Steel Reinforcement and Concrete for Multipurpose Hall Building with Seismic Design

Nur Izzati Aliah Azman, Mohd Irwan Adiyanto, Syed Abdul Haris Syed Mustapa, Azlan Adnan, Azida Rashidi

Abstract**: *Multipurpose hall is a public building of people assembly for various function and activities. It can be converted to be a temporary shelter during disaster like flood and earthquake. After experiencing tremors from both local and distant earthquakes, the time has come to implement the seismic design to new buildings in Malaysia to ensure public safety. The implementation of seismic design also affecting the cost of construction, especially materials. Therefore, this paper presents the taking off results for reinforced concrete multipurpose hall building with seismic design. In this study two parameters namely as soil type and concrete grade had been considered as design variable. Result from design and taking off demonstrated that the amount of steel reinforcement is strongly influenced by both parameters. The usage of steel for reinforced concrete buildings with seismic design is estimated to increase around 3% to 59% depend on soil type and concrete grade. Results also demonstrated that higher concrete grade require lower amount of steel as reinforcement.***

Keywords**: *Concrete grade, Cost comparison, Seismic design, Steel tonnage.***

I. INTRODUCTION

Two main land has form a country named Malaysia. The one is located at the south part of Asia continent namely as Peninsular Malaysia. Another part known as East Malaysia which is located in as island namely as Borneo. The East Malaysia is formed by two state namely as Sabah and Sarawak. Both Peninsular and East Malaysia is relatively far away from Pacific-Ring of Fire regions. The latter is a high seismicity regions affecting Indonesia and Philippines.

However, Malaysia is considered to have low seismicity profile [1]. The M_w9.1 Acheh earthquake on December 2004 caused vibration to buildings in Peninsular Malaysia. In Peninsular Malaysia, local earthquakes were recorded in Manjung, Jerantut, Janda Baik, and Bukit Tinggi. The Paleo fault line reactivation is believed to be the main cause of Bukit Tinggi earthquakes from 2007 to 2009 [2]. In East Malaysia, around 70 local earthquake events with magnitude M_w5.0 and above were recorded since 1900 to 2014 [3].

An earthquake with M_w6.1 had struck Ranau, one of the districts in Sabah on early morning 5th June 2015. The moderate earthquake was the strongest recorded since the M_w5.8 earthquake which occurred in Lahad Datu in 1976. Minor to severe damages on buildings had been detected after the 2015 Ranau earthquake event. For reinforced concrete (RC) buildings, the earthquake action caused damages especially on beam, column, and beam-column joint [4]. The nonstructural elements such as brickwall and ceiling also affected and experience damage due to the event [5]. A detail survey had reported that the 2015 Ranau earthquake had caused damages on wall, floor, column, and roof. In their report, the highest damage recorded on brickwall with X-mark crack due to shear failure [6].

After experiencing the tremors from both local and regional earthquakes, Malaysian now aware on the importance of seismic design on buildings and structures. The 2015 Ranau earthquake is seen as an accelerating factor for implementation of seismic design for new buildings in Malaysia [7]. Hence, seismic design practice should be adopted especially in Sabah which is categorized as moderate seismic region in order to reduce the damage to buildings [8]. However, usage of construction materials due to seismic design consideration need to be investigated beforehand. 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 [9]. The increment of total steel used as reinforcement for RC building is strongly related to the seismic intensity of specific region [10]-[11]. Current research work presents the study on the effect of concrete grade and soil type on the design and detailing of RC multipurpose hall with earthquake load consideration. The comparison is presented is form of total weight of steel bar used as beams and columns' reinforcement.

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II. MODELS AND METHOD

In order to achieve the objective, a total of three stages had been conducted in this study. In stage one, a RC building to function as multipurpose hall as shown in Fig. 1 was created and modelled by using computer software. The total height, H of the RC multipurpose hall is around 17.7m. The fundamental period of vibration of building, T_1 is approximately equal to 0.60 sec. The size of beams at roof level is equal to 300 x 500 mm while the size of beams at other floor level is equal to 300 x 600 mm. The size for all columns is equal to 500 mm square.

