COST EVALUATION OF STEEL TONNAGE FOR REINFORCED CONCRETE HOSTEL BUILDING WITH SEISMIC DESIGN

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Abstract
Peninsular Malaysia was exposed to the Sumatra Andaman earthquake which lead certain areas to experience tremors and cause damage to buildings and injury to people. Reinforced concrete hostel buildings can act as a temporary shelter for community to stay until the disaster dwindle. Thus, reinforced concrete hostel buildings must be able to resist the seismic load whenever earthquake happen. However, in Malaysia seismic precautions are not considered into account for design and construction since Malaysia is not located in active seismic fault zone. Until on 5th June 2015 when Ranau, Sabah was surprised by an unexpected tremor. After the incident, people became aware and starts to reconsider to implement the seismic design on new buildings in Malaysia to ensure public safety. This implementation will affect the cost of construction, especially for materials. Therefore, this paper presents the effect of seismic design consideration to the cost of steel reinforcement. Since this project focused on building in Malaysia, the seismic load derivation had been referred to Malaysia National Annex to Eurocode 8. A total of three stages had been conducted which are generate basic model, structural analysis & seismic design, and then the taking off process. A typical four storey reinforced concrete hostel building had been generated as basic model. In this study, there are two parameters had been considered as design variable which are four soil type namely as soil type B, C, D and E and four level of seismicity representing by the reference peak ground acceleration, α_{gR} equal to 0.04g, 0.06g, 0.07g and 0.09g. Based on result, the cost of steel tonnage for the whole building increases around 1% to 22% depend on soil type and level of seismicity.

Keywords: *Cost engineering; Eurocode 8; seismic design; steel tonnage; soil type.*

INTRODUCTION

Malaysia is one of the countries that are safe from earthquake as it is located at the equator of the globe which are far away from the active seismic fault zone. Therefore, in Malaysia seismic precautions are not considered into account for design and construction, except for several special buildings. However, as the previous recorded earthquakes that occurred in the neighbouring countries which are high seismicity regions such as Indonesia and Philippine, Malaysia is occasionally subjected to experiences minor to moderate earthquakes activities especially in the west coast of Peninsular Malaysia and Sabah. Even though Sabah not located in the Pacific Ring of Fire, few areas included of Tawau, Kunak, Kundasang, Ranau, Pitas, and Lahad Datu have high risk to be hit by earthquakes activities. Peninsular Malaysia also experienced local earthquakes in Bukit Tinggi, Pahang (MOSTI, 2014). According to Latiff and Khalil (2019), the main cause of Bukit Tinggi earthquakes from 2007 to 2009 because the reactivation of the Paleo fault line.

Five years ago, on 5th June 2015, an earthquake had struck Ranau, Sabah with magnitude of M_w6.0 which lasted for 30 seconds. According to Harith et al. (2018), an earthquake with magnitude M_w6.0 occurred in Ranau which followed by more than 100 aftershocks affected 61 buildings such as schools, hospital, and mosque. As reported by Khoiry et al. (2018) from his previous survey, 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 Hamid et al. (2018), seismic design practice should be implemented especially in Sabah which is categorized as moderate seismic region in order to reduce the damage to buildings. However, seismic design considerations have their own implications as it directly affecting the cost of materials which the construction industry must adopt (Adiyanto and Majid, 2014). A number of studies had been conducted dealing with seismic design which tends to increase in total usage of construction materials that will directly increase the cost of structure (Faisal et al., 2019; Ramli et al., 2017; Adiyanto et al., 2019; Roslan et al., 2019; Adiyanto et al., 2019; Azman et al., 2019; Mustapa et al., 2019). However, according to Ramli et al. (2017) the cost for repair and maintenance in the future will be reduced by implementation of seismic design. The increment of total steel used as reinforcement for Reinforced Concrete (RC) building is strongly influenced by the level of reference peak ground acceleration, α_{gR} (Adiyanto and Majid, 2014; Adiyanto et al., 2019; Roslan et al., 2019; Adiyanto et al., 2020). Furthermore, the soil type also influencing the seismic performance of building which also makes changes the total steel used for building (Roslan et al., 2019; Adiyanto et al., 2020; Azman et al., 2019; Mustapa et al., 2019).

