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Cost Estimation of Structural Work for Residential Building with Seismic Design Consideration

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Abstract: The Sumatra-Andaman earthquakes had triggered local earthquakes in Malaysia by reactivation of ancient inactive faults. Previously on 5th June 2015, Ranau, a region located in Sabah, Malaysia, had experienced a moderate earthquake of M_w6.1. The structural failures occurred because all existing buildings only designed for gravity load without any seismic provision. Recent research work exhibits the seismic designs' impact on the cost of material and its parameters that impact the cost. There are two types reinforced concrete residential buildings called Type 1 and Type 2 for two storey and four storey which had been used as models. This research applied four seismicity levels to the reference peak ground acceleration value, α_{gR} = 0.07g, 0.10g, 0.13g & 0.16g, and two soil types: Soil Types B and D. The result shows that for two storey reinforced concrete residential buildings on soil types B and D, seismic design increases structural work costs, which is around 0.62% to 1.31% and 0.61% to 2.16%, respectively, for Type 1 model compared to non-seismic design. Besides, model Type 2, the increment is around 0.24% to 1.22% and 0.20% to 1.71%, respectively. Otherwise, for reinforced concrete residential building with four storey on soil types B and D, the result shows that seismic design tends to have a higher structural work's cost around 0.41% to 2.48% and 0.98% to 11.23%, respectively, for Type 1 model. Besides, for model Type 2 the increment is around 1.80% to 2.05% and 2.34% to 8.53%, respectively, compared to non-seismic design.

Keywords: Cost estimation, Eurocode 8, National Annex, seismic design, structural work

1. Introduction

Malaysia has no exemption in encountering earthquakes because it is surrounded by high seismic countries, Indonesia and the Philippines. Acheh earthquake in 2004 is approved that Malaysia also affected by the tragedy of neighboring country. The event triggered a tsunami causing deaths and injuries. The tremors also had been felt in western part of Peninsular Malaysia.

Malaysia, except for Sabah, is considered a low seismicity region. On 5th June 2015, On 5th June 2015, a magnitude 6.1 earthquake occurred in Ranau causing structural and non-structural parts of several structures to be damaged [1-3]. The most damage observed was the X-mark crack on the brickwall because of the shear failure [4]. Despite the Ranau earthquake only being classified as a moderate earthquake, more than 100 aftershocks caused 61 damaged structures, including hospitals, mosques, and schools, and resulted in 18 fatalities [5]. Does not considering seismic design in past construction practice in Malaysia had contributed to the results.

A seismic hazard in Malaysia with low to moderate levels cannot be taken lightly. Hence, especially in Sabah, the seismic design consideration shall be applied for new buildings to reduce the damages and fatalities in the future [6].

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The seismic consideration in design leads to a higher amount of steel as a reinforcement, and the cost will be higher. Nevertheless, costs for maintenance and repairs can be reduced by implementing seismic design [7].

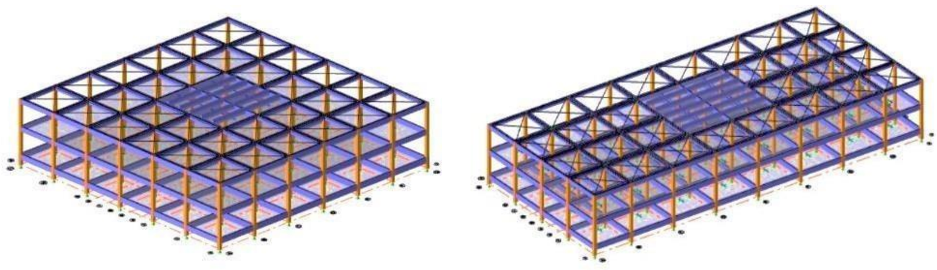
The seismic design provisions with different parameters cause the cost of construction materials will increase proportionately due to the increase in steel reinforcement [7] - [16]. However, the results from previous research works had been obtained by lateral force analysis except by [7], [10]. This research aimed to investigate the impact of reference peak ground acceleration, α_{gR}, and soil types on the seismic design of reinforced concrete (RC) residential buildings based on response spectrum analysis method. This research estimates each model's structural work cost and steel reinforcement increment, as shown by previous studies [13], [14]. This study will be necessary for construction industry stakeholders in order to estimate the percentage of increment to the cost of structural works for new buildings while considering seismic design.

