Increment of Steel Tonnage for Reinforced Concrete School Building Considering Seismic Design

H A Roslan, M I Adiyanto, S A H S Mustapa, T A Majid, N S H Harith

Abstract*: 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 damage on buildings either the structural or non-structural members. 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, current research work presents the influence of seismic design consideration on the increment of cost for steel reinforcement. For that purpose, a four storey reinforced concrete school building was generated and used as basic model for analysis, design, and taking off. Two level of seismicity representing by the reference peak ground acceleration, α_{gR} equal to 0.07g and 0.10g has been taken into account in the structural analysis and seismic design process. Besides, three soil type namely as soil type A, soil type C, and soil type E also has been considered as variable parameter. Based on result, total steel tonnage in beams for models considering seismic design increases around 14% to 119% higher than the model without seismic design. For columns, the increment is around 13% to 155%. Generally, total cost of steel used as for concrete reinforcement of the whole structure increases around 13% to 131% depending on the level of seismicity and soil type.

***Keywords* : Cost estimation; Eurocode 8; Seismic design; Steel tonnage.**

I. INTRODUCTION

Geographically, Malaysia is formed by two main land namely as Peninsular and East Malaysia. The Peninsular Malaysia is situated at the southern part of Asia continent. The East Malaysia is situated in Borneo Island. The East Malaysia consist of two large states namely as Sarawak and Sabah. 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, the nation is undergoing the 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 damage on buildings either the structural or non-structural members [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].

Positively, the 2015 Ranau earthquake is seen as one of strong reason to considering seismic design for construction industry 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].

A few research works had been conducted to determine the influence of seismic design to the cost increment of construction's materials. As an example, seismic design had been conducted with ductility class low on two storey reinforced concrete (RC) office building [10]. Authors concluded that the amount of steel reinforcement increase when seismic design consideration is taken into account. Based on seismic design on five and ten storey residential building, researchers concluded that the quantity of steel

Revised Manuscript Received on October 22, 2019.

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reinforcement had increased around 7% to 32.4% and 28% and 420.3% for beams and columns, respectively [11]. In other research work, it had been proven that the amount of steel reinforcement is highly affected by the value of reference peak ground acceleration, α_{gR} as well as the ductility class [12]. The work had been conducted on a six storey hospital building.

This research works discusses the influence of seismic design on the increment of cost for steel reinforcement. A four storey RC school building was generated and used as basic model for analysis, design, and taking off. School buildings was selected because the building is important in housing hundreds to thousands young generation during school session. It also important to act as community shelter during disaster. Therefore, school buildings must survive during earthquake. 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.

II. PROCEDURE FOR PAPER SUBMISSION

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 four storey RC school building was generated and used as basic model as presented by Fig. 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 0.60 sec. A total three sizes of beam has been considered which are 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 and 450 mm square.

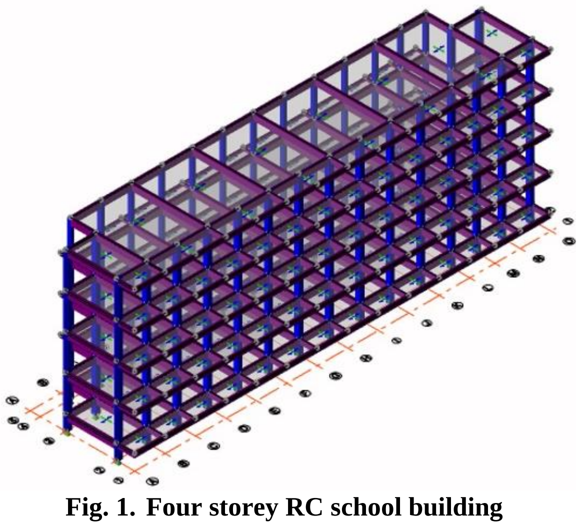


Fig. 1. Four storey RC school building

Stage 2 involving the structural analysis following by seismic design on the basic models. As recommended in [13], 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, $\gamma_I = 1.2$ in order to provide higher protection of life for such type of buildings [14]. 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 in [15].

