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Impact of seismic design on cost of structural materials for two storey hostel building in Sabah

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Abstract. Previously, damaging earthquakes were fortunately rare in Malaysia. However, after Sumatera-Andaman earthquake on 26 December 2004 affected Peninsular Malaysia causing deaths, injuries and loss of property. Furthermore, some of the local earthquake that had occurred in Malaysia are probably due to the reactivations of ancient inactive fault due to increasing seismic activities in and around Malaysia. On 5th June 2015, Malaysia experienced a devastating earthquake with magnitude M_w 6.0 in Ranau results in 18 fatalities and affected 61 buildings. Mostly, the fatalities and injuries persistent during an earthquake is caused by structural failures which not include the seismic action into design. Reinforced concrete hostel building in school area will act as a temporary shelter for refuge during the disaster and until it dwindles. Although Malaysia is located on a stable plate and far from the Pacific Ring of Fire, it is essential to consider seismic practice, especially when dealing with cost. Therefore, this paper presents the influence of seismic consideration on cost of material and the factors which influencing the cost by implementing the soil factor, S as proposed by National Annex to Eurocode 8. A typical two storey reinforced concrete hostel building has been generated as basic model. A total of four soil type namely soil type B, C, D and E and five seismicity level has been taken into account where the value of reference peak ground acceleration, α_{gR} = 0.04g, 0.06g, 0.07g, 0.12g & 0.16g. Overall, this research work had been conducted based on 3 phases. Based on result, the cost of structural works for the whole building increases around 1% to 12% depend on soil type and level of seismicity.

1. Introduction

Generally, an earthquake can occur anywhere and thousands happens every day around the world. Even though Malaysia is not located along plate tectonic edges and considered in the low seismicity zones except for Sabah, Malaysia is no exception to experience the phenomenon of earthquakes due to its position located around it with countries of high seismicity such as Indonesia and the Philippines. This can be seen when Malaysia was affected by the 2004 Indian Ocean earthquake in Acheh, Indonesia with the magnitude of M_w 9.0 which has triggered tsunami causing fatalities and injuries. This incident resulted in high magnitudes of seismic waves which caused high-rise buildings in Penang, Kuala Lumpur, Putrajaya, and Johor Bahru shake extensively [1]. Furthermore, the Bukit Tinggi earthquake occurred due to the reactivation of an ancient inactivity after the Sumatra earthquake happened which are believed to intraplate pressure formed [2, 3]. Moreover, the previous history of earthquakes in Malaysia and the increment in the number of small daily earthquakes prove that the region has experienced a devastating earthquake especially in Sabah on 1976 in Lahad Datu, and recently on 5 June 2015 in Ranau. Although the Ranau earthquake is not considered a high-level earthquake, but according to Harith et al. [4], the incident which was followed by more than 100 aftershocks, resulted in 18 deaths and 61 buildings included schools, hospitals, and mosques. This is because current practice does not consider any seismic provision in structural design in Sabah.

The low to moderate seismic hazard in Malaysia cannot be taken lightly and need to give major concern by including seismic design on buildings especially in Sabah. Therefore, the implementation of seismic design on new buildings is important as a public refuge and reduce building damage [5]. Seismic design provision tends to lead to an increase in the amount of steel reinforcement which will directly increase the costs. However, from point of view for the future, costs for repairs and maintenance will be reduced with the implementation of seismic design [6].

A few research works had been conducted to determine the influence of seismic design to the cost increment of construction's materials with different parameters [6 – 13]. Authors concluded that the cost increment of construction's materials increases as the amount of steel reinforcement increase when seismic design consideration is taken into account. Therefore, this study is to investigate the influence of soil type and reference peak ground acceleration, α_{gR} of RC hostel building with seismic design consideration which will determine the total amount of structural works. In overall, this study will be significant for structural engineers to ensure the building able to withstand seismic action and safe to use without over-costing.

2. Model and Methodology

Overall, this study has been proposed based on three phases which are model generation, structural analysis and seismic design, lastly is taking off process. In Phase 1, a two storey of reinforced concrete of hostel building has been generated by using Tekla Structural Designer 2019 computer software as shown in Figure 1. The floor to floor height is equal to 3.35m. Figure 2 and Figure 3 shows the side and front view of two storey RC hostel building model generated and Table 1 shows the summary of the member cross section for beam and column.

