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Increment of material usage in construction of four storey reinforced concrete building due to seismic design

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Abstract. Malaysia is fortunate because it is located outside the Pacific Ring-Fire region which is seismically active. However, it still exposes to earthquake hazard from Far-Field earthquake from neighbouring countries. In Peninsular, it is exposed to Sumatra-Andaman earthquake from Indonesia. In East Malaysia, to states namely as Sabah and Sarawak are exposed to Philippines earthquake. Besides, Malaysia also experienced earthquakes from local faults such as Bukit Tinggi in 2007. On 5th June 2015, a moderate earthquake with M_w 6.1 occurred in Ranau, Sabah which caused 18 fatalities. The same event also caused damage to 61 buildings around Ranau and Kundasang. For the sake of safety, construction of new buildings in Malaysia has to consider seismic design. This paper presents a study to evaluate the increment of construction materials used due to consideration of seismic design. A typical four-storey generic reinforced concrete school building had been used as model. This study adjusted the value of reference peak ground acceleration, a_{gR} in modelling, analysis, and design process. The concrete grade was fixed as C30. Four soil types had been considered for all models with seismic design consideration. Findings from this study demonstrate that the consideration of seismic design caused the increment of steel reinforcement around 16% to 32% for beam and 1% to 14% for column. In term of cost of structural work, consideration of seismic design increases the cost in range of 2% to 5% compared to the nonseismic design. Therefore, it is worth for Malaysia to fully implement the seismic design in new development.

1. Introduction

Although located relatively far away from the Pacific Ring-Fire region which is seismically active, Malaysia is still exposed to earthquake hazard from neighbouring countries. Peninsular Malaysia in the west part is exposed to Sumatra-Andaman earthquakes from Indonesia. In East part, two states namely as Sabah and Sarawak are exposed to the threat of Philippines earthquakes. The 2004 Aceh earthquake with M_w 9.1 had produced high magnitude seismic wave. The latter caused vibration to high rise buildings in Penang, Kuala Lumpur, Putrajaya, and Johor Bharu [1]. Malaysia also experienced earthquakes from local faults. As example, around 2007 the Bukit Tinggi fault re-activated after the Sumatra earthquake due to formation of intraplate pressure [2, 3]. A technical observation proved that since 140 years ago the number of earthquake event increased drastically in Sabah [4]. In the state, several regions namely as Pitas, Ranau, Lahad Datu, Kundasang, and Tawau



had been identified as at risk of earthquake. A historical earthquake from local fault had occurred in Ranau on 5th June 2015. The earthquake with M_w 6.1 was recorded as the strongest local fault earthquake in Malaysia since the M_w 5.8 earthquake in Lahad Datu which occurred in 1976. A field observation by a reconnaissance team had reported that a lot of damages had been occurred on reinforced concrete (RC) buildings which was built without any seismic provision [5,6]. The effect of Weak Column – Strong Beam triggered damage on beams, columns, and beam-column joints. Nonstructural elements such as brickwall and ceiling also badly damage during the earthquake [7]. For detail, shear failure caused X-mark diagonal crack on brickwall [8]. As reported by Harith et al. [9] the earthquake caused damage to a total of 61 buildings including mosque, schools, and hospital due to nonseismic design on the buildings. Therefore, in order to reduce the damage, seismic design should be adopted for new buildings [10]. The implementation of seismic design for new development has its own pro and contra. The construction industry might face the increment on the cost of materials [11]. However, the future and operational cost for repair and maintenance can be reduced by implementing seismic design [12]. Past studies concluded that the implementation of seismic design will increase the usage of steel reinforcement [11 – 20]. However, majority of the studies directly used the Soil Factor, S as recommended by Eurocode 8 [21] for analysis and design process. Only a few recent works [18 – 20] referred to the Soil Factor, S as recommended by Malaysia National Annex [22]. Therefore, this study conducted an investigation on the effect of seismic design on increment of construction materials usage based on Malaysia National Annex [22]. This study focused on four storey RC school buildings in Sarawak considering ductility class medium.