2. Methodology

The research was separated into three stages: (i) model generation, (ii) structural analysis and seismic designs, and (iii) take-off. For Phase 1, Tekla Structural Designer 2021 was used to generate models of two-storey and four-storey RC structures for Type 1 and Type 2, as shown in Fig. 1 and Fig. 2, respectively. The stump to ground floor and floor to floor heights were 1.2m and 3.0m, respectively. Table 1 summarizes the cross-section size of columns and beams.

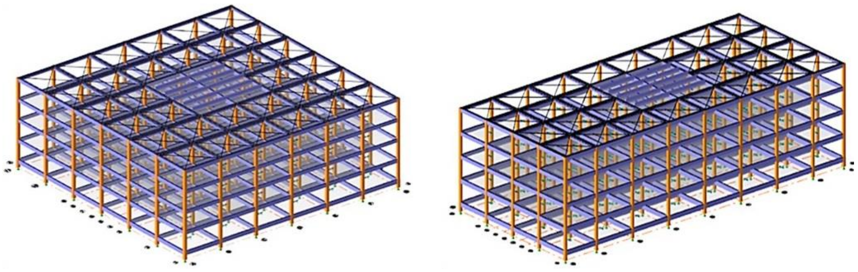
Phase 2 involves the process of structural analysis and seismic design. According to Eurocode 1 [17], both types of models were classified as Category A because the generated models were under residential areas. The imposed loads on the floor, balconies, stairs and roof were $q_k = 2.0\text{kN/m}^2$, 4.0kN/m^2, 4.0kN/m^2 and 0.5kN/m^2, respectively. According to Eurocode 8 [18], the importance factor, $\gamma_I = 1.2$ since it was considered Importance class III [18]. The proposed value is for protecting and ensuring public safety following an earthquake. This research examines the impact of seismicity and soil types on the total amount of material used in seismic design. The reference peak ground acceleration values, α_{gR} = 0.07g, 0.10g, 0.13g and 0.16g were displayed as the four levels of seismicity. The considered soil types for this research were soil types B and D. These considered values represent the seismicity level in Sabah based on National Annex [19].

The Ductility Class Medium (DCM) classification was applied to all 36 seismic models. As a result, the behavior factor, q, was assigned a value of 3.9. In addition, the non-seismic model of two storey and four storey of RC residential building has been designed and analyzed according to Eurocode 2 [20] without considering any seismic provisions for both types of models. Table 2 lists all the models considered for this study and their seismic design considerations. All models use 30 N/mm^2 for the concrete compressive strength, f_{ck}, while for the steel yield strength, f_{yk}, is 500 N/mm^2. The response spectrum method was used in the seismic design. The fundamental period of vibration, T_1, for two storey and four storey buildings was determined from the modal analysis to be roughly 0.50 sec and 1.00 sec, respectively.



(a) (b)

Fig. 1 - Two-storey RC residential building in 3D view; (a) Type 1; (b) Type 2



(a) (b)

Fig. 2 - Four-storey RC residential building in 3D view; (a) Type 1; (b) Type 2

Table 1 - Residential building's cross section for the beam and column

No. of storey	Member	Type of RC residential building	Level	Dimension (mm)
Two storey	Beam	Type 1	Ground Floor	300x600
			1st	250x525
			Roof Floor	250x500
	Beam	Type 2	Ground Floor	275x600
			1st	275x600
			Roof Floor	250x500
	Column	Type 1 and Type 2	Stump to Ground Floor	425x425
			Ground Floor to Roof Floor	400x400
Four storey	Beam	Type 1	Ground Floor	250x600
			1st	250x525
			2nd	250x500
			3rd	250x500
			Roof Floor	250x500
	Beam	Type 2	Ground Floor	275x600
			1st	275x600
			2nd	275x500
			3rd	275x500
			Roof Floor	250x500
	Column	Type 1 and Type 2	Stump to Ground Floor	425x425
			Ground Floor to Roof Floor	400x400

Table 2 - For Type 1 and Type 2 RC residential buildings, all models have distinct variables