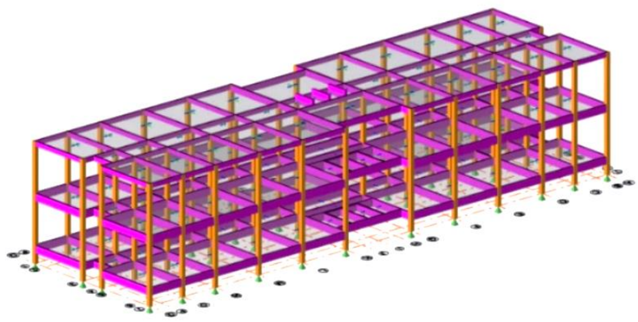

Figure 1. A 3D view of two storey RC hostel building

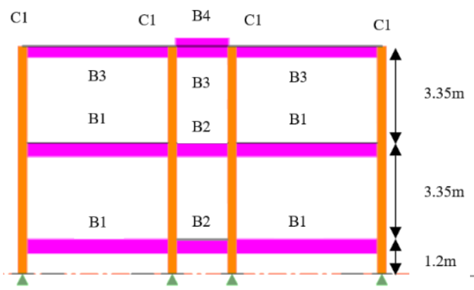

Figure 2. Side view of RC hostel building

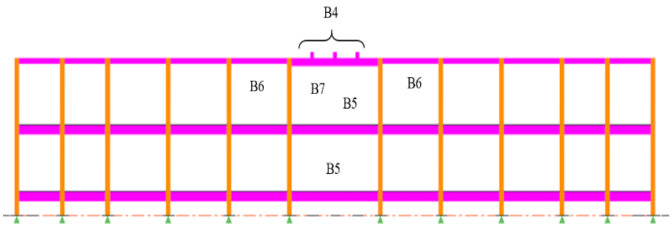

Figure 3. Front view of RC hostel building

Table 1. Cross section of Structural Member of RC hostel building.

Beam	Dimension (mm)
B1	200x500
B2	200x450
B3	200x300
B4	250x600
B5	200x500
B6	200x300
B7	200x400
Column	Dimension (mm)
C1	400x400

In Phase 2, as stated by Eurocode 1 [14], RC hostel building which categorized in Category A as the model generated based on residential areas. The imposed load on floor, balconies, stairs and roof is q_k = 2.0kN/m^2, 4.0kN/m^2, 4.0kN/m^2 and 0.5kN/m^2 is taken respectively. It was classified as importance class III with the value of importance factor, γ_I is equal to 1.2 as proposed by Eurocode 8 [15]. The value as proposed to give protection and their importance for public safety after post-earthquake period. The purpose of this study is to investigate the influence of soil type and level of seismicity for seismic design on total amount of material. As mentioned in previous section, there are four type of soil which are B, C, D and E has been considered. Furthermore, five reference peak ground acceleration, α_{gR} equal to 0.04g, 0.06g, 0.07g, 0.12g & 0.16g has been taken into account for structural analysis and design. These values representing the level of seismicity in Sabah according to National Annex [16]. Two classes of ductility namely ductility class low (DCL) and ductility class medium (DCM) also has been considered depend on the value of level of seismicity for models with seismic design. Therefore, the value of the behaviour factor, q for DCL and DCM used is equal to 1.5 and 3.9, respectively. Ductility class high is not considered in Malaysia and only suitable for high seismic region. In addition, one RC hostel model has been analysed and designed using Eurocode 2 [17] without include seismic design for non-seismic model. Table 2 shows the summarize of all models used for this study and its seismic design consideration. All model has been designed based on yield strength of steel, f_y and concrete compressive strength, f_{cu} equal to 500 N/mm^2 and 30 N/mm^2, respectively.

Table 2. All models with different variables of the RC hostel building.