2. Model and Methodology

A total of three phases had been conducted in order to achieve the objective of this study. First of all is the generation of basic model. As mentioned in previous section, this study utilized a four storey RC school building as basic model. Similar model has been used in previous study [19] which focused the site in Sabah as shown in Figure 1. The total length of the building is equal to 45.48m and 11.65m in longitudinal and transverse direction, respectively. Every storey has 3.35m of floor to floor height. Therefore, the total height of the building, H is equal to 13.4m. The fundamental period of vibration, T_1 of the building was estimated around 0.56 sec. the details of the size of structural elements can be referred to previous study [19].

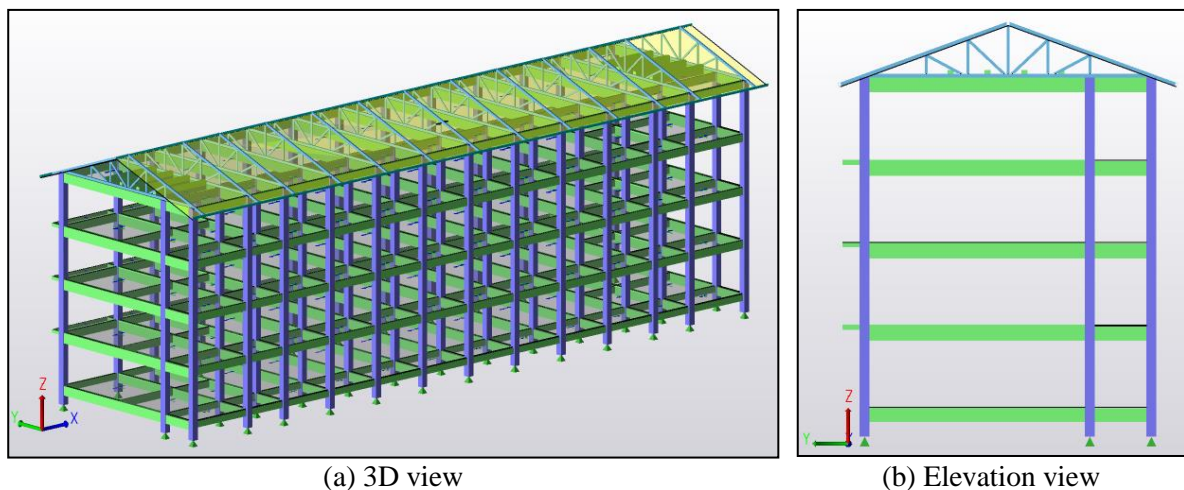


Figure 1. 3D view and elevation view of four storey RC school building [19]

Phase 2 involving the structural analysis and design. In this phase, the basic model had been generated in computer software. The imposed load, Q_k acting on slab varies from 2kN/m^2 to 4kN/m^2 depend on the floor usage as recommended by Eurocode 1 [23]. The basic model was designed based on gravity load combination only without any seismic load consideration by referring to Eurocode 2 [24] for control purpose. Then, the basic model had been designed repeatedly based on different seismic consideration namely as reference peak ground acceleration, α_{gR} and the soil type. The value of reference peak ground acceleration, α_{gR} were referred to seismic hazard map for Sarawak [22] as shown in Figure 2. Since this study only focused on ductility class medium, the value of reference peak ground acceleration, α_{gR} equal to $0.07g$ and $0.9g$ were taken into account. Four soil types had been considered namely as Soil Type B, Soil Type C, Soil Type D, and Soil Type E. Since this study referred to the Malaysia National Annex [22], the recommended value of Soil Factor, S was equal to 1.2, 1.3, 1.35, and 1.4 for Soil Type B, Soil Type C, Soil Type D, and Soil Type E, respectively. For models with seismic design, the importance factor, γ_I equal to 1.2 had been assigned as recommend for buildings categorized as importance class III including school [22]. A total of 9 models had been analyzed and designed as shown in Table 1. Lateral Force Method had been used for models with seismic design as explained in previous study [19].

