in this study. In stage one, a RC building to function as multipurpose hall as shown in Figure 5.1 was created and modelled by using computer software. The total height, H of the RC multipurpose hall is around 17.7m. The fundamental period of vibration, T_1 was estimated to be equal to 0.6 sec. The size of beams at roof level is equal to 300 x 500 mm while the size of beams at other floor level is equal to 300 x 600 mm. The size for all columns is equal to 500 mm square.

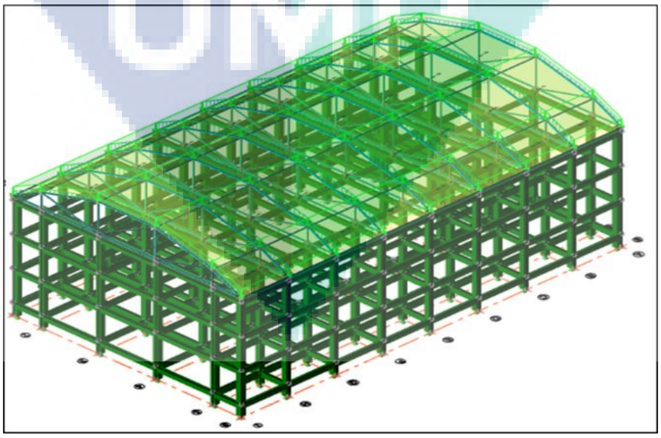


Figure 5.1 Four storey RC school building

In stage two, the structural analysis and seismic design had been conducted on all models. The RC multipurpose hall building was classified as importance class III due to its importance to public after disaster [12]. Hence, to give better protection for such building, the importance factor, γI for the building was assigned to be equal to 1.2 as proposed by Eurocode 8 [13]. The typical model was analysed and designed repeatedly based on different soil type and concrete grade. A total five soil type namely as soil type A, B, C, D, and E as proposed by Eurocode 8 [13] had been taken into account to represent variable site condition. Two concrete grade which is C25/30 and C35/45 had been considered for every soil type. The characteristic compressive cylinder strength of concrete at 28 days, f_{ck} shall be equal to $25N/mm^2$ and $35N/mm^2$ for concrete grade C25/30 and C35/45, respectively [14]. The reference peak ground acceleration, α_{gR} was fixed as equal to 0.12g by referring to latest seismic hazard map for Malaysia [15].

A total of 12 models had been designed separately as shown in Table 5.1. Two models with code as G25 – GL and G35 – GL had been designed without seismic consideration as control model, one for every concrete grade. Lateral Force Method by referring to Eurocode 8 [13] had been adopted to determine the action of earthquake load in form of base shear force, F_b. By referring to this method, the base shear force, F_b has to be distributed proportionally as lateral loads acting on every story. The magnitude of base shear force, F_b was calculated as a combination of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, effective mass of the building, m and correction factor, λ. Previous work [11] also adopted this method. All models had been designed for ductility class medium.

The taking off process took part in final stage. In this stage, the total volume of concrete and total steel reinforcement in weight were measured for all beams and columns. The comparison had been made based on weight of steel reinforcement per $1m^3$ of concrete.

Table 5.1 Design parameter for RC multipurpose hall models

No	Code	Soil Type	Concrete Grade
1	G25 – GL	Non-applicable	C25/30
2	G25 – A	A	
3	G25 – B	B	
4	G25 – C	C	
5	G25 – D	D	
6	G25 – E	E	
7	G35 – GL	Non-applicable	C35/45
8	G35 – A	A	
9	G35 – B	B	
10	G35 – C	C	
11	G35 – D	D	
12	G35 – E	E	

5.3 Result and Discussion

5.3.1 Earthquake Load on models

In this study, the earthquake load had been imposed on models as lateral load. The latter had been represented by base shear force, F_b which directly derived based on the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, effective mass of the building, m and correction factor, λ. The value of correction factor, λ shall be 0.85 for buildings with more than two story and $T_1 < 2T_c$ [13]. Based on structural analysis and member design, the size of beams and columns were similar to all models results in similar magnitude of effective mass, m. Hence, the magnitude of base shear force, F_b was determined by the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$. The latter was obtained from a series of design response spectrums which had been generated for every soil type and reference peak ground acceleration, α_{gR} equal to 0.12g.

Table 5.2 presents the magnitude of base shear force, F_b imposed as lateral loads on every models with seismic design. The magnitude of base shear force, F_b increases as the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, increases. The latter is varies to different soil type. Soil with softer profile tend to have higher magnitude of base shear force, F_b. This result is caused by different Soil Factor, S for every soil type as proposed by Eurocode 8 [13]. In Table 5.2, models G25 – D and G35 – D which considering soil type D have highest magnitude of base shear force, F_b which is equal to 4033.8 kN. This result indicates that both models had been subjected to the highest magnitude of lateral load result in highest magnitude of bending moment, M. Models with similar concrete grade have similar magnitude of base shear force, F_b regardless the soil type. This means models with similar concrete grade had been imposed to similar magnitude of lateral load result in similar bending moment, M.