No	Model	Soil Type	PGA (g)	Ductility	Behaviour factor, q
1.	NS	-	-	-	-
2.	B-0.04L	B	0.04	DCL	1.5
3.	C-0.04L	C			
4.	D-0.04L	D			
5.	E-0.04L	E			
6.	B-0.06L	B	0.06	DCL	1.5
7.	C-0.06L	C			
8.	D-0.06L	D			
9.	E-0.06L	E			
10.	B-0.07M	B	0.07	DCM	3.9
11.	C-0.07M	C			
12.	D-0.07M	D			
13.	E-0.07M	E			
14.	B-0.12M	B	0.12	DCM	3.9
15.	C-0.12M	C			
16.	D-0.12M	D			
17.	E-0.12M	E			

18.	B-0.16M	B			
19.	C-0.16M	C			
20.	D-0.16M	D	0.16	DCM	3.9
21.	E-0.16M	E			

In the last phase, taking off process will be performed to determine the amount of steel reinforcement required and cost of material for all RC hostel models. Comparison of taking off has been made based on result between non-seismic model and seismic models differ by two main parameters used such as soil type and reference peak ground acceleration, α_{gR} in form of weight of steel reinforcement per $1m^3$ of concrete. The material cost was determined based on the standard price of building material that provided by the Jabatan Kerja Raya (JKR) [18].

3. Result and discussion

3.1 Base Shear Force, F_b

In this study, the earthquake load, *E* was calculated for all models by using the lateral force method except for non-seismic model. This earthquake load has been applied as lateral load acting on each storey joints and had been derived in form of base shear force F_b. By referring to Eurocode 8 [15], 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. Thus, the correction factor where $\lambda = 0.85$ if $T_1 < 2T_c$ and the building has more than two storey, or $\lambda = 1.0$ [15]. In this study, the magnitude of the dead load, G_k and the imposed load, Q_k were similar to all models. Furthermore, the size of structural beams and columns were similar to all models results in similar effective mass of the building, *m* as well as correction factor, λ. Based on the equation proposed by Eurocode 8 [15], the fundamental period of vibration, T_1 for all models is equal to 0.35 sec. The fundamental period of vibration, $S_d(T_1)$ was obtained from the design response spectrum for every soil type and reference peak ground acceleration, α_{gR}. Hence, in Table 3 shows the magnitude of base shear force, F_b is determined by the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$.

From Table 3 shows that as the value of reference peak ground acceleration, α_{gR} increases with similar soil type, the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ increase as well as the magnitude of base shear force, F_b. Besides, for a fix value of reference peak ground acceleration, α_{gR} with different soil type result with different magnitude of base shear force, F_b. Thus, different soil type has different value of soil factor, *S* as proposed by National Annex [16]. The highest magnitude of base shear force, F_b = 1614.7 kN for both model B-0.16M and E-0.16M which considering reference peak ground acceleration, α_{gR} = 0.16g and soil type B and E. This means that model B-0.16M and E-0.16M had been imposed to the highest lateral force contributed to highest magnitude of design bending moment, *m* shear force, *v* and axial load, *P* which result in highest amount of steel reinforcement provided for the models.

As results demonstrate in Table 3 shows that with low value of reference peak ground acceleration, α_{gR} = 0.06g with DCL shows highest magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ compare than α_{gR} = 0.07g and 0.12g with DCM. Therefore, the class of ductility also influencing the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$. This means that higher ductility class which is DCM 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. This is good agreement with previous study Adiyanto et. al [19].

Table 3. Base shear force, F_b acting on all models.

No	Model	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, g (m/s^2)	Base shear force, F_b (kN)
1.	NS	Not applicable	Not applicable
2.	B-0.04L	1.098	1049.6
3.	B-0.06L	1.648	1574.3
4.	B-0.07M	0.739	706.4
5.	B-0.12M	1.267	1211
6.	B-0.16M	1.690	1614.7
7.	C-0.04L	1.059	1012.6
8.	C-0.06L	1.589	1518.1
9.	C-0.07M	0.713	681.2
10.	C-0.12M	1.222	1167.8
11.	C-0.16M	1.629	1557
12.	D-0.04L	1.059	1012.6
13.	D-0.06L	1.589	1518.1
14.	D-0.07M	0.713	681.2
15.	D-0.12M	1.222	1167.8
16.	D-0.16M	1.629	1557
17.	E-0.04L	1.098	1049.6
18.	E-0.06L	1.648	1574.3
19.	E-0.07M	0.739	706.4
20.	E-0.12M	1.267	1211
21.	E-0.16M	1.690	1614.7