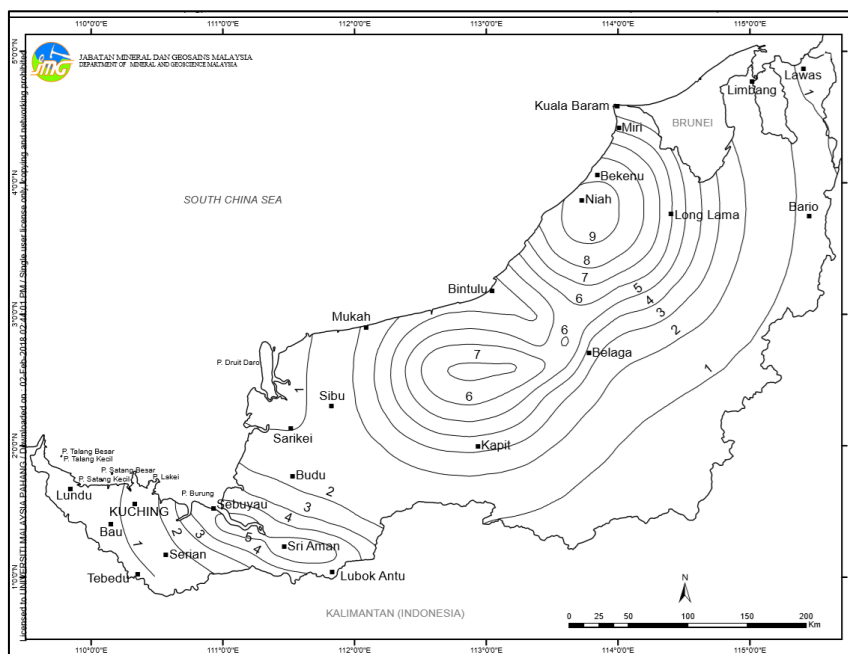


Figure 2. Seismic hazard map for Sarawak [22]

Table 1. Models and design consideration

No	Model	Soil Type	α_{gR} (g)	Ductility	Behaviour factor, q
1.	NS	-	-	-	-
2.	B-0.07M	B			
3.	C-0.07M	C			
4.	D-0.07M	D	0.07	DCM	3.9
5.	E-0.07M	E			
6.	B-0.09M	B			
7.	C-0.09M	C			
8.	D-0.09M	D	0.12	DCM	3.9
9.	E-0.09M	E			

The taking off process took part in the third phase where the total concrete volume had been measured based on the size of every structural elements. Then, the area of formwork to be used for beams, columns, and slabs also had been measured accordingly. Finally, the total steel tonnage had been determined for every models. The total weight of steel reinforcement for all models with seismic design consideration had been compared with the nonseismic model. This phase also evaluated the total cost of structural work based on the price given by JKR standard [25].

3. Result and discussion

3.1 Base Shear Force, F_b

As mentioned in previous section, the earthquake load acting on models 2 to 9 had been generated based on Lateral Force Method [21]. The earthquake load acting laterally on every storey of models with seismic design consideration. Initially, the total earthquake load had been determined as base shear force, F_b before proportionally distributed to all storey as lateral storey force, F_i . Based on structural analysis, the magnitude of base shear force, F_b is shown in Table 2.