No.	Type of RC residential building	Model	PGA (g)	Soil Type
A-1	Type 1	N2T1_NS	NA	NA
A-2		N2T1_0.07B	0.07	B
A-3		N2T1_0.10B	0.10	B
A-4		N2T1_0.13B	0.13	B
A-5		N2T1_0.16B	0.16	B
A-6		N2T1_0.07D	0.07	D
A-7		N2T1_0.10D	0.10	D
A-8		N2T1_0.13D	0.13	D
A-9		N2T1_0.16D	0.16	D
A-10	Type 2	N2T2_NS	NA	NA
A-11		N2T2_0.07B	0.07	B
A-12		N2T2_0.10B	0.10	B
A-13		N2T2_0.13B	0.13	B
A-14		N2T2_0.16B	0.16	B
A-15		N2T2_0.07D	0.07	D
A-16		N2T2_0.10D	0.10	D
A-17		N2T2_0.13D	0.13	D
A-18		N2T2_0.16D	0.16	D
B-1	Type 1	N4T1_NS	NA	NA
B-2		N4T1_0.07B	0.07	B
B-3		N4T1_0.10B	0.10	B
B-4		N4T1_0.13B	0.13	B
B-5		N4T1_0.16B	0.16	B
B-6		N4T1_0.07D	0.07	D
B-7		N4T1_0.10D	0.10	D
B-8		N4T1_0.13D	0.13	D
B-9		N4T1_0.16D	0.16	D
B-10		N4T2_NS	NA	NA

B-11		N4T2_0.07B	0.07	B
B-12		N4T2_0.10B	0.10	B
B-13	Type 2	N4T2_0.13B	0.13	B
B-14		N4T2_0.16B	0.16	B
B-15		N4T2_0.07D	0.07	D
B-16		N4T2_0.10D	0.10	D
B-17		N4T2_0.13D	0.13	D
B-18		N4T2_0.16D	0.16	D

The process of taking-off in final phase was conducted to determine the total concrete, formwork, and steel reinforcement for all RC residential models. The results from models with seismic design were compared to its non-seismic models and presented as weight of steel reinforcement per $1m^3$ concrete. The total cost of materials for structural works was estimated by referring to the standard building material prices published by Jabatan Kerja Raya Malaysia (JKR) [21].

3. Results and Discussion

3.1 Base Shear Force, F_b

The modal response spectrum analysis method was performed for all models to calculate the earthquake load, E, except for the non-seismic models. Modal analysis is a requirement for response spectrum analysis. The modal analysis aims to determine the natural mode shapes and structures' frequencies during a quake. An earthquake load, E has been derived as base shear force, F_b, which can be calculated using the following expression:

$$F_b = S_d\left(T_1\right) m\lambda \tag{1}$$

The fundamental period of vibration spectral acceleration $S_d(T_1)$, the effective mass of the building m, and the correction factor, λ are all demonstrated to be closely connected to the base shear force F_b in Eurocode 8 [18]. The effective mass of the building, m, and the correction factor, λ, were both incorporated into each model. Using peak ground accelerations, α_{gR}, and soil type for each model, the design response spectrum was used to determine spectral acceleration at the fundamental period of vibration spectral acceleration $S_d(T_1)$.

Table 3 and Table 4 demonstrate the base shear force, F_b, of a two and four storey RC residential building, depending on the acceleration of the spectral at the fundamental period of vibration, $S_d(T_1)$.

For similar soil types, Table 3 and Table 4 indicate increased reference peak ground acceleration, α_{gR}, spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, and base shear force, F_b. Varying magnitudes of base shear force, F_b, derived from the four references' peak ground acceleration, α_{gR}, with diverse soil types. According to the National Annex [19], different soil types have distinct soil factor values, S. Type 1 and Type 2 have the highest base shear force, F_b, at peak ground acceleration, α_{gR} = 0.16g, soil type D.of two storey RC residential buildings were: 2951.5 kN and 2995.1 kN while for four storey RC residential buildings were: 4982.7 kN and 5011.8 kN. According to structural analysis the N2T1_0.16D, N2T2_0.16D, N4T1_0.16D, and N4T2_0.16D models have the maximum design bending moment's magnitude, m shear force, v, and axial load, P. Thus, models are expected to use the maximum steel reinforcement.

3.2 Total Concrete Volume

The crucial consideration for this research is how much the amount of steel required and provided due to seismic action once the beam, column, and slab sizes are fixed and unchanged. In this research work, regardless of the design considerations, the beams, columns, and slabs sizes were set to be similar across all models. The sizes had been determined based on the crucial model, which is subjected to reference peak ground acceleration, α_{gR} = 0.16g. Once the sizes are PASS for such seismicity level, then similar sizes had been used on models with lower seismicity levels as well as for the non-seismic model.

