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COST EVALUATION OF RC SCHOOL BUILDING CONSIDERING SEISMIC DESIGN BASED ON MALAYSIA NATIONAL ANNEX TO EC8

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Abstract

Within fifteen years since the 2004 Acheh Earthquake, the number of tremors which had been felt on Malaysian ground is keep rising. This is due to tremors either originated from Indonesian earthquakes, or local earthquakes in Bukit Tinggi and Sabah. Since 2005 to 2013, a series of Indonesian earthquakes, especially from Sumatra Island had 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. The event had caused a lot of damages on both structural and non-structural elements of buildings especially in Ranau and Kundasang. For the sake of public safety, it is important to consider seismic design for new buildings in Malaysian regions. However, such action has its own pro and contra especially when dealing with cost. Therefore, this paper presents an evaluation study regarding the increment of cost if seismic load is taken into account in design of a new reinforced concrete school building. In this study, a four-story reinforced concrete school building has been used as basic model. A total of 13 models had been designed based on two variables namely as reference peak ground acceleration, α_{gR} and soil type. The reference peak ground acceleration, α_{gR} in range of 0.07g to 0.16g which representing seismic intensity in Sabah state in Malaysian regions had been considered in the structural analysis and seismic design process. Regarding the site condition, four soil type namely as soil type B, soil type C, soil type D, and soil type E had been taken into account. Ductility class medium had been utilized in seismic design. The design of all models had been conducted based on Eurocode 8 and referring to Malaysia National Annex to Eurocode 8 which had been officially launched in December 2017. Based on Malaysia National Annex to Eurocode 8, the value of Soil Factor, *S* in Malaysian soil are differ compared to standard value proposed by Eurocode 8. Based on result of taking off and cost evaluation, the total weight of steel in beams for models considering seismic design increases around 13% to 85% higher compared to model without seismic design. For columns, the increment is around 1% to 116%. Generally, by considering the cumulative price of steel reinforcement, concrete, and formwork the cost of a new four-story reinforced concrete school building with seismic design in Malaysia is increases around 2% to 19%. The percentage of increment depends on the seismic intensity and soil type. Hence, it is worth for Malaysia to fully implement seismic design for the sake of public safety and preventing greater loss.

Keywords: Eurocode 8, Seismic Design, Cost Evaluation, Malaysia National Annex, Ductility Class Medium

1. Introduction

Geographically, Malaysia is surrounded by archipelago of Indonesia and Philippine. The former is formed based on two part namely as Peninsular Malaysia which is connected to the main land of Asia continent, and another part known as East Malaysia located in Borneo Island. Malaysia is situated relatively far away from the Pacific-Ring of Fire Region, a highly active seismic region in South East Asia which strongly affecting Indonesia and Philippine as shown in Fig.1. Therefore, Malaysia was classified to have low seismicity profile [2]. However, for the past 16 years since December 2004, the number of tremors caused by earthquakes are keep rising and can be felt on Malaysian soil. This is due to tremors either originated from Indonesian earthquakes, or local earthquakes in Bukit Tinggi and Sabah. In Peninsular Malaysia, local earthquakes were originated from Jerantut, Manjung, Janda Baik, and Bukit Tinggi. 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, some regions set at risk of earthquake namely as Tawau, Pitas, Lahad Datu, Ranau, and Kundasang. A technical observation reported that large increment of earthquake events has been recorded in Sabah for the last 140 years ago [4].