Table 2. 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-0.07M	0.566	1173.45
3.	C-0.07M	0.613	1271.24
4.	D-0.07M	0.636	1320.13
5.	E-0.07M	0.660	1369.02
6.	B-0.09M	0.727	1508.72
7.	C-0.09M	0.788	1634.45
8.	D-0.09M	0.818	1697.31
9.	E-0.09M	0.848	1760.17

As shown in Table 2, the magnitude of base shear force, F_b are different for every model with seismic design. Models with higher value of reference peak ground acceleration, α_{gR} tend to have higher magnitude of base shear force, F_b and vice versa. As an example, the base shear force, F_b for model B-0.07M and B-0.09M are equal to 1173.45kN and 1508.72kN, respectively. The increment is around 28.6% even considering similar soil type. This is because the value of reference peak ground acceleration, α_{gR} strongly indicating the level of seismicity. Higher value of reference peak ground acceleration, α_{gR} indicates higher level of seismicity. This result in higher value of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$. Therefore, the earthquake load acting on buildings also high. Similar pattern had been presented in previous works [13, 16, 17, 19].

Table 2 also shows that different soil type tends to result in different magnitude of base shear force, F_b . As an example, model B-0.09M and model E-0.09M were exposed to base shear force, F_b equal to 1508.72kN and 1760.17kN, respectively. The increment is around 16.7%. This result is strongly associated with the value of Soil Factor, S which is different for every soil type. According to Malaysia National Annex [22], the value of Soil Factor, S for soil type B, C, D, and E in Sarawak are equal to 1.2, 1.3, 1.35, and 1.4, respectively. Higher value of Soil Factor, S amplified the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$. The directly increase the magnitude of base shear force, F_b . This result is in good agreement with previous works [15, 19, 20]. In Table 2, it is clearly shown that model E-0.09M had been imposed to the highest base shear force, F_b which is equal to 1760.17kN. Therefore, the model also imposed to the higher lateral storey force, F_i .

3.2. Total weight of steel reinforcement

In this study, the size of section for columns, beams, and slabs were similar for all models regardless the design consideration. Therefore, the total concrete volume also similar for all models. The total concrete volume for columns, beams and slabs are equal to 91.104m^3 , 237.959m^3 , and 296.658m^3 , respectively. Total volume of concrete for every model is 625.721m^3 . Hence the cost of concrete is similar for all models as well as the cost of formwork.

The comparison had been made on the total usage of steel reinforcement. The latter is normalized to the total steel tonnage of model NS in order to study the increment of steel reinforcement once seismic design is taken into account. As presented in previous works [11 - 20] the total steel tonnage is the summation of steel bar used as the shear and flexural reinforcement. Figure 3 presents the normalized steel tonnage used in all beams for every model. It is clear that the seismic design consideration requires higher usage of steel reinforcement. This result is in good agreement for previous works [11-20]. As shown in Figure 3, the usage of steel reinforcement in beams increases around 16% to 32% compared to the nonseismic model. The steel tonnage increases as the value of reference peak ground acceleration, α_{gR} increases. As expected, model D-0.09M and model E-0.09M require highest usage of steel reinforcement. This is due to highest magnitude of base shear force, F_b resulting in highest bending moment, M and shear force, V . Therefore, highest steel has to be provided in beam for both models. This result is in line with previous work [13, 19, 20]. The increment of steel usage due to different soil type is also significant. Based on difference of steel tonnage between Soil Type B and Soil Type E is around 28%. Therefore, soil type also significantly influencing the result of design [15].

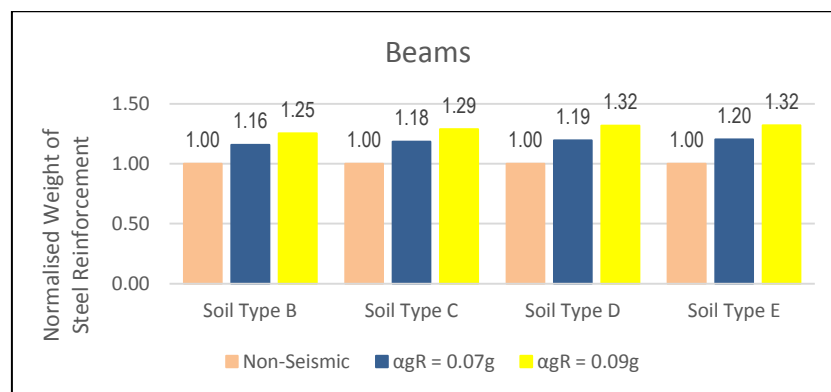


Figure 3. Normalized total steel tonnage for beams.