This approach enables fair comparison on the effect of steel used as reinforcement. In other word, sizes have to be fixed to study the effect of different loading (in term of level of seismicity - represented by base shear force, F_b) on the usage of steel as reinforcement. Hence, concrete volumes for beams, columns, and slabs for every model of two storey RC residential building for Type 1 and Type 2 is equal to 645.25 m^3 and 647.12 m^3, respectively. For the four storey RC residential building, the total volume of concrete is equal 1155.86m^3 and 1171.47 m^3 for Type 1 and Type 2, respectively. The lean concrete of beam and slab at ground level for two storey RC residential building for Type 1 and Type 2 every model consumes 65.81 m^3 and 66.00 m^3, respectively. For the four storey RC residential building, every Type 1 and Type 2 model consumes 65.81 m^3 and 66.00 m^3 of lean concrete, respectively. Therefore, the concretes' cost was estimated to be similar for each model of both storey.

Table 3 - All two storey RC residential building models, the base shear force is F_b

No.	Model	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, g (m/s^2)	Base shear force, F_b (kN)
A-1	N2T1_NS	NA	NA
A-2	N2T1_0.07B	0.594	1074.9
A-3	N2T1_0.10B	0.849	1535.5
A-4	N2T1_0.13B	1.103	1996.2
A-5	N2T1_0.16B	1.358	2456.9
A-6	N2T1_0.07D	0.713	1291.3
A-7	N2T1_0.10D	1.018	1844.7
A-8	N2T1_0.13D	1.324	2398.1
A-9	N2T1_0.16D	1.629	2951.5
A-10	N2T2_NS	NA	NA
A-11	N2T2_0.07B	0.589	1083.8
A-12	N2T2_0.10B	0.841	1548.2
A-13	N2T2_0.13B	1.094	2012.7
A-14	N2T2_0.16B	1.346	2477.2
A-15	N2T2_0.07D	0.716	1310.4
A-16	N2T2_0.10D	1.021	1872.0
A-17	N2T2_0.13D	1.328	2433.5
A-18	N2T2_0.16D	1.632	2995.1

Table 4 - All four storey RC residential building models, the base shear force is F_b

No.	Model	Spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, g (m/s^2)	Base shear force, F_b (kN)
B-1	N4T1_NS	NA	NA
B-2	N4T1_0.07B	0.295	1154.3
B-3	N4T1_0.10B	0.421	1649.1
B-4	N4T1_0.13B	0.547	2143.8
B-5	N4T1_0.16B	0.673	2638.5
B-6	N4T1_0.07D	0.568	2180.0
B-7	N4T1_0.10D	0.812	3114.2
B-8	N4T1_0.13D	1.055	4048.5
B-9	N4T1_0.16D	1.299	4982.7
B-10	N4T2_NS	NA	NA
B-11	N4T2_0.07B	0.298	1166.3
B-12	N4T2_0.10B	0.425	1665.3
B-13	N4T2_0.13B	0.552	2164.8
B-14	N4T2_0.16B	0.680	2664.4
B-15	N4T2_0.07D	0.574	2192.7
B-16	N4T2_0.10D	0.820	3132.4
B-17	N4T2_0.13D	1.066	4072.1
B-18	N4T2_0.16D	1.312	5011.8

3.3 Total Volume of Formwork

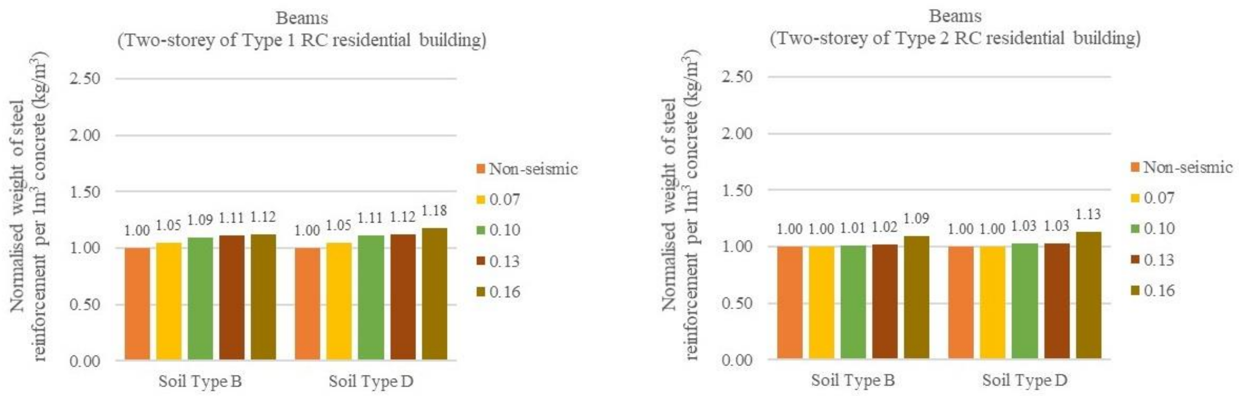
As mentioned before, regardless of the design considerations for this research, since the beam, column and slab sizes were set to be similar across all models, the formwork also became similar for all models. Hence, the formworks' areas of beams, columns and slabs were equal for every model of two storey RC residential building for Type 1 and Type 2 equal to 3847.44 m^2 and 3846.82 m^2, respectively. For the four storey RC residential building, the formworks' areas are equal to 7958.38 m^2 and 7890.58 m^2 for Type 1 and Type 2, respectively. Therefore, the formwork's cost for all models was estimated to be similar for every corresponding Types and number of storey.