This paper presents the effect of seismic design consideration on the cost increment of steel reinforcement. For that purpose, a typical four storey RC hostel building had been generated as basic model for analysis, design, and taking off processes. Different soil type and level of seismicity had been considered as variable in this study. The result is presented in term of normalised total steel tonnage used as reinforcement.

MODELS AND METHODS

A total of three stages had been conducted in order to achieve the objective. The three stages are generate basic model, structural analysis & seismic design, and then the taking off process. In stage 1 by using computer software a typical four storey RC hostel building has been generated as basic model as presented by Figure 1. The total height, H of the RC hostel building is around 14.6m from rigid foundation. The fundamental period of vibration, T_1 is estimated to be equal to 0.5 sec. There are several sizes of beam has been considered which is equal to 200 mm x 500 mm, 200 mm x 450 mm, 200 mm x 300 mm, 200 mm x 400 mm and 250 mm x 600 mm depend on the position and span. The columns has been modelled with two sizes which is equal to 400 mm x 400 mm and 375 mm x 375 mm for bottom two stories and top two upper stories, respectively.

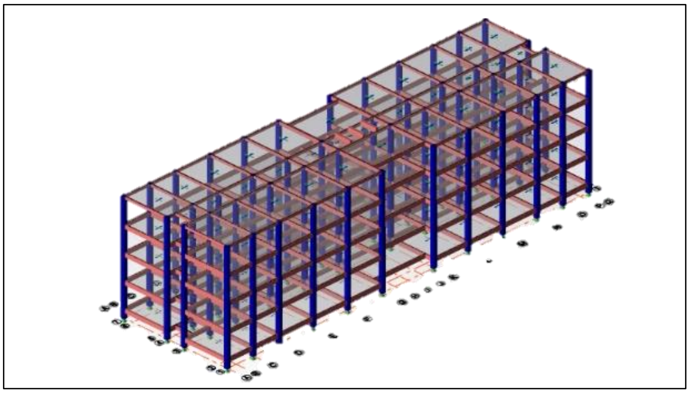

Figure 1. Four storey RC hostel building

In stage 2, the structural analysis and seismic design for all models had been conducted. The building had been designed according to Eurocode 8 (2004) which is with seismic consideration. Thus, the structure classified into important class III. Due to its importance after disaster, the recommended value of importance factor, γI is 1.2 to give better protection of life for such buildings (Fardis et al. 2015). As mentioned in previous subsection, a typical four storey RC hostel building has been analysed and designed repeatedly based on different soil type and level of seismicity. As proposed by Eurocode 8 (2004) a total of four soil type namely soil type B, C, D and E had been considered into the study to represent the variable. Besides, four level of seismicity has been taken into account where the value of reference peak ground acceleration, αgR = 0.04g, 0.06g, 0.07g and 0.09g. According to Malaysian seismic hazard map proposed in National Annex (2017) the values of such reference peak ground acceleration, αgR are representing the seismicity in Alor Setar, Shah Alam, Kuala Lumpur and Bukit Tinggi, respectively. While for the fixed parameter in this analysis, all models have been designed based on concrete grade C30/37 and yield strength of steel, fy = 500 N/mm2.

Based on Eurocode 8 (2004), the building standard allows the design to be conducted for ductility classes low (DCL) or ductility class medium (DCM) based on the product of $\alpha g.S$ as shown in Table 1. For RC moment resisting frame, the behaviour factor, q varies proportionally to 1.5 and 3.9, respectively for DCL and DCM. As proposed by National Annex (2017) every soil type have different soil factor, S. As shown in Table 2, 17 models has been analysed and designed for this study. In this study, regions having the reference peak ground acceleration, αgR = 0.04g & 0.06g had been considered for DCL. The DCM was applied for regions with reference peak ground acceleration, αgR = 0.07g & 0.09g. For control mode one model without seismic consideration has been taken into consideration. By referring to Eurocode 8 (2004) the lateral force method has been applied for the structural analysis on models with seismic design. Previous work by Adiyanto et al. (2019) also conducted this method for his study.