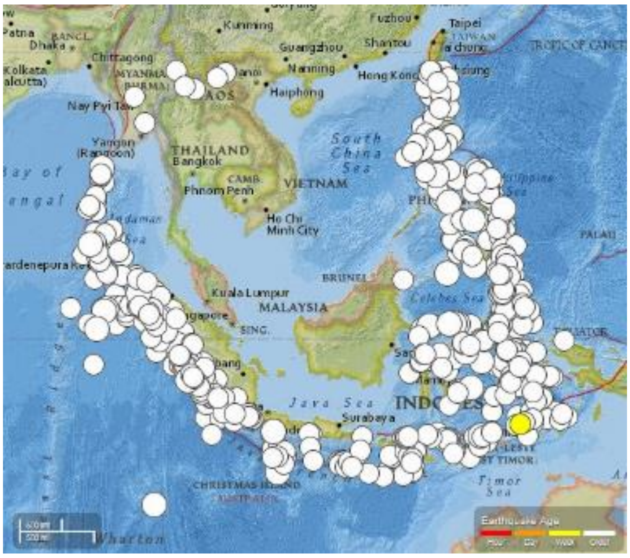


Fig. 1 – Active seismic regions in South East Asia [1]

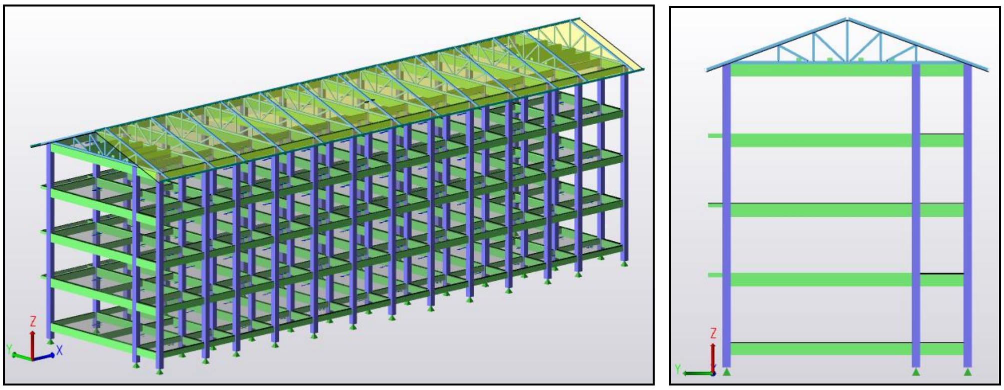
On 5th June 2015, a memorable earthquake of the nation occurred in Ranau, Sabah with magnitude M_w6.1. The epicentre was located around 16 km to the northwest of Ranau city. The 2015 event was the strongest earthquake recorded in Malaysia since 1976 in Lahad Datu with M_w5.8. Based on preliminary insitu observatiion during a reconnaisance study which conducted just a few days after the event, it had been reported that the 2015 Ranau earthquake caused a lot of damages to reinforced concrete (RC) buildings. The damages had been clearly observed on beams, column, and beam-column joints which is strongly related to efftect of Weak Column – Strong Beam design of nonseismic building [5,6]. İn addition, the damages also reported on nonstructural elements including brickwall and ceiling [7]. By refering to more detail study, the highest damage recorded on brickwall with X-mark associated with shear failure [8].

After experienced several tremors especially the 2004 Acheh and 2015 Ranau earthquakes, the awareness for importance of seismic design consideration for new development is now arising. For decades, the design of RC buildings in Malaysia only referred to BS8110 which not comply for seismic provision [9]. Therefore, the RC buildings were highly exposed to severe damage when subjected to earthquake as reported in Ranau. Based on previous structural analysis and evaluation, the vibration during earthquake may cause concrete deterioration on at least 50% of selected buildings in Malaysia [10]. In addition, the vertical element design provision were reported as inadequate to deal which earthquake load. Therefore, seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage of buildings [11]. One of the initiative taken by the government toward the implementation of seismic design is to introduce Malaysia National Annex to Eurocode 8 [12] in 2017. This National Annex gives seismic parameters which compatible with Malaysia such as the seismic hazard map with value of reference peak ground acceleration, α_{gR} and the soil factor, S for every region in Malaysia.