3.4 Steel Reinforcement's Overall Weight

This component examined the total weight of steel reinforcement for each 1m^3 of concrete needed for beams and columns for each model for both storeys, impacted by reference peak ground acceleration, α_{gR}, and soil types. The increase in steel reinforcement imposed by seismic design considerations was compared to non-seismic design in this comparison, which was normalised to the non-seismic model. The results of comparing the total weight of steel reinforcement for every 1m^3 concrete required for beams of two storey and four storey RC residential buildings for Types 1 and 2, respectively, are shown in Fig. 3 and Fig. 4.

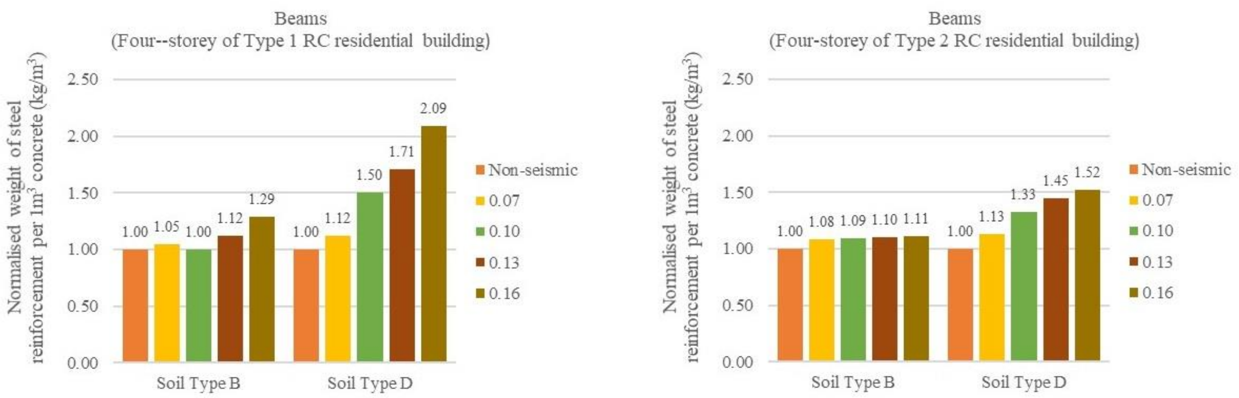
Regardless of the soil type, Fig. 3 shows a higher reference peak ground acceleration, α_{gR} increases total weight of steel reinforcement for every 1m^3 concrete for beams of a two storey RC residential building by roughly 5% to 18% and 1% to 13%, respectively, as compared to the model of non-seismic. The total weight of steel reinforcement for every 1m^3 concrete for beams in a four storey RC residential building is increased by reference peak ground acceleration, α_{gR}, compared to non-seismic model, by approximately 5% to 109% and 5% to 40%, respectively. This is because Fig. 4 shows a higher reference peak ground acceleration, α_{gR}.

As a result, steel reinforcement costs increase as overall steel weight increases. Despite the reference peak ground acceleration values, α_{gR}, it is seen that in comparison to the other soil types, soil type D models have the highest total weight of steel reinforcement. As a result, the soil types affected the percentage of steel reinforcement increase [8]-[16]. According to the preceding subsection, soil type D models have the most significant base shear force, F_b, which leads to the maximum design bending moment magnitude, m shear force, v, and axial load, P. As a result, the models utilised a higher amount of steel reinforcement.