Table 1. Classification of Ductility class on the Seismic zone

Seismic Zone	$\alpha_{g.}$ S	Ductility
Very Low Seismicity	$\alpha_{g.} S \leq 0.05$	no need seismic design
Low Seismicity	$0.05 < \alpha_{g.} S \leq 0.10$	DCL
Medium Seismicity	$\alpha_{g.} S > 0.10$	DCM or DCH

Table 2. Design parameters and RC Hostel models

No	Model Code	Reference peak ground acceleration, α_{gR} (g)	Soil Type	Ductility
1	NS	-	-	-
2	B – 0.04L	0.04	B	DCL
3	B – 0.06L	0.06	B	DCL
4	B – 0.07M	0.07	B	DCM
5	B – 0.09M	0.09	B	DCM
6	C – 0.04L	0.04	C	DCL
7	C – 0.06L	0.06	C	DCL
8	C – 0.07M	0.07	C	DCM
9	C – 0.09M	0.09	C	DCM
10	D – 0.04L	0.04	D	DCL
11	D – 0.06L	0.06	D	DCL
12	D – 0.07M	0.07	D	DCM
13	D – 0.09M	0.09	D	DCM
14	E – 0.04L	0.04	E	DCL
15	E – 0.06L	0.06	E	DCL
16	E – 0.07M	0.07	E	DCM
17	E – 0.09M	0.09	E	DCM

The stage 3 is the taking off process. During this process, the total volume of concrete and total steel reinforcement in weight were measured for all beams and columns. The comparison between nonseismic model and seismic models had been made based on weight of steel reinforcement per 1m3 of concrete.

RESULTS AND DISCUSSION

Earthquake Load, E on Models

The lateral force method (Eurocode 8, 2004) has been conducted on models in order to derives the magnitude of total earthquake load, E imposed on all models with seismic design. The latter had been represented by base shear force, Fb then being distributed on every storey as mentioned by Elghazouli (2009). Hence, the magnitude of base shear force, Fb is directly proportional to the value of spectral acceleration at the fundamental period of vibration, Sd(T1), effective mass of the building, m and correction factor, λ. By referring to Eurocode 8 (2004) the value of correction factor, λ shall be 0.85 for buildings with more than two story and T1 < 2Tc. In this study, the value of spectral acceleration at the fundamental period of vibration, Sd(T1) was obtained from a series of design response spectrums which had been developed for every soil type and level of seismicity. All models have similar effective mass of the building, m and correction factor, λ.

Table 3 shows that the magnitude of base shear force, Fb imposed as lateral loads are differ for each models. The magnitude of base shear force, Fb increases as the magnitude of spectral acceleration at the fundamental period of vibration, Sd(T1), increases. It also shows that once the level of seismicity is similar, the magnitude of base shear force, Fb will be differed for different soil type where softer soil profile tends to have higher magnitude of base shear force, Fb. This result is caused by different soil factor, S for every soil type as proposed by National Annex (2017). As an example, for seismicity with reference peak ground acceleration, αgR = 0.06g the magnitude of base shear force, Fb are equal to 1976.5 kN, 2705.9 kN, 3176.5 kN and 3294.1 kN for models considering soil type B, C, D and E, respectively. By referring to Table 3, model E-0.06L which considering reference peak ground acceleration, $\alpha gR = 0.06g$ and soil type E is the highest magnitude of lateral load result in highest magnitude of bending moment, M. This means the model had been imposed to the highest magnitude of lateral force on every storey.

Table 3. Base shear force, F_b 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	B – 0.04L	0.659	1317.7
3	B – 0.06L	0.989	1976.5
4	B – 0.07M	0.444	886.9
5	B – 0.09M	0.570	1140.3
6	C – 0.04L	0.902	1803.9
7	C – 0.06L	1.353	2705.9
8	C – 0.07M	0.607	1214.2
9	C – 0.09M	0.781	1561.1
10	D – 0.04L	1.059	2117.7
11	D – 0.06L	1.589	3176.5
12	D – 0.07M	0.713	1425.3
13	D – 0.09M	0.917	1832.6
14	E – 0.04L	1.098	2196.1
15	E – 0.06L	1.648	3294.1
16	E – 0.07M	0.739	1478.1
17	E – 0.09M	0.950	1900.5

Total Volume of Concrete

In this study, the size of RC beams, columns and slabs are similar for all models regardless the design consideration. Therefore, the volume of concrete is similar for all models which is equal to 526.52 m3.