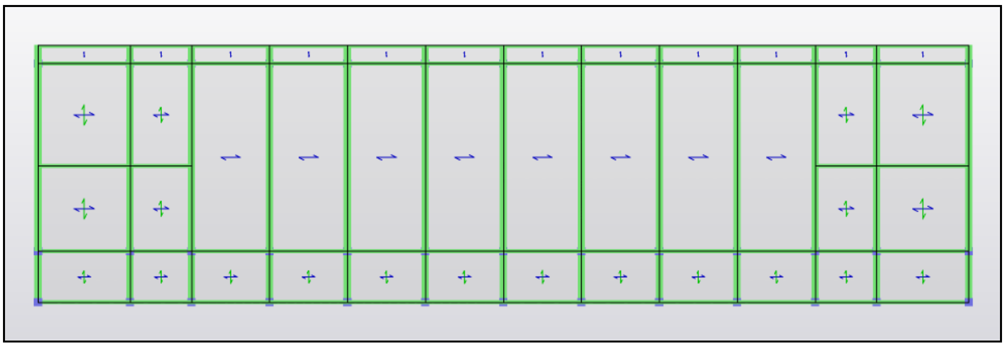
The effect of seismic design consideration on initial construction cost also has to be taken into account. A few study had been conducted in order to investigate the effect of seismic design on the usage of construction materials for RC buildings. Past studies [13,14] had concluded that seismic design strongly influencing the usage of steel as reinforcement which result in higher cost. Two design parameters namely as seismic intensity and soil type are strongly influencing the usage of steel for reinforcement [15-19]. Besides, concrete grade and ductility class also influencing the usage of steel as reinforcement [18,19]. However, all past studies direcly referred to Eurocode 8 [20] for value of soil factor, S. As mentioned in previous paragraph, every region in Malaysia has different value of soil factor, S to be considered in design. Therefore, in order to give more precise result which relevant to soil condition in Malaysia, current research work are refering to Malaysia National Annex to Eurocode 8 [12].

2. Model and Methodology

Three stages had been conducted in this study. Stage one is known as generate basic model. Then, stage two is the structural analysis & seismic design on basic model based on two different variables namely as seismic intensity and soil type. Finally, stage three was the taking off process on all models. In stage one, a four storey RC school building was generated to be the basic model as presented by Fig.2.



(a) 3D view (b) Elevation view



(c) Plan view

Fig. 2 – Four storey RC school model

The longitudinal dimension along x-direction of the building is equal to 45.48m while the transverse dimension along y-direction is equal to 11.65m. The floor to floor height is equal to 3.35m for every storey. The fundamental period of vibration, T_1 for the basic model is estimated based on Eq. (1) as proposed by Eurocode 8 [20].

$$T_1 = C_t . H^{3/4} \tag{1}$$

where H is the height of the building measured from the foundation which is equal to 14.6m. C_t is equal to 0.075 as a coefficient for moment resistant space concrete frame [20]. Hence, the fundamental period of vibration, T_1 is equal to 0.56 sec. The function of the building is as school which has a set of classroom, toilet, corridor, and staircase. The size of beams is varying from 200mm x 400mm, 200mm x 500mm, 300mm x 600mm, and 350mm x 650mm which depend on the position and span. All 39 columns are 400mm square in size from top of foundation until the roof beam level.

The structural analysis and seismic design had been conducted in stage two. Since the building is function as school, the building is categorized as importance class III and the value of importance factor, γ_I is equal to 1.2 [12,20]. The imposed load, Q_k acting vertically on slab area for classroom, toilet, corridor, and staircase are equal to 3kN/m^2, 2kN/m^2, 4kN/m^2, and 3kN/m^2, respectively [21]. Initially, the basic model had been designed for gravity load only by referring to Eurocode 2 [22] without any seismic consideration. This nonseismic design model had been used as control for comparison and discussion.

The basic model had been designed repeatedly by considering seismic action based on different variable namely as seismic intensity and soil type as shown in Table 1. This study focused on Sabah state which located in East Malaysia. Based on Malaysian seismic hazard map [12], the seismic intensity for that region lies in range of 0.02g to 0.16g as shown in Fig.3. This study only focused on ductility class medium. Therefore, the level of seismic intensity was represented by value of reference peak ground acceleration, α_{gR} which was equal to 0.07g, 0.12g, and 0.16g. A total of four soil types namely as Soil Type B, C, D, and E as compatible with Malaysian condition [12] had been taken into account. A total of 13 models had been analyzed and designed including the basic model. For ductility class medium, the value of behavior factor, q was equal to 3.9 for all models with seismic design consideration.