Table 5.2 Base shear force, F_b acting on all models

No	Model Code	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ (g)	Base shear force, F_b (kN)
1	G25 – GL & G35 – GL	Non applicable	Non applicable
2	G25 – A & G35 – A	0.0615	1865.8
3	G25 – B & G35 – B	0.0923	2798.6
4	G25 – C & G35 – C	0.1062	3175.6
5	G25 – D & G35 – D	0.1246	4033.8
6	G25 – E & G35 – E	0.1077	3221.7

5.3.2 *Total volume of concrete*

The size of RC beams and columns are similar for all models regardless the design consideration. Therefore, the volume of concrete for beams and columns is similar for all models which is equal to 470 m^3. However, the cost for concrete is not similar for all models. This is due to different price of concrete for different grade. The price for concrete grade C35/45 is estimated around 21% higher than the price for concrete grade C25/30 [16]. In this study, the total cost of concrete was estimated to be equal to RM152,825.94 and RM185,430.06 for models with concrete grade C25/30 and C35/45, respectively.

5.3.3 *Total steel reinforcement*

Total weight of steel reinforcement is the summation of steel used as flexural and shear reinforcement in all RC beams and columns. Total weight of steel reinforcement for every models with seismic design is normalized by the total weight of steel reinforcement of its corresponding nonseismic model. This is to compare the increment of steel reinforcement due to seismic design consideration to current practice which neglecting seismic design. Figure 5.2 depicts the normalized total weight of steel reinforcement for models with concrete grade C25/30. Result demonstrates that total weight of steel reinforcement are differ for every models. The increment of steel reinforcement is around 6% to 59% higher compared to the nonseismic model. The increment of steel reinforcement occurred on both beams and columns as discussed by previous studies [9-11]. In Figure 5.2, the highest total weight of steel reinforcement correspond to model G25 – D. The result is as expected because the model has the highest magnitude of base shear force, F_b. The latter result in highest magnitude of bending moment, M. Based on design calculation for RC beam and column [17], the increasing of bending moment, M lead to increasing of total area of steel required, As_{req} as well as the total area of steel provided, As_{prov}. The latter leads to increase the total weight of steel reinforcement.

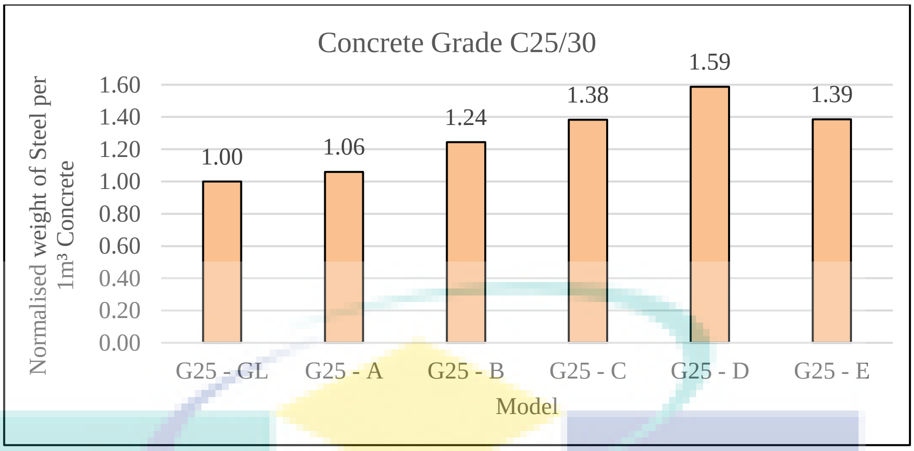


Figure 5.2 Normalised weight of steel reinforcement for model with concrete grade C25/30

The normalized total weight of steel reinforcement for models with concrete grade C35/45 is depicted by Figure 5.3. Result for this group also demonstrates that total weight of steel used as reinforcement are differ for every models. The total weight of steel reinforcement in beam increased around 3% to 47% higher compared to its nonseismic model. For this group, model on soil type D also has the highest total weight of steel reinforcement. This result is due to highest magnitude of base shear force, F_b. The pattern of increment is similar to models with concrete grade C25/30 but with lower percentage. As example, total weight of steel reinforcement for model G35 – D is 20% lower compared to model G25 – D even being imposed to similar magnitude of lateral load. This means that models with concrete grade C35/45 require lower amount of steel as reinforcement. This result is strongly related to the calculation of RC design. Higher concrete grade will increase the value of lever arm, z which result in lower area of steel required, As_{req} [17]. Hence, the area of steel provided, As_{prov} also lower.