(a) (b)

Fig. 3 - Total steel reinforcement weight normalized to 1m^3 concrete for two storey RC residential building beams; (a) Type 1; (b) Type 2

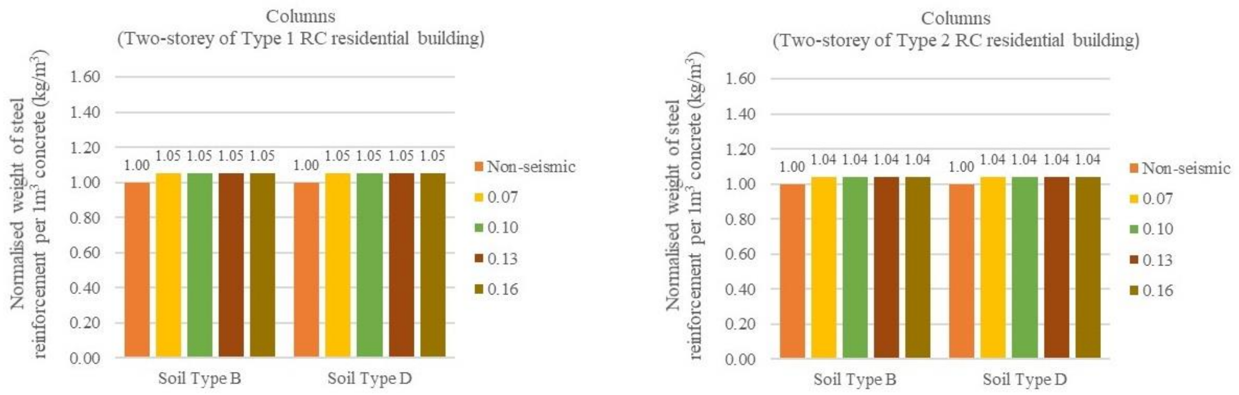


(a) (b)

Fig. 4 - Total steel reinforcement weight normalized to 1m^3 concrete for four storey RC residential building beams; (a) Type 1; (b) Type 2

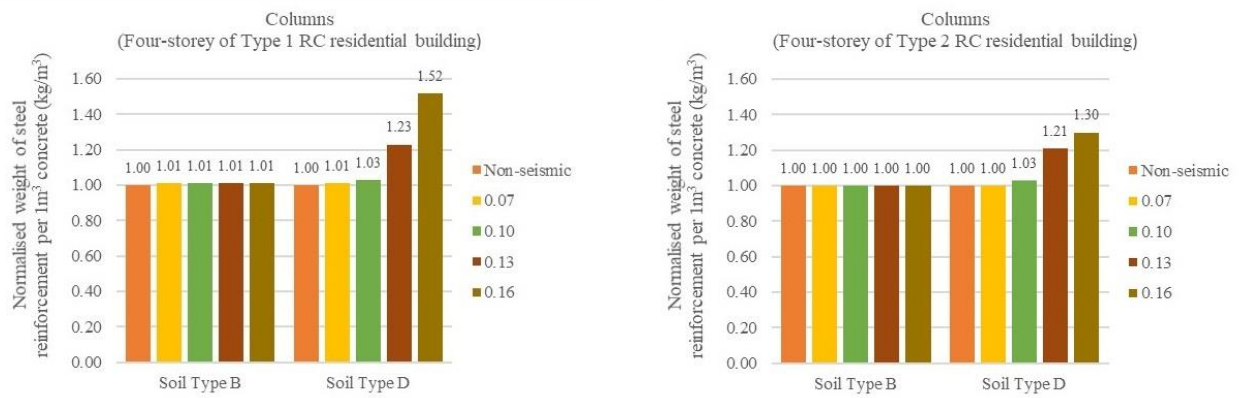
Fig. 5 and Fig. 6 compare the necessary total weight of steel reinforcement per 1m^3 of concrete for two storey and four storey RC residential building columns for Type 1 and Type 2 models, respectively. According to the Strong Column - Weak Beam theory, seismic columns must be at least 1.3 times stronger than beams [18]. Regardless of the soil type, based on Fig. 5, the total weight of steel reinforcement per 1m^3 concrete for columns for two storey RC residential building for Type 1 and Type 2 show increments between 5% and 4%, respectively, compared to non-seismic models. Otherwise, four storey RC residential for Type 1 and Type 2 display in Fig. 6 which show increments between 1% to 52% and 1% to 32%, respectively, compared to the non-seismic models. These designs were strongly affected by the Strong Column - Weak Beam theory requirement. Therefore, the reference peak ground acceleration,

α_{gR} = 0.16g models resulted in the highest amount for the provided steel reinforcement as in the design for beams since the base shear forces, F_b, were the highest in value, regardless the soil type. The percentage increase is proportional to the reference peak ground acceleration, α_{gR}. Model with a larger base shear force, F_b, produces a greater bending moment, *m*, shear force, *v*, and axial load, *P*. As a result, the models utilised the most steel reinforcing. This conclusion is compatible with the preceding literature [8], [9], [11]- [16].