In second stage, the structural analysis and seismic design had been conducted on all models. The RC multipurpose hall building was classified as importance class III due to its importance to public after disaster [12]. Hence, to give better protection for such building, the importance factor, γ_I for the building was assigned to be equal to 1.2 as proposed by [13]. The typical model was analysed and designed repeatedly based on different soil type and concrete grade. A total five soil type namely as soil type A, B, C, D, and E as proposed in[13] had been taken into account to represent variable site condition. Two concrete grade which is C25/30 and C35/45 had been considered for every soil type. The characteristic compressive cylinder strength of concrete at 28 days, f_{ck} shall be equal to 25N/mm^2 and 35N/mm^2 for concrete grade C25/30 and C35/45, respectively [14]. The value of reference peak ground acceleration, α_{gR} was fixed as 0.12g by referring to the latest Malaysian seismic hazard map by [15].

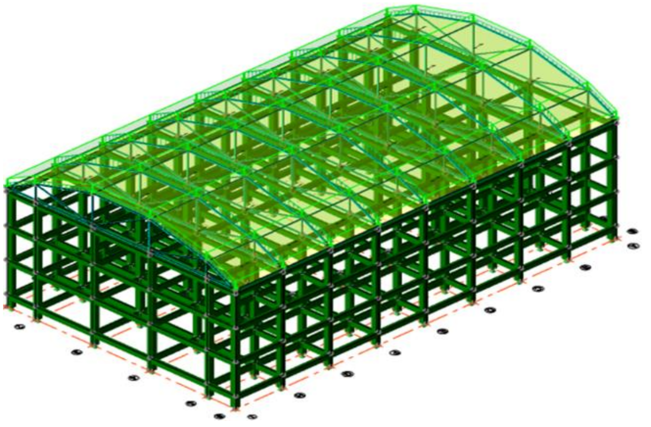

Fig. 1. 3D view of multipurpose hall

In this research works, 12 models had been analysed and designed as shown in Table I. Two models with code as G25 – GL and G35 – GL had been designed without seismic consideration as control model, one for every concrete grade. Lateral Force Method by referring to [13] had been adopted to determine the action of earthquake load in form of base shear force, F_b. By referring to this method, the base shear force, F_b has to be distributed proportionally as lateral loads acting on every story. 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 . Previous work by [11] also adopted this method. All models had been designed for ductility class medium.

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 weight of steel reinforcement per 1m^3 of concrete.

Table- I: Design parameters for RC multipurpose hall models

No	Code	Soil Type	Concrete Grade
1	G25 – GL	Non applicable	G25/30
2	G25 – A	A	
3	G25 – B	B	
4	G25 – C	C	
5	G25 – D	D	
6	G25 – E	E	
7	G35 – GL	Non applicable	G35/45
8	G35 – A	A	
9	G35 – B	B	
10	G35 – C	C	
11	G35 – D	D	
12	G35 – E	E	

III. RESULT AND DISCUSSION

A. Earthquake Load on Models

In this study, the earthquake action had been imposed on models as lateral load. The latter had been represented by base shear force, F_b which directly depends on the spectral acceleration at the fundamental period of vibration, $S_d(T_1)$ and the effective mass of the building, m. Another parameter is known as correction factor, λ. The latter shall be equal to 0.85 for buildings with more than two story and $T_1 < 2T_c$ [13]. Based on structural analysis and member design, the size of beams and columns were similar to all models results in similar magnitude of effective mass, m. Hence, the magnitude of base shear force, F_b was determined 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 soil type.

Table II presents the magnitude of base shear force, F_b imposed as lateral load on every models with seismic design. The magnitude of lateral load increases as the magnitude of spectral acceleration at the fundamental period of vibration, $S_d(T_1)$, increases. The latter is varies to different soil type. Soil with softer profile tend to have higher magnitude of lateral load. This result is contributed by different Soil Factor, S for every soil type as proposed in [13] as shown in Table II. By referring to Table II, models G25 – D and G35 – D which considering soil type D have highest magnitude of lateral load = 4033.8 kN. This result indicates that both models had been subjected to the greatest density of lateral load result in highest magnitude of bending moment, M. Models with similar concrete grade have similar magnitude of base shear force, F_b regardless the soil type.

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This means models with similar concrete grade had been imposed to similar magnitude of lateral load result in similar bending moment, *M*.