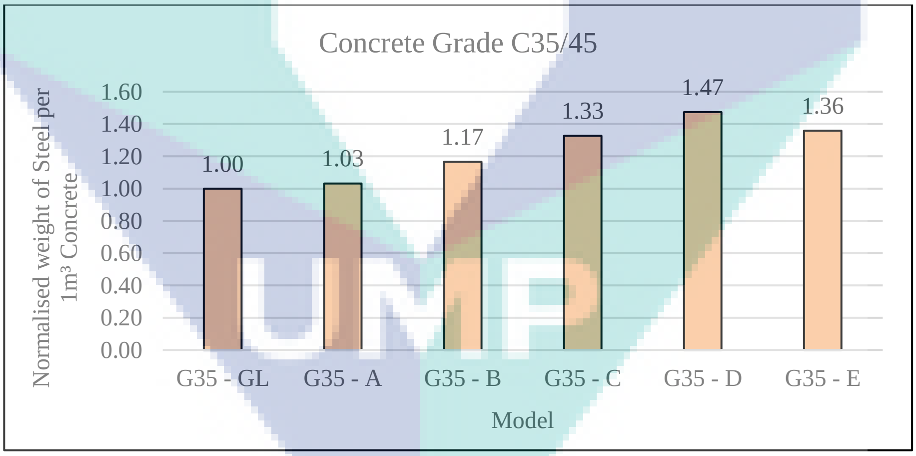
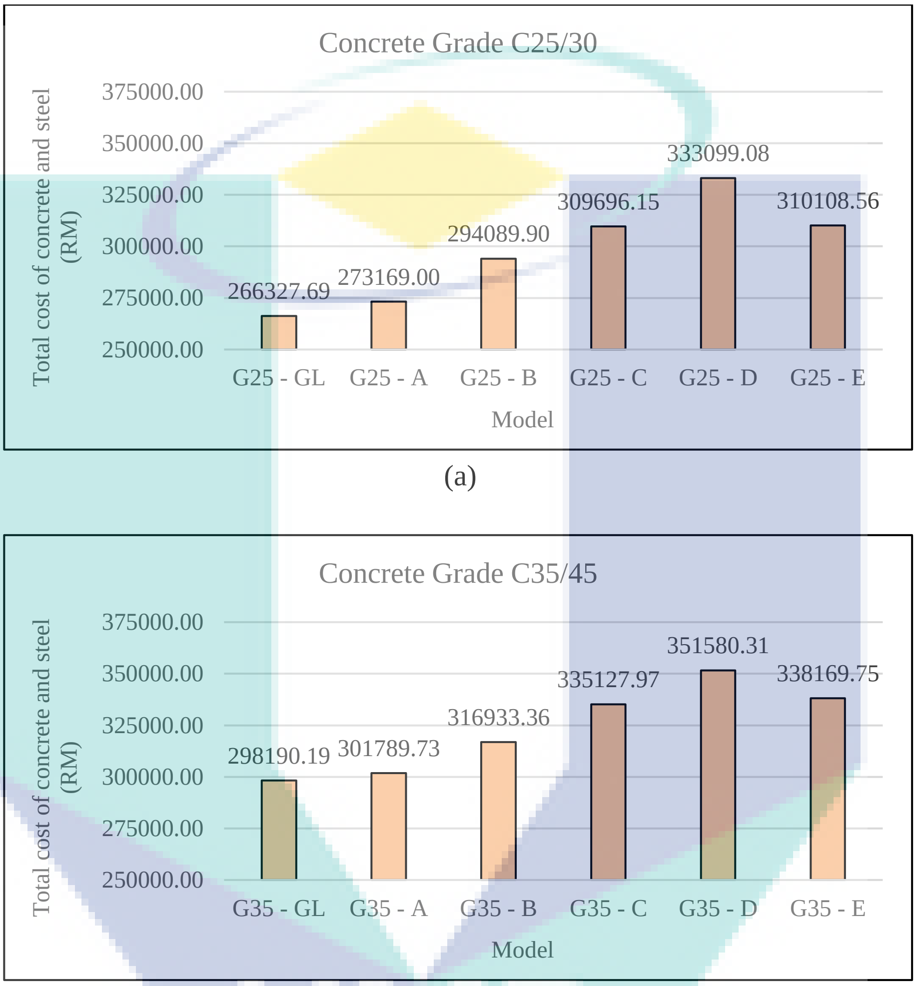


Figure 5.3 Normalised weight of steel reinforcement for model with concrete grade C35/45

5.3.4 Cost estimation for steel reinforcement

For better understanding, the comparison had been made in form of total cost or price of materials, which is concrete and steel reinforcement. In this study, the price of steel was estimated around RM3500.00 per tonne [16]. The price of concrete for grade C25/30 and C35/45 were estimated around RM325.30 and RM394.70, respectively for every 1m^3. Figure 5.4a and Figure 5.4b depicts the comparison of total cost of concrete and steel reinforcement for models with concrete grade C25/30 and C35/45, respectively. For models with concrete grade C25/30, seismic design caused increment around 3% to 25% to total cost of concrete and steel reinforcement. By considering concrete grade C35/45, the total cost of concrete and steel reinforcement increased around 1% to 18% compared to its nonseismic model. Regardless the soil type, models with concrete grade

C35/45 required higher cost of concrete and steel reinforcement compared to its companion models with concrete grade C25/30. Despite require lesser amount of steel reinforcement, the models with concrete grade C35/45 have around 6% to 12% higher total cost of concrete and steel reinforcement compared to models with concrete grade C25/30. This is due to higher price of concrete for grade C35/45. Therefore, the selection of concrete grade also important to control the cost.