Table 1 – Models and design variables

Model Number	**Design Consideration**	**Reference peak ground acceleration, α_{gR} (g)**	**Ductility Class**	**Soil Type**
1	Gravity load only	Non applicable	Non applicable	Non applicable
2	Gravity + Seismic load	0.07	Medium	B
3	Gravity + Seismic load	0.07	Medium	C
4	Gravity + Seismic load	0.07	Medium	D
5	Gravity + Seismic load	0.07	Medium	E
6	Gravity + Seismic load	0.12	Medium	B
7	Gravity + Seismic load	0.12	Medium	C
8	Gravity + Seismic load	0.12	Medium	D
9	Gravity + Seismic load	0.12	Medium	E
10	Gravity + Seismic load	0.16	Medium	B
11	Gravity + Seismic load	0.16	Medium	C
12	Gravity + Seismic load	0.16	Medium	D
13	Gravity + Seismic load	0.16	Medium	E

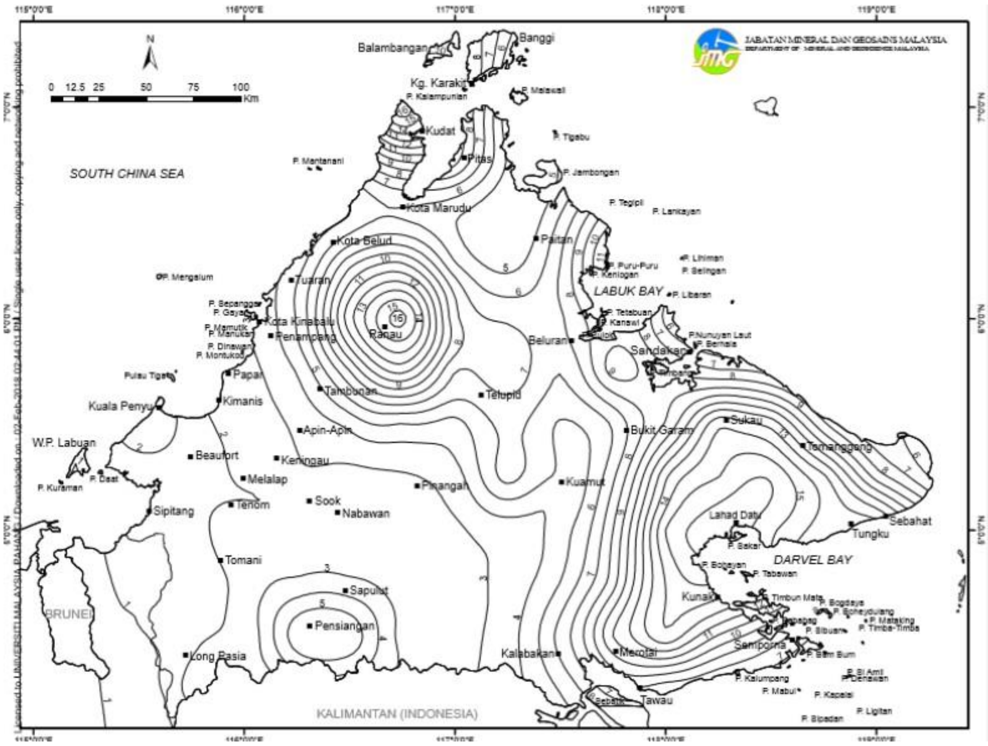


Fig. 3 – Seismic Hazard map for Sabah, Malaysia [12]