3.2. Total weight of steel reinforcement

In this subsection, Figure 4 and Figure 5 will present the comparison of the normalized total weight of steel reinforcement per 1m^3 concrete required for beams and columns for all models which influenced by different soil type and reference peak ground acceleration, α_{gR}. This comparison had been normalized to the non-seismic model and it is to compare the increment of steel reinforcement due to seismic design consideration to non-seismic design. In Figure 4, with regardless soil type, 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 around 8% to 34% compared to non-seismic model. In other words, as the number of total weights of steel reinforcement increases, the cost of steel reinforcement also will increase. It significantly shows that models considering soil type B and E has the highest total weight of steel reinforcement compared to other soil types regardless the value of reference peak ground acceleration, α_{gR}. Therefore, the increment percentage of steel reinforcement also influenced by soil type [7, 8, 10 - 13]. As mentioned in previous subsection, model on soil type B and E has the highest magnitude of base shear force, F_b which then contributed to the highest magnitude of design bending moment, m shear force, v and axial load, P as well as highest amount of steel to be provided as reinforcement.

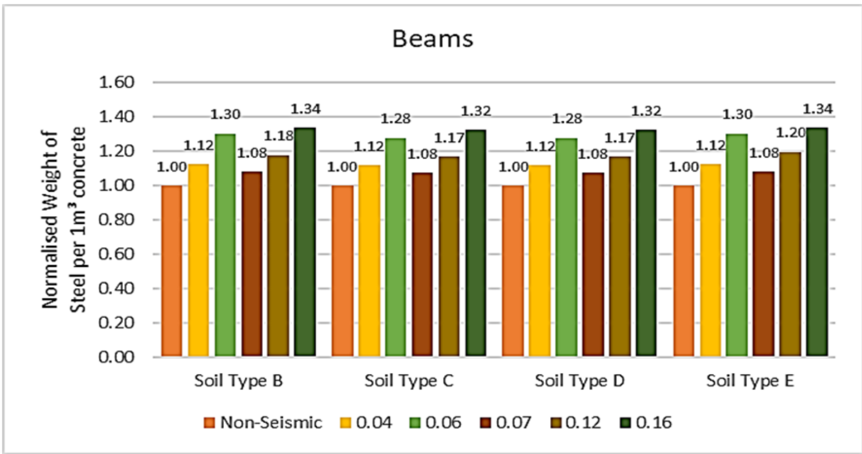

Figure 4. Normalized total weight of steel reinforcement per 1m^3 concrete for beams

In Figure 5 shows the comparison normalized total weight of steel reinforcement per $1m^3$ concrete for columns. The seismic design for column must approach the Strong Column – Weak Beam philosophy which means that columns shall be stronger at least 1.3 times than beams in order to resist the earthquake load, *E* [15]. Regardless the soil type, total weight of steel reinforcement per $1m^3$ concrete for columns with seismic design increases around 69% to 142% higher compared to the non-seismic model. This pattern is strongly influenced by the requirement of Strong Column – Weak Beam philosophy as mentioned before. Hence, regardless the soil type, the result shows pattern where model with low value of reference peak ground acceleration, α_{gR} = 0.06g with DCL and model with high value of reference peak ground acceleration α_{gR} = 0.16g with DCM shows highest amount of steel to be provided as reinforcement due to the highest magnitude of base shear force, F_b. Increasing of reference peak ground acceleration, α_{gR} result in higher percentage of increment [7, 11, 12, 13 & 18]. As discussed in previous subsection, model has the highest magnitude of base shear force, F_b were imposed to the highest lateral force result in highest magnitude of design bending moment, *m* shear force, *v* and axial load, *P*. Thus, it leads to highest amount of steel to be provided as reinforcement.

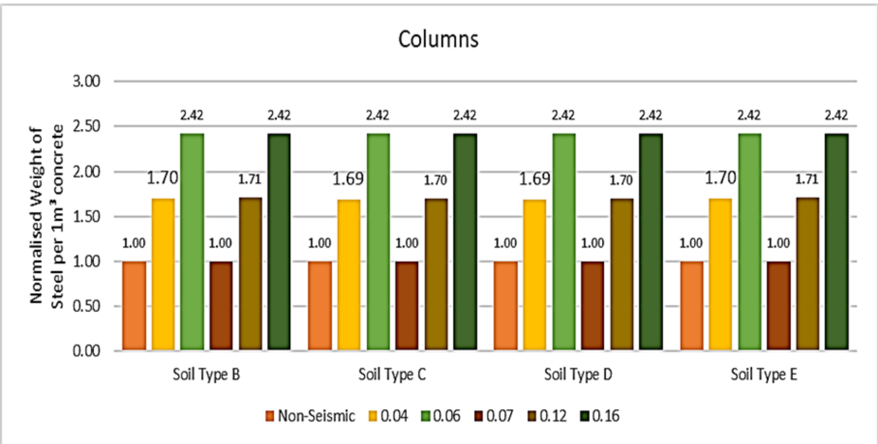

Figure 5. Normalized total weight of steel reinforcement per $1m^3$ concrete for columns