(a)

(b)

Figure 5.4 Total cost of steel and concrete (a) concrete grade C25/30 (b) concrete grade C35/45

5.4 Conclusion

The study on the influence of soil type and concrete grade on the design and detailing of RC multipurpose hall with earthquake load consideration is discussed in this paper. A total of five soil conditions namely as soil type A, B, C, D, and E had been considered alongside two concrete grade namely as C25/30 and C35/45. The reference peak ground acceleration, α_{gR} was fixed as 0.12g. A few conclusions are drawn as follow:

- Total weight of steel reinforcement was strongly influenced by soil type. Regardless concrete grade, the total weight of steel reinforcement increased around 3% to 59% compared to nonseismic model. Higher amount of steel reinforcement was required for models considering soil with softer profile.

- Total weight of steel reinforcement also was influenced by concrete grade. Models with concrete grade C25/30 require higher amount of steel reinforcement compared to its companion models with concrete grade C35/45. Lower concrete grade requires higher amount of steel reinforcement

- Models with higher concrete grade will have higher total cost of concrete and steel reinforcement. In this study, the cost of concrete and steel reinforcement for models with concrete grade C35/45 is around 6% to 12% higher compared to models with concrete grade C25/30. Therefore, the selection of material is important to control the cost.

CHAPTER 6

COMPARISON ON TOTAL WEIGHT OF STEEL REINFORCEMENT FOR 5 STORY REINFORCED CONCRETE BUILDING WITH AND WITHOUT SEISMIC DESIGN

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Abstract On June 5th 2015, Malaysia was shocked by an earthquake with M_w6.1 which had struck Ranau, one of the districts in Sabah. The moderate earthquake was the strongest recorded since the M_w5.8 earthquake which occurred in Lahad Datu in 1976. The Ranau earthquake had caused minor to severe damages to local buildings. Although Sabah is located outside the Pacific Ring of Fire, there are some regions which set at risk of earthquake namely as Kundasang, Ranau, Pitas, Lahad Datu and Tawau. After experiencing the tremors from both local and regional earthquakes, Malaysian now aware on the importance of seismic design on buildings and structures. However, the effect of seismic design application on cost of materials need to be studied beforehand. In relation to that, this study presents the seismic design of reinforced concrete hotel or dormitory building with consideration of different magnitude of reference peak ground acceleration, α_{gR} and different soil type. Result shows that both parameters strongly influencing the cost of steel reinforcement. The latter is estimated to be increase around 14% to 247% higher compared to similar building without seismic design.

Keywords: Seismic Design, Eurocode 8, Peak Ground Acceleration, Soil Type, Cost Estimation

6.1 Introduction

Earthquake occurs in a fault due to release of energy that has been stored within the crust of the earth. Earthquakes with small magnitude will liberate small amount of energy and stress, vice versa with large-magnitude earthquakes. However, the energy released by earthquakes with small magnitude can be accumulate in just a few of years to decades. While, it may take several hundred years and perhaps several thousand years for energy released by large magnitude earthquake to accumulate (McClure et al., 2011). Malaysia is formed by two main parts of land. The West Malaysia which is known as Peninsular Malaysia is located in the mainland of Asia, which consist of 12 states including Federal Territory. The East Malaysia is located in Borneo island, which consist of two states namely as Sabah and Sarawak. Both West and East Malaysia is relatively far away from Pacific Ring of Fire regions, which produced most Indonesian and Philippines earthquakes. However, according to Marto et al., (2013) Malaysia is considered to have low seismicity profile. In addition, although such regions are situated outside the Pacific-Ring of Fire, there are some regions which set at risk of earthquake namely as Tawau, Pitas, Lahad Datu, Ranau, and Kundasang (Bernama, 2015). In Peninsular Malaysia, local earthquakes were recorded in Manjung, Jerantut, Bukit Tinggi, and Janda Baik. In East Malaysia, around 70 local earthquake events with magnitude M_w5.0 and above were recorded since 1900 to 2014 (Harith et al., 2015).

On June 5th 2015, Malaysia was shocked by an earthquake with M_w6.1 which had struck Ranau, one of the districts in Sabah. The moderate earthquake was the strongest recorded since the M_w5.8 earthquake which occurred in Lahad Datu in 1976. The 2015 Ranau earthquake had caused minor to severe damages on buildings. According to Majid et al., (2017) the earthquake had caused damages to reinforced concrete (RC) buildings especially on beam, column, and beam-column joint. The nonstructural elements such as brickwall and ceiling also damaged due to the earthquake (Adiyanto et al., 2017). Based on detail survey, Khoiry et al., (2018) reported that the 2015 Ranau earthquake had caused damages on wall, floor, column, and roof. In their report, the highest damage recorded on brickwall with X-mark crack due to shear failure.

According to Tukiar et al., (2016) majority of existing RC buildings in Malaysia had been designed by referring to BS8110 without any seismic provision. To detail, less than one percent of buildings in Malaysia are seismic resistant (Majid, 2009). After experiencing the tremors from both local and regional earthquakes, Malaysian now aware on the importance of seismic design on buildings and structures. According to Hamid et al., (2018) seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage to buildings. However, usage of construction materials due to seismic design consideration need to be studied beforehand. According to Adiyanto and Majid (2014) the consideration of earthquake load in design will directly influencing the cost of material, and the effect should be adopted by construction industry. Hence, this paper discusses the influence of reference peak ground acceleration, α_{gR} and soil type on the total usage of steel in beam and column as reinforcement for 5 story RC building considering seismic design.