Figure 4 presents the comparison of normalized steel tonnage used for reinforcement in column. The usage of steel reinforcement in columns also increases for models with seismic design consideration. In this study, the steel tonnage increases around 1% to 14% compared to model with seismic design. The increment of steel tonnage in column follow similar pattern with the increment of steel tonnage in beam. This mean model D-0.09M and model E-0.09M require the highest steel reinforcement for columns as in the result for beams. This result is strongly associated with the requirement to provide Strong Column – Weak Beam for seismic design consideration as recommended in Eurocode 8 [21]. By adopting this approach, the strength of column is derived based on the strength of the beam passing through its joint. This mean higher steel tonnage in beam will result in higher steel tonnage in its supporting column [19]. For ductility class medium, the spacing of shear reinforcement in column, s is limited to 175 mm only to ensure better confinement of concrete core [21]. This provision result in higher steel required as shear reinforcement [13].

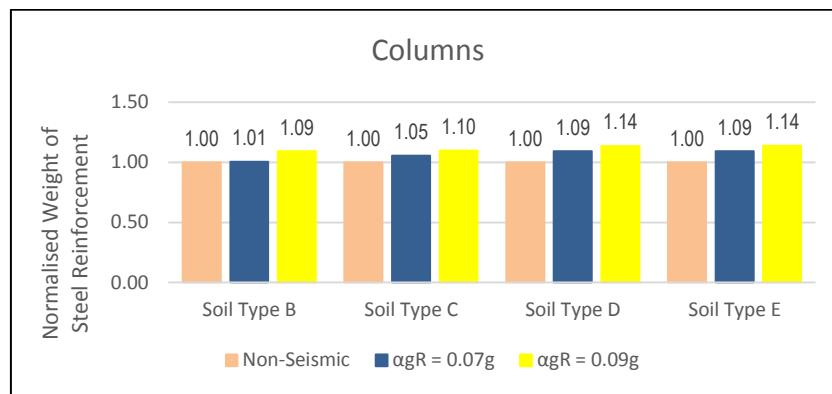


Figure 4. Normalized total steel tonnage for columns

3.3. Cost estimation of structural works

In order to give clearer picture to construction industry, the effect of seismic design shall be presented in form of increment to the total cost of structural works. This involving the cost of concrete, formwork, and steel reinforcement. As highlighted in previous section, the cost had been estimated based on the price given by the JKR standard [25]. Figure 5 presents the comparison of cost of structural work for all models, normalized to the cost of structural work for model without seismic design. As mentioned in previous subsection, the total cost of concrete and formwork are similar for all models. This is because the size of section for columns, beams, and slabs are similar for all models. Therefore, the increment of total cost of structural work is strongly influenced by the increment of steel tonnage. In Figure 5, it is clearly shown that the total cost of structural work increases once seismic load had been considered in design. In this study, the total cost of structural works increases around 2% to 5% depending on the reference peak ground acceleration, α_{gR} and the soil type. This increment is relatively low compared to the increment for Sabah state as presented earlier [19]. This is because the seismic intensity in Sarawak is relatively lower compared to Sabah.