Table- II: Base shear force, F_b acting on all models

No	***Model Code***	***Soil Type***	***$v_{s,30}$ (m/s)***	***Soil factor, S***	***$S_d(T_1)$ (g)***	***Base shear force, F_b (kN)***
1	G25 – GL & G35 – GL		NA		NA	NA
2	G25 – A & G35 – A	A	>800	1.0	0.0615	1865.8
3	G25 – B & G35 – B	B	360 -- 800	1.2	0.0923	2798.6
4	G25 – C & G35 – C	C	180 – 360	1.15	0.1062	3175.6
5	G25 – D & G35 – D	D	<180	1.35	0.1246	4033.8
6	G25 – E & G35 – E	E	-	1.4	0.1077	3221.7

B. Total Volume of Concrete

The size of RC beams and columns are similar for all models regardless the design consideration. Therefore, the volume of concrete used for beams and columns is similar for all models which is equal to 470 m^3. However, the cost for concrete is not similar for all models. This is caused by different price of concrete for different grade. The price for concrete grade C35/45 is estimated around 21% higher than the price for concrete grade C25/30 [16]. The price for concrete grade C35/45 is higher than concrete grade C25/30 due to the composition of its mixture design. Usually, concrete grade C35/45 requires more fine and coarse aggregates for every $1m^3$ compared to concrete grade C25/30 in order to provide higher compressive strength. Therefore, cost considering concrete grade C35/45 is higher. In this study, the total cost of concrete was estimated to be equal to RM152,825.94 and RM185,430.06 for models with concrete grade of C25/30 and C35/45, respectively.

C. Total Steel Tonnage

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. Total weight of steel reinforcement for every models with seismic design is normalized to the total weight of steel reinforcement used for its corresponding nonseismic model. This is to compare the increment of steel reinforcement due to seismic design consideration to current practice which neglecting seismic design. Fig. 2 depicts the normalized total weight of steel reinforcement for models considering concrete grade C25/30. Result demonstrates that total weight of steel reinforcement are differ to every models. The increment of steel reinforcement is around 6% to 59% higher compared to the nonseismic model. The increment of steel reinforcement occurred on both beams and columns as discussed by previous studies [9]-[11]. In Fig. 2, the largest total weight of steel reinforcement correspond to model G25 – D. The result is as expected because the model has the highest magnitude of base shear force, F_b. The latter result in highest magnitude of bending moment, *M*. Based on design calculation for RC beam and column [17], the increasing of bending moment, *M* lead to increasing of total area of steel required, As_{req} and the total area of steel provided, As_{prov}. The latter leads to the increment to the total weight of steel reinforcement.

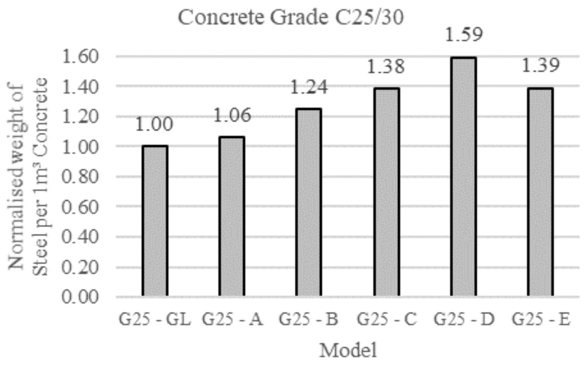

Fig. 2.Normalised weight of steel reinforcement for models considering concrete grade C25/30

The normalized total weight of steel reinforcement for models considering concrete grade C35/45 is depicted by Fig. 3. Result for this group also demonstrates that total weight of steel used as reinforcement are differ for every models. The total weight of steel reinforcement for beam increased around 3% to 47% higher compared to its nonseismic model. For this group, model on soil type D also has the largest total weight of steel reinforcement. This result is due to highest magnitude of base shear force, F_b. The increment pattern is similar to models considering concrete grade C25/30 but with lower percentage. As example, total weight of steel reinforcement for model G35 – D is 20% lower compared to model G25 – D even being imposed to similar magnitude of lateral load. This means that models with concrete grade C35/45 require lower amount of steel as reinforcement. This result is directly related to the calculation for RC design. Higher concrete grade will increase the value of lever arm, *z*. The latter contributed to lower area of steel required, As_{req} [17]. Hence, the area of steel to be provided, As_{prov} also lower.