6.2 Methodology

In this study, a total of three stages had been conducted namely as generation of basic model, followed by structural analysis & seismic design, and then the taking off as shown in Figure 6.1. In first stage, a 5 story RC building was created and modeled by using computer software. The building was generated to function as hotel or dormitory as shown in Figure 6.2. The total building's height, *H* is set to be equal to 16.5m. The building also is square in plan with 30.0m of total length. The fundamental period of vibration, T_1 is estimated around 0.6 sec. The size of beams at roof level is equal to 250 x 550 mm while the size of beams at other floor level is equal to 350 x 600 mm. The column size is equal to 450 mm square.

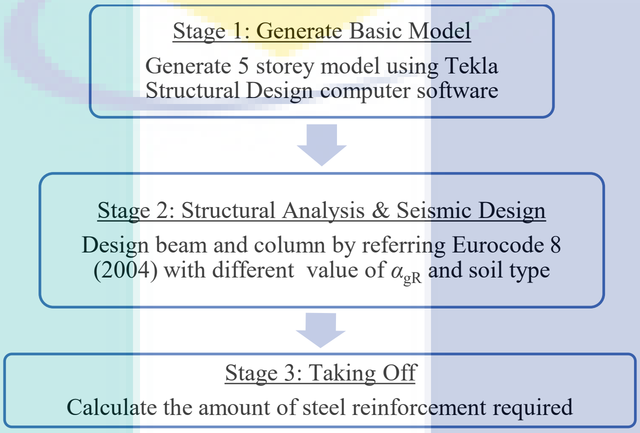

Fig. 6.1 Flowchart of research methodology

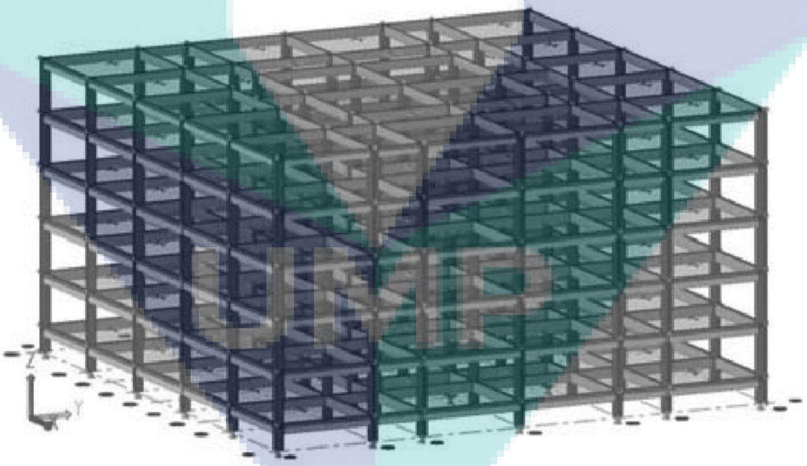

Fig. 6.2 3D view of generated model

In second stage, the structural analysis and seismic design had been conducted on the model. The building was classified in importance class II. Hence, the importance factor, γ_I for the building is equal to 1.0 as proposed by Eurocode 8 (2004). The imposed load on floor, Q_k = 2.0kN/m^2 for the building in Category A as referred to Eurocode 1 (2002). The same model were analyzed and designed repeatedly for different value of reference peak ground acceleration, α_{gR} and different soil type. The reference peak ground acceleration, α_{gR} = 0.10g, and 0.16g were selected as similar to the level of seismicity in Semporna and Ranau, respectively (National Annex, 2017). A total of three soil type had been considered namely as B, D, and E as proposed in Eurocode 8 (2004).

A total of 7 models had been designed as shown in Table 6.1. One model had been designed without seismic consideration as control model. The structural analysis on models with seismic design had been conducted by using Lateral Force Method (Eurocode 8, 2004). According to this method, the earthquake load had been imposed as lateral loads acting on every story. The lateral loads acting on every story was determined from the base shear force, F_b. By referring to Eurocode 8 (2004) the magnitude of base shear force, F_b was calculated as a combination of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, effective mass of the building, m and correction factor, λ. Details can be referred to previous study by Adiyanto et al., (2019). The load combination is shown in Eq. (1) as proposed by Eurocode (2002).

$$E_d = \sum G_{kj} + A_{Ed} + \sum \Psi_{2i} Q_{ki} \tag{1}$$

where E_d is the design action effect, G_{kj} is the permanent load, A_{Ed} is the design value of seismic action which acting laterally on each storey joints, and $\Psi_{2i}Q_{ki}$ is the reduced variable load. For models with seismic design, the value of permanent load, G_{kj} and reduced variable load $\Psi_{2i}Q_{ki}$ were fixed. Hence, the design action effect, E_d was developed by the design value of seismic action, A_{Ed}. All models had been designed for concrete grade 30 with ductility class medium (DCM). The taking off process took part in final stage. In this stage, the total volume of concrete and total steel reinforcement in weight were measured for all beams and columns. The comparison had been made based on weight of steel reinforcement per $1m^3$ of concrete.