The structural analysis on models numbering 2 to 13 which considering seismic design had been conducted by using Lateral Force Method as proposed by Eurocode 8 [20]. This method is applicable because the model fulfilled the condition of regularity in plan and elevation. Based on this method, the earthquake load had been imposed as lateral loads acting on every story which was determined from the base shear force, F_b. By referring to Eurocode 8 [20] 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 as shown in Eq. (2). In this study, all models have similar effective mass of the building, m which is estimated around 2441 tonne. The correction factor, $\lambda = 0.85$ was applicable to all models with seismic design.

$$F_b = S_d(T_1).m.\lambda \tag{2}$$

The load combination is shown in Eq. (3) as proposed by Eurocode [23].

$$E_d = \sum G_{kj} + A_{Ed} + \sum \Psi_{2i} Q_{ki} \tag{3}$$

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 story joints, and $\Psi_{2i}Q_{ki}$ is the reduced variable load. All models were designed by considering concrete grade C30/37 and yield strength of steel, $f_y = 500$ N/mm^2.

The taking off process took part in final stage. In this stage, the total concrete volume and total steel used for reinforcement in weight were measured for all beams and columns. The comparison had been made based on normalized weight of steel reinforcement. Final cost evaluation on structural works is presented in form of total price of materials namely as cost of concrete, cost of steel, and cost of formwork.

3. Result and discussion

3.1 Base shear force, F_b

As mentioned in previous section, the action of earthquake load on model number 2 to 13 was imposed as lateral loads acting on every story. The latter was derived from the base shear force, F_b. As shown in Eq. (2), 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. Table 2 presents the magnitude of base shear force, F_b for every model with seismic design.

Table 2 – Base shear force, F_b imposed on all models

Model Number	Reference peak ground acceleration, α_{gR} (g)	Soil Type	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ (m/s^2)	Base Shear Force, F_b (kN)
1	Non applicable	Non applicable	Non applicable	Non applicable
2	0.07	B	0.528	1095.22
3	0.07	C	0.713	1479.02
4	0.07	D	0.713	1479.02
5	0.07	E	0.660	1369.02
6	0.12	B	0.905	1877.52
7	0.12	C	1.222	2535.46
8	0.12	D	1.222	2535.46
9	0.12	E	1.131	2346.90
10	0.16	B	1.207	2503.36
11	0.16	C	1.629	3380.61
12	0.16	D	1.629	3380.61
13	0.16	E	1.508	3129.20

As mentioned in previous section, effective mass of the building, m and correction factor, λ were fixed for all models. Hence, the magnitude of base shear force, F_b was differentiated 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 seismic intensity and soil type. As shown in Table 2, the magnitude of base shear force, F_b increases as the level of seismicity increases. This result is in good agreement with previous studies [16,17,19]. In Table 2, the magnitude of base shear force, F_b increased up to 3380.61 kN for models' number 11 and 12 which imposed to reference peak ground acceleration, α_{gR} = 0.16g. Higher level of seismic intensity tend to imposed higher magnitude of lateral force on building as explained in previous study [19]. This means that both models had been imposed to the highest lateral force.

Generally, models on different soil type tend to be imposed to different magnitude of base shear force, F_b as concluded by previous studies [15,18] which directly adopted the value of soil factor, S as proposed by Eurocode 8 [20]. However, in this study the models on soil type C and soil type D had been imposed to similar magnitude of base shear force, F_b. As an example, model number 2 and 3 had been imposed to similar magnitude of base shear force, F_b which is equal to 1479.02 kN. This result is caused by similar soil factor, S for both soil type C and soil type D which is equal to 1.35 [12].

3.2 Influence of seismic design on steel reinforcement

Due to uniqueness of every single project such as function, layout, and special requirements it is hard to determine the cost increment caused by seismic design consideration [24]. However, it is worth to study the effect of seismic design on costing to give clear picture to every stakeholder in construction industry for better planning and management [15]. Total weight of steel reinforcement is defined as the summation of steel bar used as the flexural and shear reinforcement for all RC beams and RC columns as presented in previous studies [14-19]. Total weight of steel reinforcement for every model with seismic design is normalized to the total weight of steel reinforcement used for model number 1 which is the nonseismic model. This is to compare the increment of steel reinforcement due to seismic design consideration to current practice which neglecting seismic design. Fig.4 presents the normalized total weight of steel reinforcement for all beams considering all seismicity level and soil types.