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. Two level of seismicity has been considered which is equal to 0.07g and 0.10g to represent the seismicity in Lumut, and Semporna, respectively as in [16]. In addition, a total of three soil type has been considered namely as A, C, and E as proposed in [13]. In this study, seven models has been analysed and designed as shown in Table I. One model without seismic consideration has been taken into account for control and result normalisation purpose. All models were designed by considering 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 was conducted by using lateral force method by referring to [13].

Table- I: Design parameters for rc school models

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

III. RESULT AND DISCUSSION

A. Earthquake Load on Models

In this study, earthquake load, E acting on all models with seismic design was calculated by using the lateral force method. This method derives the total earthquake load, E which imposed laterally in form of base shear force, F_b. The latter is then being distributed on every storey as explained by [17]. The magnitude of the dead load, G_k and the imposed load, Q_k were similar to all models. By referring to [13], 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. 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 which has been developed for every level of seismicity and soil type. Besides, the effective mass of the building, m as well as the correction factor, λ are similar and fix for all models.

The magnitude of base shear force, F_b is presented in Table II which shows the magnitude of base shear force, F_b are differ for every models. The results clearly 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 depending on level of seismicity of a specific region. Results in Table 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 by different soil factor, *S* specified for every soil type as proposed by [13]. 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 II, 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- II: Earthquake load, *E* acting on all models

No	*Model Code*	*Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ (m/s²)*	*Base shear force, F_b (kN)*
1	NS	Non applicable	Non applicable
2	A–0.07	0.361	752.2
3	A–0.10	0.515	1074.6
4	C–0.07	0.607	1267.1
5	C–0.10	0.868	1810.1
6	E–0.07	0.631	1316.4
7	E–0.10	0.901	1880.6

B. 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.

C. Total Steel Tonnage

The steel tonnage representing the total amount of steel bar used as the flexural and the 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* [12]. The steel tonnage in 1m^3 concrete of beams for all models is shown in Fig. 2. The steel tonnage is normalised to the nonseismic model for comparison to the current practice which not considering seismic design. In Fig. 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 14% to 119%. The increment is higher for models considering higher value of reference peak ground acceleration, α_{gR}. This result mean regions with higher level of seismicity tend to demanding higher cost of steel reinforcement for beam. Previous study [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 the bending moment, *M* as well as the shear force, *V* which result in highest amount of steel to be provided as reinforcement.

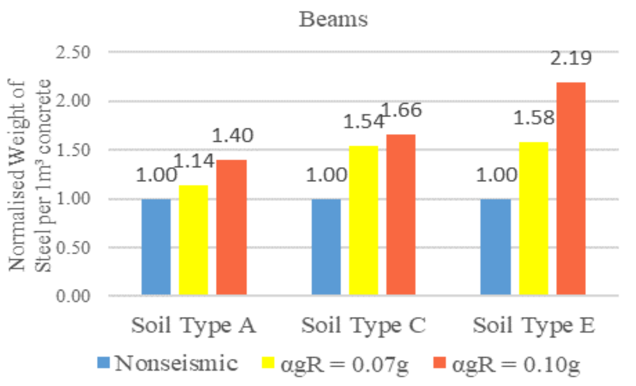
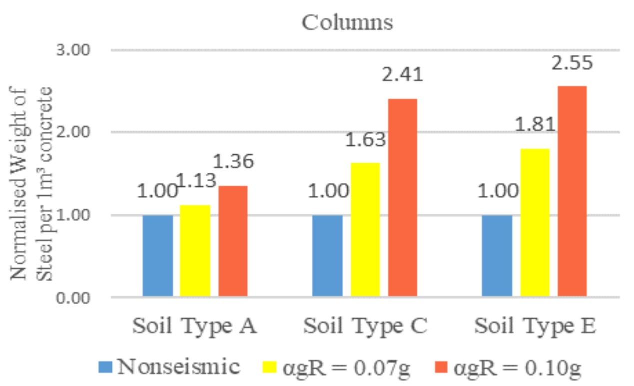