Table 6.1 List of models used for structural analysis and seismic design.

No	Code	Soil Type	α_{gR} (g)
1	NS	Not Applicable	Not Applicable
2	B-0.10	B	0.10
3	B-0.16	B	0.16
4	D-0.10	D	0.10
5	D-0.16	D	0.16
6	E-0.10	E	0.10
7	E-0.16	E	0.16

6.3 Result and Discussion

6.3.1 Base Shear Force, F_b

As mentioned in previous section, the earthquake load had been imposed on models as lateral load. The latter had been derived as base shear force, F_b which strongly influenced by the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, effective mass of the building, m and correction factor, λ. According to Eurocode 8 (2004) the correction factor, λ shall be 0.85 for buildings with more than two story and $T_1 < 2T_c$. In this study, the size of structural beams and columns were similar to all models results in similar magnitude of effective mass, m. Hence, in this study the magnitude of base shear force, F_b is determined by the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ as shown in Table 6.2. The magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, was obtained from the design response spectrum for every reference peak ground acceleration, α_{gR} and soil type as shown in Figure 6.3.

From Table 6.2, it is clear that for similar soil type the magnitude of base shear force, F_b increases as the value of reference peak ground acceleration, α_{gR} and the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ increase. For a fix value of reference peak ground acceleration, α_{gR} the magnitude of base shear force, F_b is differ for different soil type. Different value of soil factor, S for every soil type as proposed by Eurocode 8 (2004) contributed to this result. In Table 6.2, the highest magnitude of base shear force, F_b = 6514.6kN is model D-0.16 which considering reference peak ground acceleration, α_{gR} = 0.16g and soil type D. This means that model D-0.16 had been imposed to the highest lateral force.

Table 6.2 Base Shear Force, F_b imposed on all models

Model Code	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ (g)	Base Shear Force, F_b (kN)
NS	Not Applicable	Not Applicable
B-0.10	0.064	2947.2
B-0.16	0.103	4715.5
D-0.10	0.087	4071.6
D-0.16	0.138	6514.6
E-0.10	0.075	3438.4
E-0.16	0.120	5501.4

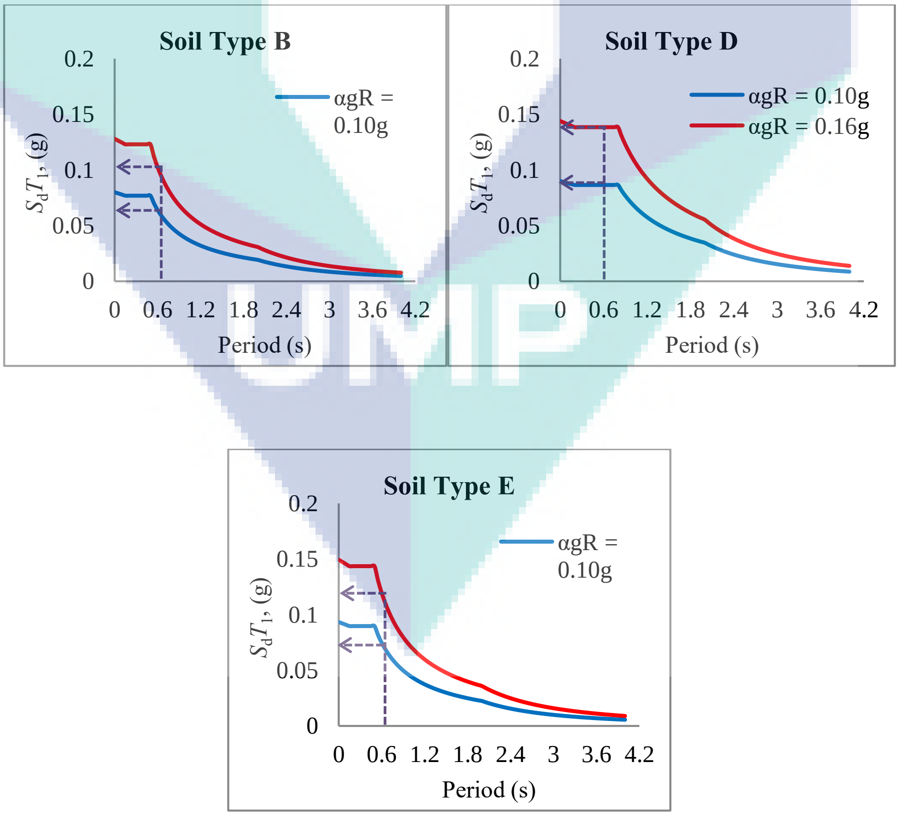

Fig. 6.3 Design response spectrum for Soil Type B, Soil Type D, and Soil Type E

6.3.2 Total Weight of Steel Reinforcement

Total weight of steel reinforcement of beams and columns for all models had been normalized to similar elements belong to the nonseismic model. This is to compare the increment of steel reinforcement due to seismic design consideration to current practice which neglecting seismic design. Figure 6.4 depicts the normalized total weight of steel reinforcement for beams per 1m^3 concrete. Result demonstrates that total weight of steel used as reinforcement for beams differs for every model. Regardless the soil type, the total weight of steel reinforcement in beams with seismic design increases around 43% to 119% higher compared to the nonseismic model. Increasing of reference peak ground acceleration, α_{gR} result in higher percentage of increment. Previous findings by Ramli et al., (2017) also presents similar pattern to current result.