3.3. Cost estimation of structural works

In this subsection will be discussed about the normalized total cost of structural works (steel reinforcement, concrete, lean concrete and formwork) for all models as shown in Figure 6. All models have similar total cost of concrete, lean concrete and formwork RM 97,791.95, RM 7,162.94 and RM 113,217.88, respectively except for steel reinforcement. As referring to the results obtained, the cost of structural works increases with seismic design consideration around 1% to 12% which was influenced by the soil type and the value of reference peak ground acceleration, $\alpha_{gR.}$ As mentioned in previous subsection, both parameters strongly influencing the magnitude of base shear force, F_b. The increase of base shear force, F_b tends to increase the magnitude of design bending moment, *m* shear force, *v* and axial load, *P* which also increases proportionally the area of steel required, $As_{req.}$ As solution in this study, the higher number of steel bar is use in order to increase the area of steel provided, As_{prov}. In a conclusion, from results obtained in this study it is important to proper selection of site in order to prevent the over costing for future development planning when seismic design included.

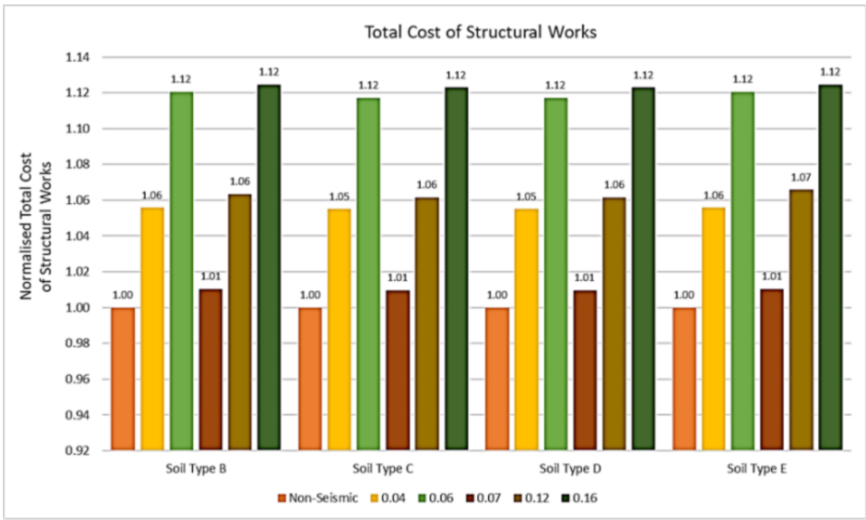

Figure 6. Normalized cost of concrete and steel reinforcement

4. Conclusion

This study investigates the influence of soil type and the value of reference peak ground acceleration, α_{gR} on total weight of steel reinforcement. For that purpose, a two storey of RC hostel building has been generated as model and a total of 21 models has been designed separately with different soil type and the value of reference peak ground acceleration, $\alpha_{gR.}$ Soil type B, C, D and E has been considered in design and the value of reference peak ground acceleration, $\alpha_{gR\,=}$ 0.04g, 0.06g, 0.07g, 0.12g & 0.16g to represent the seismicity in Sabah region. The conclusion has been drawn from this study:

- The soil type influencing the total weight of steel reinforcement. In this study, Soil Type B and Soil Type E required higher amount of steel reinforcement compared to other soil type regardless the value of reference peak ground acceleration, α_{gR}.
- Regardless the soil type, as the value of reference peak ground acceleration, α_{gR} increases, the weight of steel reinforcement also increasing around 8% to 34% and 69% to 142% for beams and columns, respectively compared to non-seismic model. The results show that, even building with similar structural configuration tends to have different amount of steel as reinforcement.
- By considering seismic design, total cost of structural works tends to increase around 1% to 12% which was influenced by the soil type and the value of reference peak ground acceleration, α_{gR}.

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