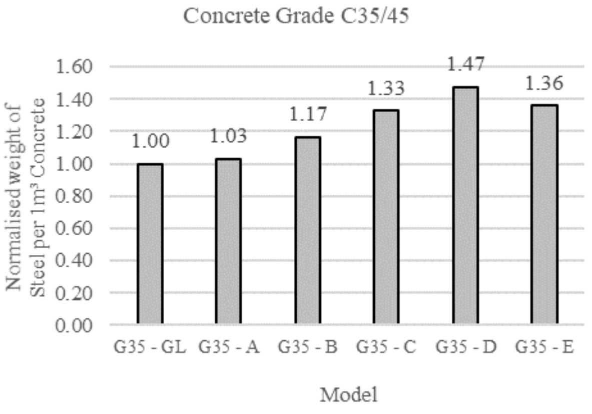

Fig. 3.Normalised weight of steel reinforcement for models considering concrete grade C35/45

D. Total Cost Estimation for Concrete and Steel Reinforcement

For better understanding, the comparison had been made in form of total cost or price of materials, which is steel reinforcement and concrete. In this study, the price of steel was estimated around RM3500.00 per tonne [16]. The price of concrete for grade C25/30 and C35/45 were estimated around RM325.30 and RM394.70, respectively for every 1m^3. Fig. 4 and Fig. 5 present the comparison on the total cost of steel reinforcement and concrete for models considering concrete grade C25/30 and C35/45, respectively. For models considering concrete grade C25/30, seismic design caused increment around 3% to 25% to total cost of steel reinforcement and concrete. By considering concrete grade C35/45, the latter has increased by 1% to 18% compared to its nonseismic model. Regardless the soil type, models with concrete grade C35/45 required higher cost of steel reinforcement and concrete compared to its companion models with concrete grade C25/30. Despite require lesser amount of steel reinforcement, the models considering concrete grade C35/45 have around 6% to 12% higher total cost of steel reinforcement and concrete than the models considering concrete grade C25/30. This is due to higher price of concrete for grade C35/45. Therefore, the selection of concrete grade also important to control the cost.

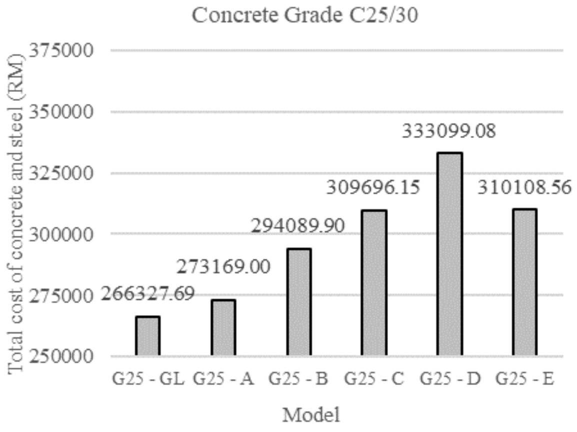

Fig. 4.Total cost of concrete and steel reinforcement for models considering concrete grade C25/30

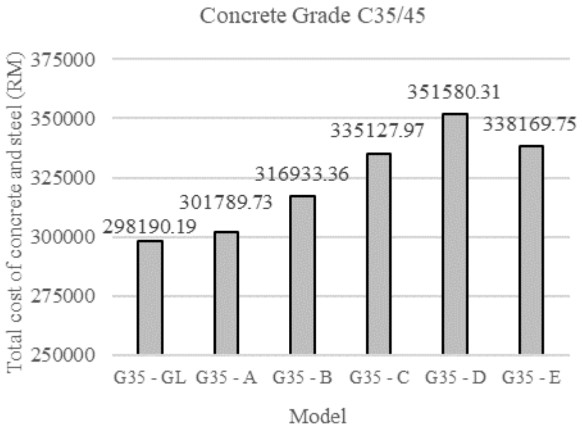

Fig. 5.Total cost of concrete and steel reinforcement for models considering concrete grade C35/45

IV. CONCLUSION

The study on the effect of concrete grade and soil type on the design and detailing of RC multipurpose hall with earthquake load consideration is discussed in this paper. A total of five soil conditions which is soil type A, B, C, D, and E had been taken into account alongside two concrete grade namely as C25/30 and C35/45. The reference peak ground acceleration, α_{gR} was fixed as 0.12g. A few conclusions are drawn as follow:

- Total weight of steel reinforcement was strongly influenced by soil type. Regardless concrete grade, the total weight of steel reinforcement increased around 3% to 59% compared to nonseismic model. Higher amount of steel reinforcement was required for models considering soil with softer profile.
- Total weight of steel reinforcement also was influenced by concrete grade. Models with concrete grade C25/30 require higher amount of steel reinforcement compared to its companion models with concrete grade C35/45. Lower concrete grade requires higher amount of steel reinforcement.
- Models with higher concrete grade will have higher total cost of steel reinforcement and concrete. In this research work, the cost of steel reinforcement and concrete for models considering concrete grade C35/45 is around 6% to 12% higher compared to models considering concrete grade C25/30. Therefore, the selection of material is important to control the cost.

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