Total Steel Tonnage

Total steel tonnage is the summation of steel bar used as flexural and shear reinforcement in all RC beams and columns. According to Adiyanto et al. (2019) the number and size of steel reinforcement strongly influenced by the magnitude of bending moment, M shear force, V and axial load, P. In Figure 2 shows the steel tonnage in 1m3 concrete of beams for all models which considering seismic design is normalized to the nonseismic model. Thus, it shows the comparison of the steel tonnage of beams for seismic models and the current practice which neglecting seismic design. Figure 2 shows that as the seismic design is applied, the steel tonnage used as reinforcement in beam increases. The increment of steel tonnage of beams increased around 12% to 111% higher compared to the nonseismic model. The soil type 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 – 0.06L has the highest magnitude of base shear force, Fb 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 tonnage to be provided as reinforcement.

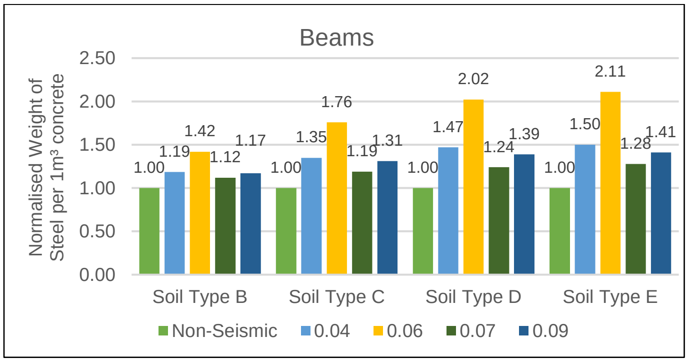

Figure 2. Total steel tonnage for all beams

As mentioned by Noor et al. (2019) the torsional effect tends to caused heavier damage on columns. The seismic design must approach the concept of Strong Column – Weak Beam which means that the column shall be stronger than beam Eurocode 8 (2004). Thus, column really plays important role for stability of structural system. Figure 3 shows the steel tonnage in 1m3 concrete of columns for all models. Figure 3 shows similar pattern to the increment steel tonnage in beams but with higher percentage. The increment of steel tonnage of columns increased around 17% to 157% higher compared to the nonseismic model. 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.

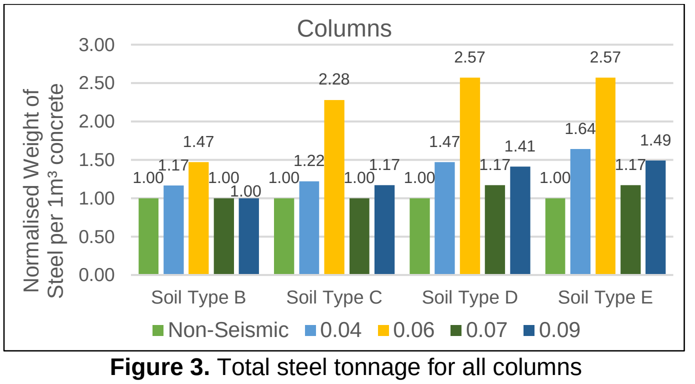

Figure 3. Total steel tonnage for all columns

Figure 4 shows the normalized total weight of steel reinforcement for whole structure for all models. Result for this group also demonstrates that total steel tonnage used as reinforcement are differ for every models. In Figure 4, the increment of steel reinforcement is around 7% to 116% higher compared to the nonseismic model. The increment of steel reinforcement occurred on both beams and columns as discussed by previous studies Adiyanto and Majid (2014); Faisal et al. (2019); Adiyanto et al. (2019); Roslan et al. (2019); Adiyanto et al. (2020); Azman et al. (2019); Mustapa et al. (2019). In Figure 4, the highest total steel tonnage corresponds to model E-0.06L. The result is as expected because the model has the highest magnitude of base shear force, Fb. The latter result in highest magnitude of bending moment, M. Based on design calculation for RC beam and column by Elghazouli (2009), the increasing of bending moment, M lead to increasing of total area of steel required, Asreq as well as the total area of steel provided, Asprov. The latter leads to increase the total weight of steel reinforcement.