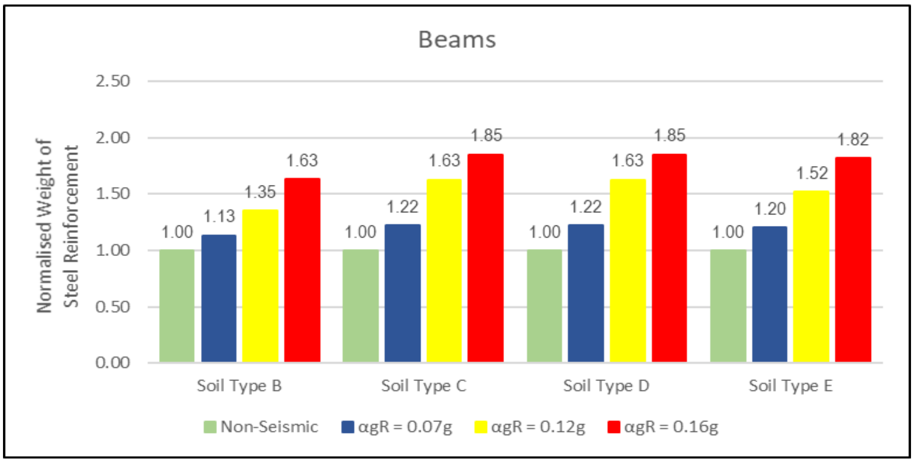


Fig. 4 – Normalised total weight of steel reinforcement for beams

In Fig. 4, it is clear that the seismic design consideration required increment to the total usage of steel reinforcement for beams. Regardless the soil type, the total weight of steel reinforcement increases as the value of reference peak ground acceleration, α_{gR} increases. The increment is in range of 13% to 85% higher than beams for model without seismic design consideration. This result is in similar pattern to previous study [16,17]. According to Fig.4, the highest total weight of steel reinforcement belongs to models considering reference peak ground acceleration, α_{gR} = 0.16 on soil type C and soil type D. As discussed before, both models have the highest magnitude of base shear force, F_b. Therefore, is it clear that both models have the highest magnitude of design bending moment, M_{Ed} which finally result in highest amount of steel reinforcement.

Soil type also influencing the total weight of steel reinforcement. As shown in Fig.4, for fixed seismic intensity, the total weight of steel reinforcement is differing for every model. Results in this study is in good agreement with previous finding [15] which concluded that the cost of steel reinforcement for a similar building layout and configuration will be differ due to different soil type. In this study, models on soil type C and soil type D always have similar total weight of steel reinforcement for similar value of reference peak ground acceleration, α_{gR}. This result is associated with value of soil factor, S as discussed in previous subsection.

The stability of structural system is strongly depending on columns [17]. The latter will vibrate back and forth during earthquake events. Therefore, special attention has to be given on column design. In order to perform better during earthquake, the seismic design must adopt the Strong Column – Weak Beam philosophy [20]. According to the latter, a column must be designed stronger than its beam. Fig.5 presents the normalized total weight of steel reinforcement for columns. It is clear that models with seismic design consideration have higher total weight of steel reinforcement.