As discussed in previous subsection, model D-0.16 which considering reference peak ground acceleration, α_{gR} = 0.16g and soil type D has the highest magnitude of base shear force, F_b. Therefore, the model were imposed to the highest lateral force result in highest magnitude of design bending moment, M_{Ed}. Based on design calculation for RC beam, the increasing of design bending moment, M_{Ed} leads to increasing of total area of steel required, As_{req} as well as total area of steel provided, As_{prov}. The latter leads to increase the total weight of steel reinforcement.

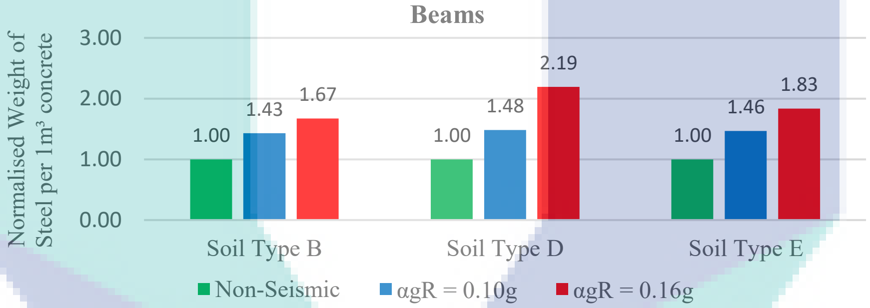

Fig. 6.4 Normalized total weight of steel reinforcement per 1m^3 concrete for beams

As an example, Figure 6.5 depicts the bending moment diagram for beam 1B32 which is located at the first floor. The beam has two equal span of 5.55 m length. Region 1, 3, and 5 are located near the support while region 2 and 4 are located at the midspan of the beam. It is clearly shown that the highest magnitude of design bending moment, M_{Ed} is belong to model D – 0.16 while the lowest magnitude of design bending moment, M_{Ed} is belong to model NS regardless the region. The detail results of design calculation for steel reinforcement in region 3 for all models is shown in Table 6.3. It is clear that model D – 0.16 which has the highest magnitude of design bending moment, M_{Ed} also has the highest total total area of steel required, As_{req} as well as the highest total area of steel provided, As_{prov}. The combination of 3Y25 + 2Y20 has been provided as solution. For beams with seismic design, the DCM provision has mentioned that the maximum spacing for shear reinforcement within critical region, s_{max} shall be limited to 225 mm only (Eurocode 8, 2004). This limitation also caused increment to the usage of steel reinforcement.

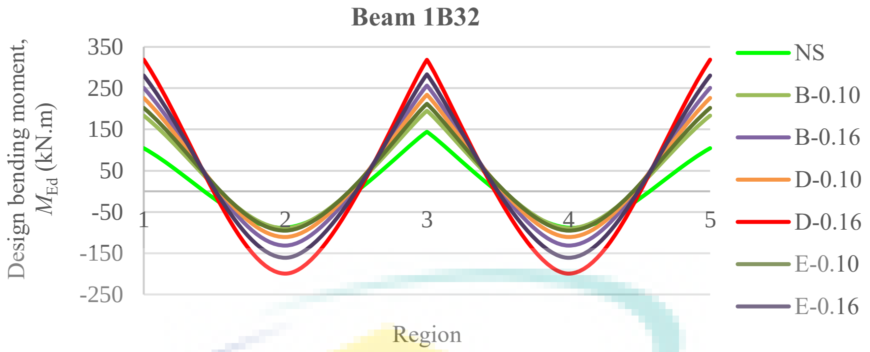

Fig. 6.5 Design bending moment, M_{Ed} for beam 1B32

Table 6.3 Result of design calculation for steel reinforcement in region 3 for beam 1B32.

Model code	Design bending moment, M_{Ed} (kN.m)	Total area of steel required, As_{req} (mm^2)	Total area of steel provided, As_{prov} (mm^2)	Steel reinforcement provided
NS	144.2	771	942	3Y20
B-0.10	195.1	1048	1473	3Y25
B-0.16	256.3	1399	1473	3Y25
D-0.10	234.0	1269	1473	3Y25
D-0.16	318.7	1829	2101	3Y25 + 2Y20
E-0.10	212.1	1143	1473	3Y25
E-0.16	283.5	1609	2101	3Y25 + 2Y20