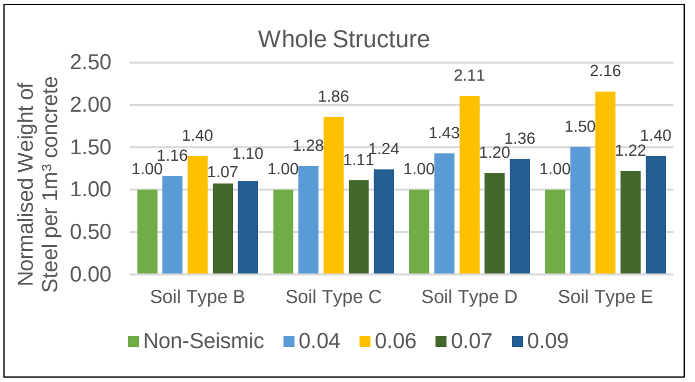

Figure 4. Total steel tonnage for whole structure for all models

Total Cost Estimation for Steel Reinforcement

In this study, the comparison also been made in form of total cost or price of materials. According to Standard Price Malaysia (2017), the standard price for concrete grade C30/37 differ depend on usage. In this study, the total cost of concrete which is summation of beams, columns, and slabs was estimated to be equal to RM194,200.079 for all models with concrete grade C30/37. Thus, the cost of concrete for whole structure is estimated to be similar for all models. While for the standard price of steel reinforcement is RM3.50 per kg.

The normalized total cost of steel reinforcement for beams and columns of all models is shown in Figure 5. Model that consider seismic design caused increment around 1% to 22% to total cost of concrete and steel reinforcement compared to its nonseismic model. Generally, the cost for steel reinforcement increases depend on the soil type and level of seismicity. In this study, models E-0.06L required higher cost of steel reinforcement compared to its other models. Both parameters strongly influencing the magnitude of base shear force, Fb. As discussed in previous subsection, the increase of base shear force, Fb tends to increase the magnitude of bending moment, M which also directly increases the area of steel required, Asreq. For solution, engineers have to use combination of increase number and size of steel bar to increase the area of steel provided, Asprov. This means higher steel tonnage has to be used as reinforcement. The result from this study indicates that soil type and the level of seismicity strongly influencing the cost of steel reinforcement. Therefore, by choosing a suitable selection on site for development can reduce the cost of steel reinforcement.

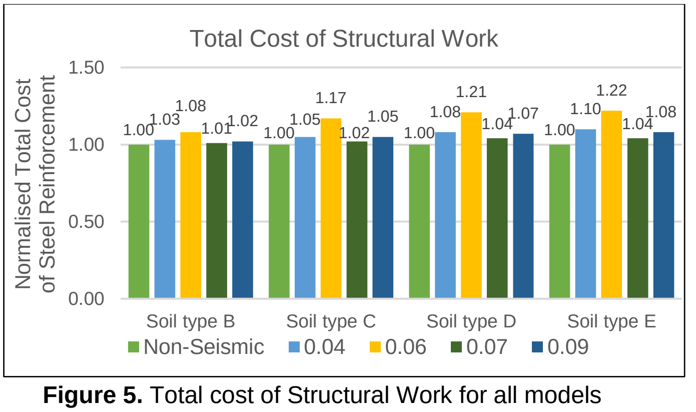

Figure 5. Total cost of Structural Work for all models

CONCLUSION

This study presents the influence of soil type and level of seismicity on amount of steel tonnage. A four storey of RC hostel building with earthquake load consideration is discussed in this paper. A total of four soil conditions namely as soil type B, C, D, and E had been considered to represent the site conditions in Malaysia. Therefore, four level of seismicity has been taken into account where the value of reference peak ground acceleration, αgR = 0.04g, 0.06g, 0.07g and 0.09g. A few conclusions are drawn as follow:

- The increment of steel tonnage was strongly influenced by soil type. Higher amount of steel reinforcement was required for models considering soil with softer profile. Thus, it is important to consider soil type when design the building.

- Total of steel tonnage also was influenced by level of seismicity. Models with value of reference peak ground acceleration, αgR = 0.06g require higher amount of steel reinforcement compared to other models. This model has the highest magnitude of base shear force, Fb result in highest magnitude of bending moment, M as well as shear force, V which result in highest amount of steel to be provided as reinforcement.

- By considering seismic design, total cost of steel reinforcement for beams and columns tend to increase around 1% to 22% depend on soil type and level of seismicity.

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