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Estimation on 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.

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 1.

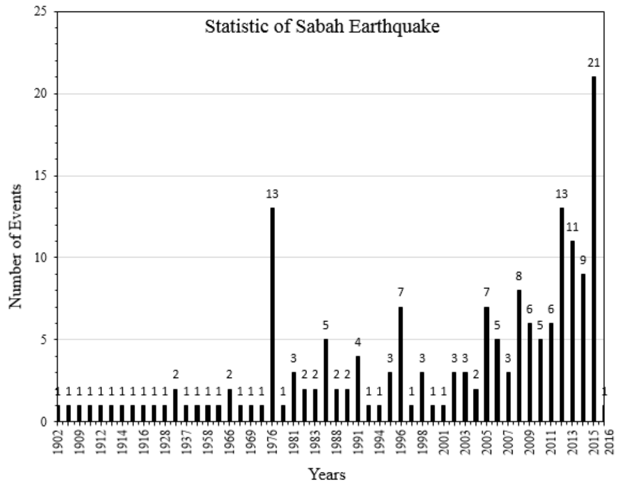

Figure 1. Number of local earthquakes reported (1900-2016) around Sabah [3]

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. 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. 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 1 presents the dimension of all beams and columns for the generated hospital RC building.

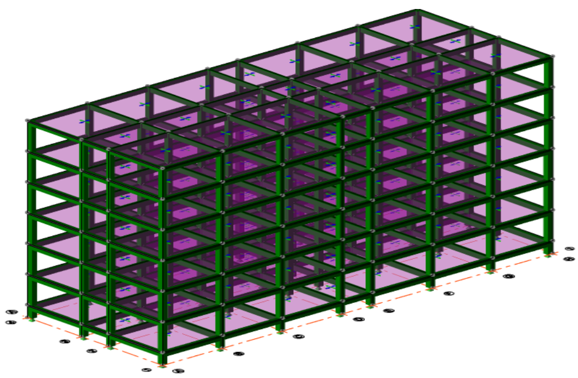

Figure 2. 3D view of six storey hospital RC building

Table 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 summarized all RC hospital models used in this study and its design consideration.

Table 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:

$$F_b = S_d(T_1).m.\lambda. \quad (1)$$

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 λ = 0.85 if $T_1 < 2T_c$ and the building has more than two storey, or λ = 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.

3. Result and Discussion

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 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.

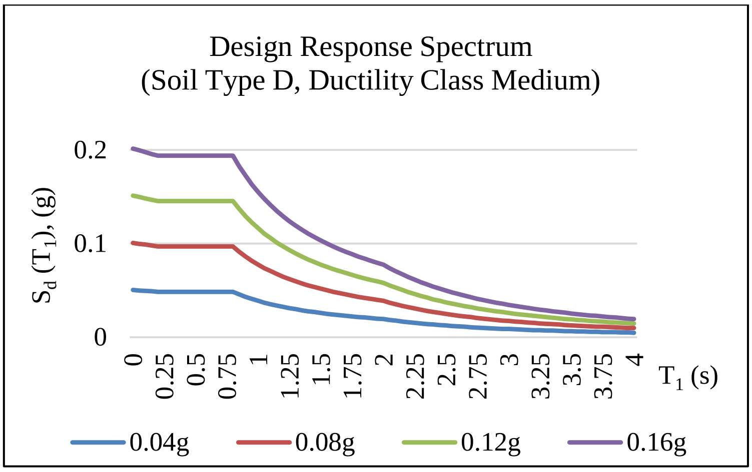

Figure 3. Design response spectrum for different value of reference peak ground acceleration

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 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].

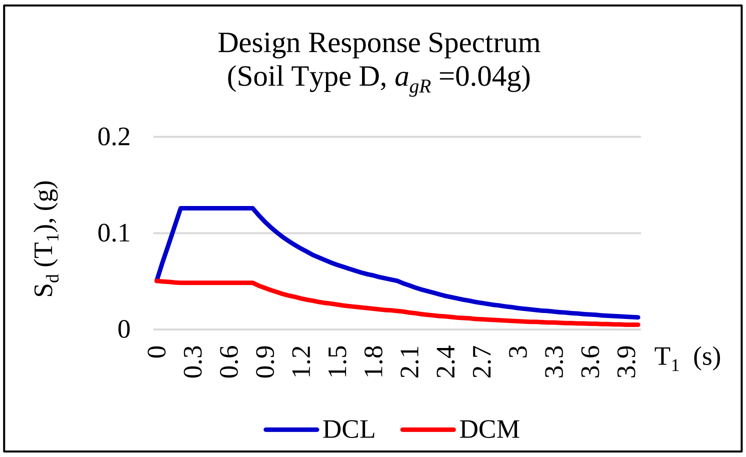

Figure 4. Design response spectrum for different class of ductility

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

Figure 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.

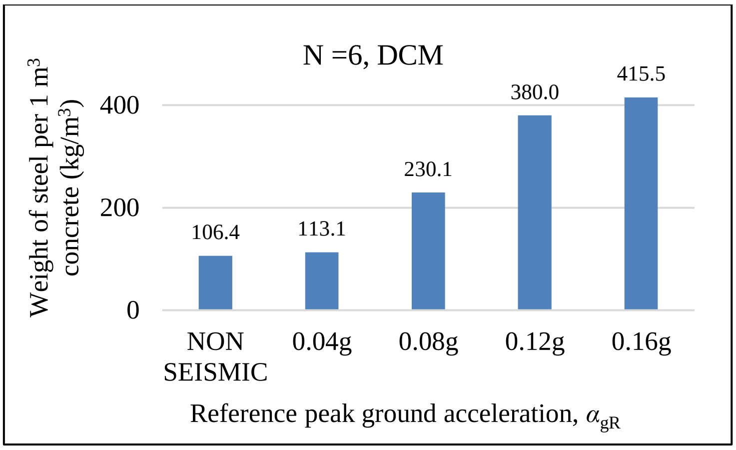

Figure 5. Total weight of steel reinforcement for 1m^3 concrete for different value of reference peak ground acceleration, α_{gR}

Based on Figure 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}.

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 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].

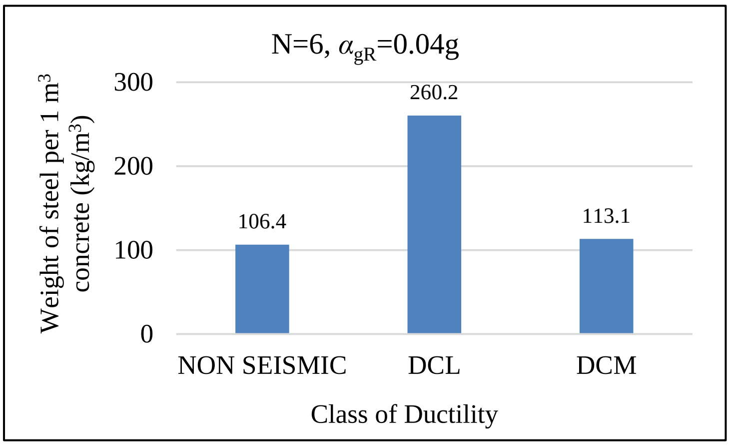

Figure 6. Total weight of steel reinforcement for 1m^3 concrete for different class of ductility

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.

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