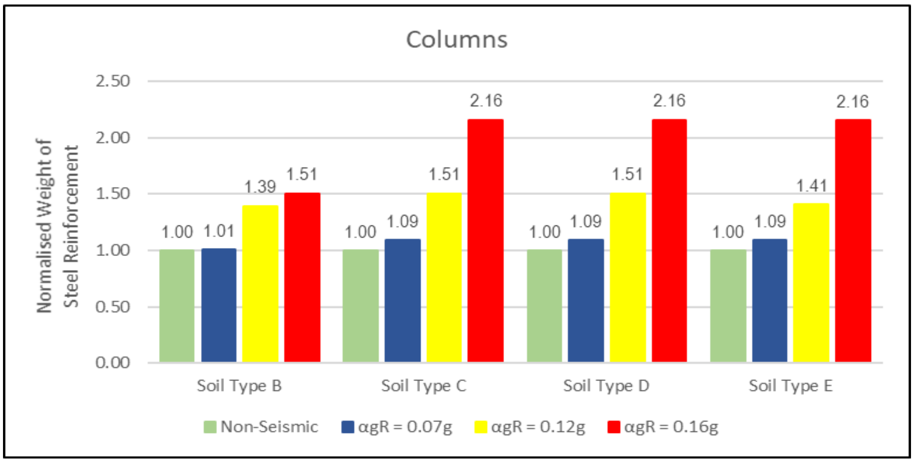


Fig. 5 – Normalised total weight of steel reinforcement for columns

In Fig. 5, the total weight of steel reinforcement for column increases around 1% to 116% higher compared to the nonseismic model regardless the soil type. The increment is significant especially for models considering higher value of reference peak ground acceleration, α_{gR}. The result following similar pattern with beams where the total weight of steel reinforcement increases as the level of seismicity increases. This result shows that the Strong Column – Weak Beam philosophy had been fully implemented where the design bending moment, M_{Ed} of a column had been derived based on the resistance bending moment, M_R of its beam. The amount of steel reinforcement in column is proportional to the amount of steel reinforcement in beam attached to it. For simple explanation, higher amount of steel reinforcement in beam will result in higher amount of steel reinforcement in column which supporting the beam, vice versa. This result is in good agreement with previous findings [14-19]. In addition, the ductility class medium limits the spacing of shear reinforcement, s in column's critical region which shall not exceed 175 mm [20]. This limitation result in the increasing of the usage of steel reinforcement [16].

3.3 Cost evaluation of structural works

In order to get clearer picture about the effect of seismic design on construction industry, the evaluation and comparison shall be made based on the total cost of structural works. The latter is divided to cost of concrete, formwork, and steel reinforcement. The cost had been estimated based on the standard schedule of rates [25] provided by Malaysian Department of Works. In this study, the size of section of all beams and columns are similar for every model regardless the value of reference peak ground acceleration, α_{gR} and soil type. Therefore, the amount of materials for concrete, lean concrete, formwork, and steel reinforcement for slabs were similar for every model as shown in Table 3. As an example, the concrete volume for every model was estimated to be similar which is around 625.721m^3 covering beams, columns, and slabs. Hence, the estimated cost of concrete for every model is around RM230982.95.

Table 4 presents the cost estimation for every model considering steel reinforcement in beams and columns. The latter strongly contributed to the difference of total estimated cost. The total estimated cost for structural works is around RM801,483.57 to RM956,165.72. The lowest cost belongs to model number which only consider gravity load. It is clear that seismic design consideration caused increment on the total cost of structural works. For a better comparison and evaluation, the total estimated cost for every model are normalized to the total estimated cost for model number 1 as shown in Fig.6. This is important in order to present the increment of total cost of structural works caused by seismic design. Based on Fig.6 the increment of total cost of structural works is in range of 2% to 19% depending on the level of seismicity and soil type. The increment is only considering the total cost of structural works. If the total cost of architectural works is taken into account alongside with the mechanical and electrical works, it is believed that the increment of total cost shall be lower than the aforementioned value above.

Table 3 – Estimated cost of similar materials for every model

Item	Materials	Amount	Unit	Estimated cost (RM)
1	Concrete grade C30/37 (beams, columns, slabs)	625.721	m^3	230,982.95
2	Lean concrete (ground beams and ground slabs)	27.216	m^3	7,781.05
3	Sawn formwork	4567.538	m^2	271,158.88
4	Slab reinforcement (BRC)	5571.977	m^2	131,122.92
5	Slab reinforcement (Steel bar)	353.911	kg	1,238.69
Grand Total				642,284.49

Table 4 – Total estimated cost considering steel reinforcement in beams and columns