(a) (b)

Fig. 5 - Total steel reinforcement weight normalized to 1m³ concrete for two storey RC residential building columns; (a) Type 1; (b) Type 2



(a) (b)

Fig. 6 - Total steel reinforcement weight normalized to 1m³ concrete for four storey RC residential building columns; (a) Type 1; (b) Type 2

3.5 Standard of Rates

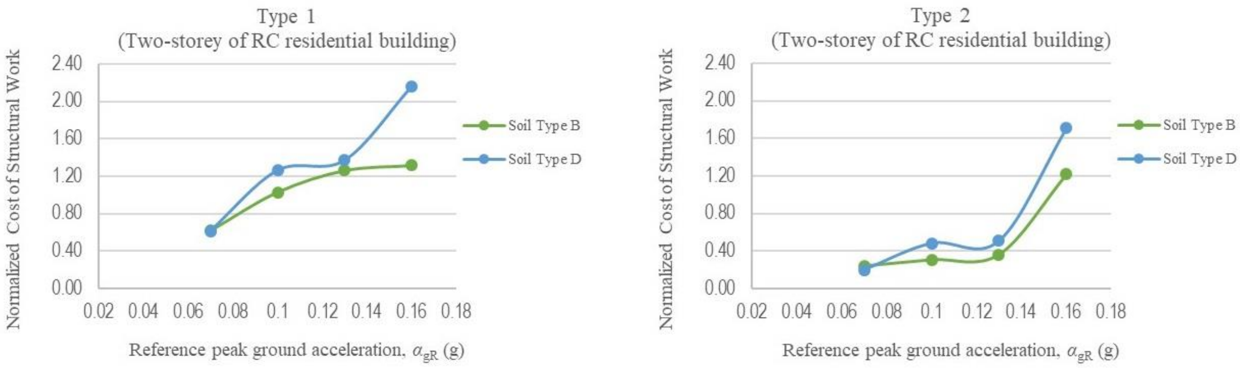
The estimated material costs for concrete, formwork and reinforcement were based on the Jabatan Kerja Raya 2021[21] of the building materials' standard of Rates (SoR). For two storey RC residential building, the cost of concrete is RM370.90 per 1m^3, while the cost of formwork ranges from RM78.90 to RM84.30 for 1m^2 of timber formwork. Steel reinforcement placement costs between RM3.80 and RM4.20 per kg. While for four storey RC residential building, the cost of concrete is equal to RM370.90 for every 1m^3, while for formwork is around RM78.90 to RM84.30 per 1m^2 of timber formwork. For steel reinforcement, the cost of placement is around RM3.80 to RM4.20 per kg.

3.6 Cost Estimation of Structural Works

Fig. 7 and Fig. 8 demonstrate the normalized total costs of structural work's cost of two- and four storey RC residential buildings, comprising steel reinforcement, concrete, lean concrete, and formwork for Type 1 and Type 2 models, respectively. Every model for two storey RC residential building has similar concretes' and formworks' total cost except for cost of steel reinforcements. Concretes' total cost according to SoR 2021[21] is equals RM239,323.97 and RM240,015.32 for Type 1 and Type 2, respectively. The total cost of formwork equals RM 311,525.85 and RM 311,832.37 for Type 1 and Type 2, respectively. While every model for four storey RC residential building has similar concretes' and formworks' total cost except for cost of steel reinforcements. Concretes' total cost is equal to RM428,708.47 and RM434,498.96 for Type 1 and Type 2, respectively. The total cost of formwork is equal to RM640,471.82 and RM635,547.17 Type 1 and Type 2, respectively.