Fig. 2.Total steel tonnage for all beams

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 [13] the seismic design approach must include the Strong Column – Weak Beam philosophy which means that columns shall be stronger than beams. Fig. 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. In Fig. 3, the steel tonnage in columns for models with seismic design consideration increases around 13% to 155% higher compared to the control model without seismic design. This pattern is strongly influenced by the requirement of Strong Column – Weak Beam philosophy 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 proportionately to level of seismicity. The results from this study is in good agreement compared to previous study [12].



Total steel tonnage for all columns

D. Cost Estimation for Steel Reinforcement

The art of RC design requires structural engineers to smartly selecting the size of section, as well as the number and size of steel bar for its reinforcement. Larger size of section will reduce the number as well as the size of steel bar, vice versa. The structural engineers also has to follow the minimum and maximum percentage of area of steel reinforcement per area of concrete section. For a typical building like school, standard size of section are preferred in order to maintain the aesthetic value of the building. Hence, the amount of steel reinforcement will be differ for every seismic level. Therefore, it is interesting to investigate the influence of seismic design on steel tonnage because it will determine the cost of material for beams and columns. The result will be useful for future development planning. The normalised total cost of steel reinforcement for beams and columns of all models is shown in Fig. 4. As referring to the results obtained for beams and columns, the cost of steel reinforcement increases by implementation of seismic design. For models on soil type A, the cost of steel reinforcement increases up to 38%. The cost increment lies in range of 57% to 92% and 66% to 131% for models on soil type C and soil type E, respectively.

Generally, the cost for steel reinforcement increases around 13% to 131% depend on the level of seismicity and soil type. As discussed 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 bending moment, M which also directly increases the area of steel required, As_{req}. As solution, the structural engineers has to use combination of larger size and/or higher number of steel bar in order to increase the area of steel provided, As_{prov}. This means higher steel tonnage has to be used as reinforcement. Result from this study indicates that the level of seismicity and soil type strongly influencing the cost of steel reinforcement. Therefore, proper selection of site for development is important in order to reduce the cost of steel reinforcement.

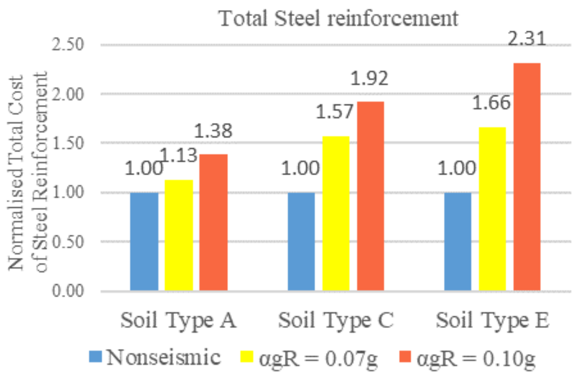


Fig. 3. Normalized cost of steel reinforcement

IV. CONCLUSION

The increment of steel tonnage due to seismic design consideration has been investigated in this study. For that purpose, a four storey RC school building was generated and used 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 14% to 119% higher compared to nonseismic design. For columns, the increment is in range from 13% 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 13% to 131% depend on level of seismicity and soil type.

Current research works is improved by ongoing analysis and design considering various number of storey, function of buildings, soil type, level of seismicity, and concrete grade.

ACKNOWLEDGMENT

All authors acknowledged the financial support from Internal Research Grant number RDU1703240 (June 2017 – June 2019) provided by Universiti Malaysia Pahang as well as facilities provided in design laboratory. Special thanks is dedicated to Azlina Nordin, Ummu Nurulatiqah Kamis, Anis Farhana Mazlan, Nur Hazwani Mohd Rashid, and Nur Izzati Aliah Azman for their effort as research assistants.

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