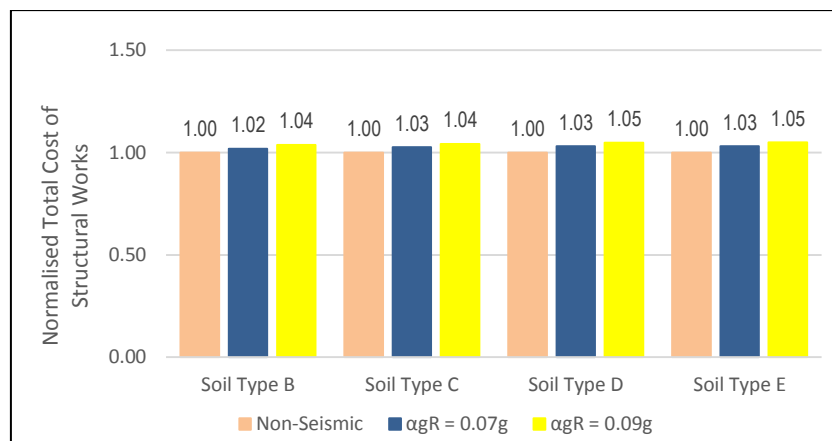


Figure 5. Normalized cost of structural work.

4. Conclusion

The evaluation on increment of materials for RC building due to seismic design had been conducted in this study. A typical four storey RC school building had been used as basic model. This study used two variables namely as reference peak ground acceleration, α_{gR} and soil type. This study referring to the Malaysia National Annex [22] for the value of reference peak ground acceleration, α_{gR} and Soil Factor, S for Sarawak. A total of 9 models had been analysed and designed separately including one

model with seismic design consideration for comparison purpose. The following conclusion had been drawn from this study:

- Considering seismic load in design clearly increasing the usage of steel reinforcement. For beam, the total steel tonnage increased in range of 16% to 32% compared to the nonseismic model. The increment of steel tonnage in column is recorded as in range of 1% to 14%.
- The increment of steel reinforcement is strongly influenced by the value of reference peak ground acceleration, α_{gR} and soil type.
- It is worth to consider seismic design for medium seismic region in Sarawak as the increment to the total cost of structural work in only up to 5%. However, this result only applicable for the four storey RC school building. More research work has to be conducted by using various structural models in order to get more precise result.

5. References

- [1] Ramli M Z and Adnan A 2016 Malaysian bridges and the influence of Sumatran earthquake in bridge design *Malaysian Construction Research Journal*. **18(1)** pp 123-134.
- [2] Shuib M K 2009 The recent Bukit Tinggi earthquakes and their relationship to major geological structures *Geological Society of Malaysia*. Bulletin 55 pp 67-72.
- [3] Abdul Latiff A H and Khalil A E 2019 Seismic site effect along Bukit Tinggi fault line from microtremor analysis *IOP Conference Series: Earth and Environmental Sciences*. **244** 012042.
- [4] Harith N S H, Adnan A, Tongkul F and Shoushtari A V 2017 Analysis on earthquake databases of Sabah region and its application for seismic design *International Journal of Civil Engineering & Geo-Environmental*. **Special Publication NCWE2017** pp 1-5.
- [5] Majid T A, Adnan A, Adiyanto M I, Ramli M Z and Ghuan T C 2017 Preliminary damage assessment due to 2015 Ranau earthquake *International Journal of Civil Engineering & Geo-Environmental*. **Special Publication NCWE2017** pp 49-54.
- [6] Alih S C and Vafaei M 2019 Performance of reinforced concrete buildings and wooden structures during the 2015 Mw 6.0 Sabah earthquake in Malaysia. *Engineering Failure Analysis*. **102** pp 351-368.
- [7] Adiyanto M I, Majid T A and Nazri F M 2017 Nonstructural damages of reinforced concrete buildings due to 2015 Ranau earthquake *AIP Conference Proceedings*. **1865** 090002.
- [8] Khoiry M A, Hamzah N, Osman S A, Mutalib A A and Hamid R 2018 Physical damages effect on residential houses caused by the earthquake at Ranau, Sabah Malaysia *International Journal of Engineering and Technology*. **10(5)** pp 414-418.
- [9] Harith N S H, Kibata L H C and Mirasa A K 2018 Suitability of Dbela methods as seismic vulnerability assessment for buildings in Kota Kinabalu, Sabah *Geological Behavior*. **2(1)** pp 29-31.
- [10] Hamid N H, Azmi A, Adiyanto M I and Mohamad M 2018 Seismic performance of two-bay two-storey RC frame under InPlane lateral cyclic loading *Malaysian Construction Research Journal*. **25(2)** pp 61-73.
- [11] Adiyanto M I and Majid T A 2014 Seismic design of two storey reinforced concrete building in Malaysia with low class ductility *Journal of Engineering Science and Technology*, **9(1)** pp 27-46.
- [12] Ramli M Z, Adnan A, Kadir M A A, and Alel M N A 2017 Cost comparison for non-seismic (EC@) and seismic (EC8) design in different ductility class *International Journal of Civil Engineering & Geo-Environmental*. **Special Publication NCWE2017** pp 38-42.
- [13] Adiyanto M I, Rashid N H M, Mustapha S A H S and Ramli N I 2020 Comparison on total weight of steel reinforcement for 5 story reinforced concrete building with and without seismic design *Lecture Notes in Civil Engineering*. **53** pp. 685-694.
- [14] Azman N I A, Adiyanto M I, Mustapha S A H S, Majid T A, Noor S M and Harith N S H 2019 Comparison study on cost of concrete and steel reinforcement of multipurpose hall building with