Normalized total weight of steel reinforcement per $1m^3$ concrete for columns is presented in Figure 6.6. Regardless the soil type, total weight of steel reinforcement for columns with seismic design increases around 14% to 247% higher compared to the nonseismic model. The increasing of total weight of steel reinforcement is significant especially for models on soil type D. This result is similar pattern to previous study by Adiyanto et al., (2019). The result follow similar pattern with beam where model D-0.16 has the highest total weight of steel reinforcement. The result is caused by requirement of seismic design where the strength of column shall be determined by referring to the strength of its beam in order to implement the Strong Column ~ Weak Beam design philosophy (Eurocode 8, 2004). Models considering soil type D has the highest total weight of steel reinforcement compared to other soil types regardless the value of reference peak ground acceleration, α_{gR}. The result is caused by higher magnitude of base shear force, *F*b for models on soil type D contributed by higher magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ as mentioned in previous subsection. As for the beam, the DCM provision also limits the spacing of shear reinforcement, *s* in column's critical region. According to Eurocode 8 (2004), the maximum spacing for shear reinforcement within critical region, s_{max} for column shall be limited to 175 mm only. This limitation also caused increment to the usage of steel reinforcement.

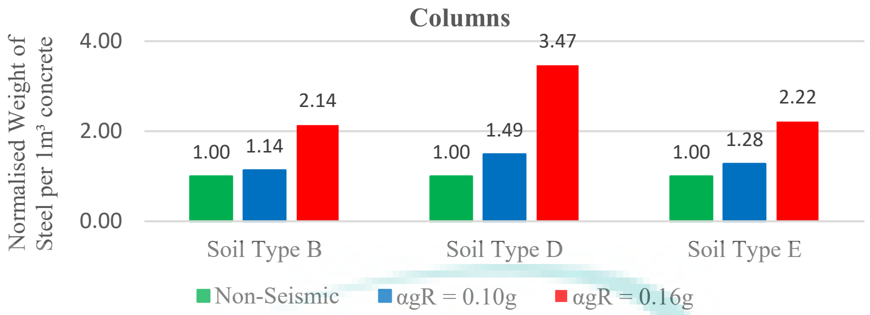

Fig. 6.6 Normalized total weight of steel reinforcement per 1m^3 concrete for columns

6.4 Conclusions

This paper investigates the influence of reference peak ground acceleration, α_{gR} and soil type on total weight of steel reinforcement for 5 story RC building by considering earthquake load. As a conclusion, the total weight of steel reinforcement in beams and columns are strongly influenced by the value of reference peak ground acceleration, α_{gR} and soil type. Total weight of steel reinforcement increases around 43% to 119% and 14% to 247% for beams and columns, respectively when seismic design consideration has been taken into account. This means building with similar structural configuration tends to have different amount of steel as reinforcement.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

This study investigated the effect of seismic design on the amount of steel used as reinforcement in reinforced concrete (RC) buildings. This study focused on low rise RC buildings as models covering various function namely as hospital, office, school, and multipurpose hall. A total of four seismic design parameters namely as reference peak ground acceleration, α_{gR} soil type, concrete grade, and ductility class had been considered in analysis and design process. The reference peak ground acceleration, α_{gR} in range from 0.04g to 0.16g had been considered to represent seismicity in Malaysia. Besides, five soil types namely as Soil Type A, Soil Type B, Soil Type C, Soil Type D and Soil Type E as proposed by Eurocode 8 (2004) had been taken into account. Structural elements namely as beam and column had been designed for concrete grade C25, C30, and C35. In order to study the effect of ductility, two class of ductility namely as Ductility Class Low and Ductility Class Medium had been considered in analysis and design. A few general conclusions is listed as follow:

- The value of reference peak ground acceleration, α_{gR} is strongly influencing the total weight of steel reinforcement. The latter is increase as the former increase, vice versa.

- Soil Type strongly influencing the design and detailing of beams and columns. Except for Soil Type A, models considering seismic design with Soil Type B to Soil Type E generally require higher amount of steel reinforcement compared to the nonseismic model. The increment of steel reinforcement is in range of 1.16 to

2.11 times higher compared to the nonseismic design. Therefore, the Soil Type will result in different cost of steel reinforcement even for similar building layout and configuration.

- Total weight of steel reinforcement also was influenced by concrete grade. Models with concrete grade C25 require higher amount of steel reinforcement compared to its companion models with concrete grade C30 and C35. Lower concrete grade requires higher amount of steel reinforcement

- The class of ductility also influencing the total weight of steel reinforcement. Higher class of ductility tends to reduce the amount of steel reinforcement used in design. In this study, the cost of steel reinforcement tends to increase around 6% to 145% when considering DCM and DCL, respectively in seismic design. It can be concluded that DCM is preferable for more economical design. However, the seismic performance has to be evaluated to ensure it pass the desired performance level.

7.2 Future Recommendation

In order to improve the study of seismic design, these are several recommendations need to be consider in the future research works:

i. This study only considered 3 to 6 storey RC buildings as model which can be categorised as low rise building. It will be better to consider building with more number of storey to represent the medium and high rise building in future research

ii. Since this study only consider the beam and column element in analysis, design, and taking off, further research could be performed by also considering the foundation.

iii. Similar research on steel building also will be worth to be conducted.

iv. The value of Soil Factor, *S* used in this study had been referred to Eurocode 8 (2004). It will be better to refer the value of Soil Factor, *S* as proposed by Malaysia National Annex (2017) to represent real situation for Malaysia

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