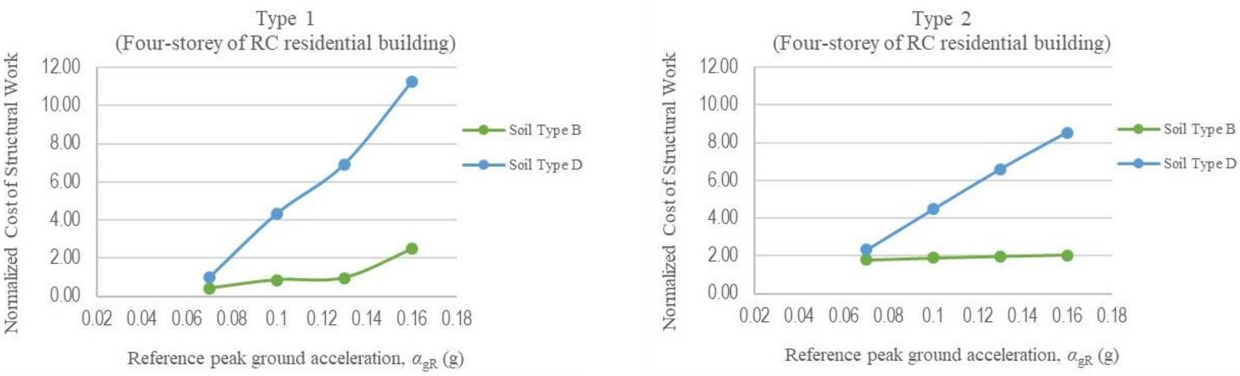
According to the results in Fig. 7(a), soil type B and soil type D shows an increment for the normalised cost of structural works for Type 1 models for seismic design consideration of approximately 0.62% to 1.31% and 0.61% to 2.16%, respectively, depending on the reference peak ground acceleration, α_{gR} and soil type. Furthermore, Fig.7(b) shows soil type B and soil type D models showing an increment for the normalised cost of structural works for Type 2 for seismic design consideration of approximately 0.24% to 1.22% and 0.20% to 1.71%, respectively.

According to the results in Fig. 8 (a), the normalised cost of structural works for Type 1 models of soil types B and D indicates an increase for seismic design consideration of approximately 0.41% to 2.48% and 0.98% to 11.23%, respectively depending on the reference peak ground acceleration, α_{gR} and soil type. Otherwise, Fig. 8(b) shows the normalised cost of structural works for Type 2 models of soil types B and D indicates an increase for seismic design consideration of approximately 1.80% to 2.05% and 2.34% to 8.53%, respectively. These two factors have a significant impact on the magnitude of the base shear force, F_b. A higher base shear force, F_b, leads to a higher bending moment, m shear force, v and axial load, P that directly increase the areas of steels required, As_{req}. A higher number of steel bars is needed for a higher area of steel provided, As_{prov} concerning the solution. In conclusion, based on the findings of this study, it is essential for construction industry participants to estimate the cost escalation of structural work while incorporating seismic design for future development planning.



(a) (b)

Fig. 7 - Normalized cost of structural works for two storey of RC residential building; (a) Type 1; (b) Type 2



(a) (b)

Fig. 8 - Normalized cost of structural works for four storey of RC residential building; (a) Type 1; (b) Type 2

4. Conclusion

This research examines the link between structural work cost, steel reinforcement weight, reference peak ground acceleration, α_{gR}, and soil types. A total of 36 number of two and four-storey RC residential building models for Type 1 and Type 2 were created using reference peak ground acceleration values of α_{gR} = 0.07g, 0.10g, 0.13g, and 0.16g, which are representative of Sabah's seismicity and soil types B and D, respectively. The following is the conclusion of this investigation:

- Regardless of the soil types, higher reference peak ground acceleration, α_{gR} increases total weight of steel reinforcement for every 1m^3 concrete for beams of two storey RC residential building for Type 1 and Type 2 by approximately around 5% to 18% and 1% to 13%, respectively. Otherwise, for four storey RC residential building for Type 1 and Type 2, higher reference peak ground acceleration, α_{gR} increases total steel reinforcement weight for every 1m^3 concrete for beams by about 5% to 109% and 5% to 40%, respectively. Otherwise, compared to the non-seismic model, the weight of steel reinforcement for columns for two storey RC residential building for Type

1 and Type 2 show increments between 5% and 4%, respectively. Furthermore, four storey RC residential for Type 1 and Type 2 will be increased by roughly 1% to 52% and 1% to 32%, respectively. Although a building with an identical structural layout would have a different quantity of steel reinforcement, according to the findings.

- When seismic design is considered, overall cost of two storey RC residential structural works on soil types B and D increases by roughly 0.62% to 1.31% and 0.61% to 2.16%, respectively. Meanwhile, due to the soil types and the reference peak ground acceleration values, α_{gR}, The total cost of structural work for Type 2 models on soil types B and D rises by roughly 0.24% to 1.22% and 0.20% to 1.71%, respectively. Furthermore, the entire cost of structural works for four storey RC residential Type 1 models on soil types B and D rises by 0.41% to 2.48% and 0.98% to 11.23%, respectively. Otherwise, the overall cost of structural works for Type 2 models on soil types B and D increases by around 1.80% to 2.05% and 2.34% to 8.53%, respectively, due to the soil types and the reference peak ground acceleration values, α_{gR}.
- Despite Type 1 and Type 2 models' reference peak ground acceleration values, α_{gR}, soil type D has the most steel reinforcement. In conclusion, soil types affect steel reinforcing weight.

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