- seismic design *International Journal of Recent Technology and Engineering*. **Special Publication NCWE2019** pp 543-547.
- [15] Mustapha S A H S, Adiyanto M I, Majid T A and Ali M I 2019 Influence of soil type on steel reinforcement of four storey reinforced concrete building with seismic design *Malaysian Construction Research Journal*. **7(2)** pp. 81-87.
- [16] Roslan H A, Adiyanto M I, Mustapha S A H S, Majid T A, Noor S M and Harith N S H 2019 Increment of steel tonnage for reinforced concrete school building considering seismic design *International Journal of Recent Technology and Engineering*. **Special Publication NCWE2019** pp 351-355.
- [17] Adiyanto M I, Majid T A, Jani F A, Mustapha S A H S and Ahmad S W 2019 Estimation on amount of steel reinforcement for six storey hospital with seismic design consideration in Malaysia *IOP Conference Series: Earth and Environmental Sciences*. **244** 012015.
- [18] Faisal F, Zaini S S and Selokumar T 2020 Evaluation of cost analyses for earthquake resistant reinforced concrete buildings based on Malaysian National Annex to Eurocode 8 *Lecture Notes in Civil Engineering*. **53** pp. 1485-1492.
- [19] Adiyanto M I, Majid T A and Mustapha S A H S 2020 Cost evaluation of RC school building considering seismic design based on Malaysia National Annex to EC8 *17th World Conference on Earthquake Engineering, 17WCEE*. September 13-18, Sendai, Japan 2b-0137.
- [20] Roslan H A, Adiyanto M I and Mustapha S A H S 2020 Cost evaluation of steel tonnage for reinforced concrete hostel building with seismic design *Malaysian Construction Research Journal*. **9(1)** pp. 1-9.
- [21] CEN 2004 Eurocode 8: *Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings* (Brussels: European Committee for Standardization).
- [22] Malaysia National Annex to Eurocode 8 2017 *Design of structures for earthquake resistance part 1: General rules, seismic actions and rules for buildings* (Selangor: Department of Standards Malaysia).
- [23] CEN 2002 Eurocode 1: *Action on structures Part 1: General actions - densities, self-weight, imposed loads for buildings* (Brussels: European Committee for Standardization)
- [24] CEN 2004 Eurocode 2: *Design of concrete structures Part 1-1: General rules and rules for buildings* (Brussels: European Committee for Standardization).
- [25] Standard Price Malaysia 2017 *Schedule of rates* (Kuala Lumpur: Jabatan Kerja Raya).

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