Model Number	Total weight of steel reinforcement in beams and columns (kg)	Estimated cost of steel reinforcement (RM)	Estimated cost of similar materials (RM)	Total estimated cost (RM)
1	45,485.45	159,199.08	642,284.49	801,483.57
2	49,317.68	172,611.88	642,284.49	814,896.37
3	53,266.70	186,433.45	642,284.49	828,717.94
4	53,266.70	186,433.45	642,284.49	828,717.94
5	52,802.51	184,808.79	642,284.49	827,093.28
6	62,174.79	217,611.77	642,284.49	859,896.26
7	71,831.43	251,410.01	642,284.49	893,694.50
8	71,831.43	251,410.01	642,284.49	893,694.50
9	67,233.77	235,318.20	642,284.49	877,602.69
10	71,947.49	251,816.22	642,284.49	894,100.71
11	89,680.35	313,881.23	642,284.49	956,165.72
12	89,680.35	313,881.23	642,284.49	956,165.72
13	88,594.16	310,079.56	642,284.49	952,364.05

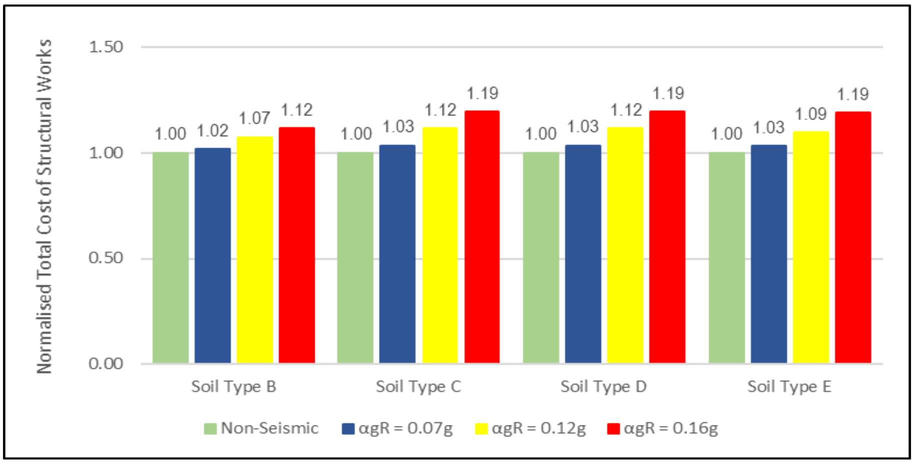


Fig. 6 – Normalised total cost of structural works

4. Conclusions

This study evaluated the effect of seismic design on the increment of total cost of structural works. A four-story RC school building was generated and used as basic model. This study focused on Sabah state which is located in East part of Malaysia. 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 was equal to 0.07g, 0.12g, and 0.16g by referring to the seismic hazard map of Sabah [12]. A total of four soil type namely as soil type B, soil type C, soil type D, and soil type E had been taken into account to represent variability of site condition in Sabah. The value of soil factor, *S* was directly referred to the proposed value by Malaysia National Annex to Eurocode 8 [12]. A few conclusions are drawn as follow:

- The total weight of steel reinforcement increases as the seismic intensity increases regardless the soil type. For beams, the increment is in range from 13% to 85% higher compared to nonseismic design. For columns, the increment is in range from 1% to 116%.

- Soil type also influencing the total weight of steel reinforcement. Although imposed on similar seismic intensity, a similar building could have different total weight of steel reinforcement. This result is strongly associated with the soil factor, *S* which is differ for every soil type. Therefore, the site selection also important in order to reduce the cost.

- By considering seismic design, the total cost of structural works increased around 2% to 19%. The increment is depending on the seismic intensity and soil type. However, the increment is only considering the total cost of structural works. If the total cost of architectural works is taken into account alongside with the mechanical and electrical works, it is believed that the increment of total cost shall be lower than the aforementioned value above.

Hence, it is worth for Malaysia to fully implement seismic design since it will give better protection on buildings against the earthquake. The safety of public citizen could be increased and repairing cost in future could be minimized.

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