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COST EVALUATION FOR 12-STOREY REINFORCED CONCRETE APARTMENT BUILDING IN SABAH DUE TO SEISMIC DESIGN

N. S. Zulkhibri*[1], H. A. Roslan[1] and M. I. Adiyanto[1]

[1] Department of Civil Engineering, College of Engineering,

Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia.

*corresponding_shairahzulkhibri@gmail.com

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Abstract— In June 2015, Ranau stated earthquake of moment magnitude M_W 6.1 which cause a lot of damage to buildings. Therefore, seismic design input should be applied for new buildings to minimize the damage. This work investigates the influence of seismic design on structural works cost. A 12-storey apartment reinforced concrete apartment has been used as a model for the project. In this research, soil type D and 3 levels of seismicity were used as design variables. The reference peak ground acceleration, α_{gR} used were 0.08g, 0.12g and 0.16g. The results indicate that models with seismic design have greater structural costs by increasing from 3.4% to 19.1%.

I. Introduction

Several regions in Sabah which are Pitas, Ranau, Lahad Datu, Kundasang, and Tawau had been identified as risk zone of earthquake. A moderate earthquake with M_W 6.1 from a local fault was struck in Ranau, Sabah on the early morning of 5th June 2015. That earthquake was recorded as the most substantial local fault earthquake in Malaysia after the M_w 5.8 earthquake event in Lahad Datu in 1976 [1, 2].

Building constructions in Malaysia were designed without considering the possibility of earthquake damage [3]. The building industry is predicting an increase in construction costs if seismic design is implemented [4]. However, the seismic design can reduce future and operational costs for repair and maintenance [5].

II. Literature Review

Neighboring countries such as Indonesia and the Philippines are seismically active areas surrounding Malaysia. Hence, the low seismic hazard Malaysia shall be taken seriously. Malaysia's west coast and Sabah are prone to earthquakes [6].

The level of reference peak ground acceleration, αgR, influences the increment for buildings' total steel used as reinforcement [7,8]. However, Malaysian Public Works Department concluded that it is beneficial to implement a seismic design in new buildings in moderate and high-risk earthquake zones for future safety [6]. Thus, this study investigated a 12-storey reinforced concrete (RC) apartment building with seismic and non-seismic design considerations. There are two objectives to be achieves in this research; (1) To investigate the influence of level of seismicity on the total weight of steel reinforcement and (2) To study the cost estimation for all non-seismic and seismic models with varying levels of seismicity.

III. Research Methodology

The selection model for this research was the RC apartment building as the basis. This work investigates the effect of various peak ground acceleration (PGA) parameters on the total steel reinforcing weight. Tekla Structural Designer 2021 was utilised forthe analysis in this work, whileEurocode 8 (2004) and National Annex (2007) served as the primary reference while modelling the RC apartment building [9,10]. In general, the planning and modelling approach for this research involves three steps.

A. Phase 1: Model Generation

In the first phase, a typical key plan for medium-rise RC apartment structures was developed as model. The latter will have 12 storey, representing Malaysia's medium-rise RC structures as shown in Figures 1 and 2. The multi-bay moment-resisting frame system is completed with shear wall and lift core. The basic model had been designed without seismic consideration by following Eurocode 2 (2004) as a representation of current construction practice inMalaysia [11]. Then, the taking off had been conducted by measuring the total concretevolume and the steel reinforcement weight for thebasic model. Phase 1 data had been referred to as controls and used in the normalization process to Phases 2 and 3 results. Tables 1 to 3 present the dimension of structuralelements for the 12 storey RC apartment models.

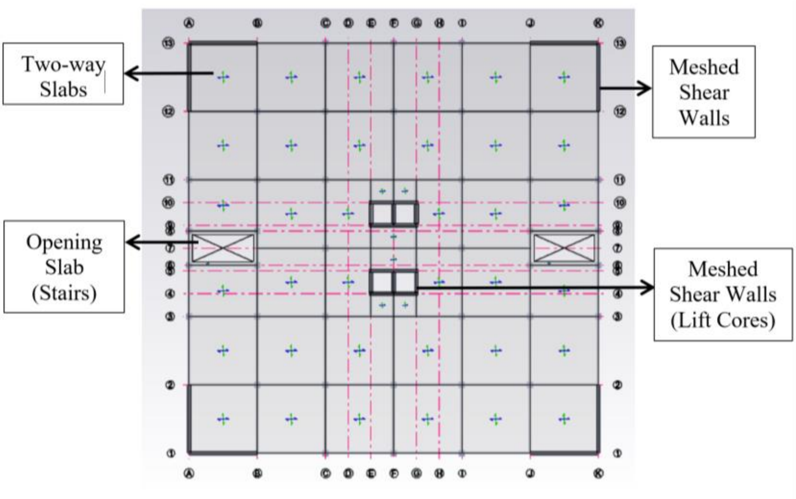

Figure 1: Plan view of 12 storey of RC apartment structures model

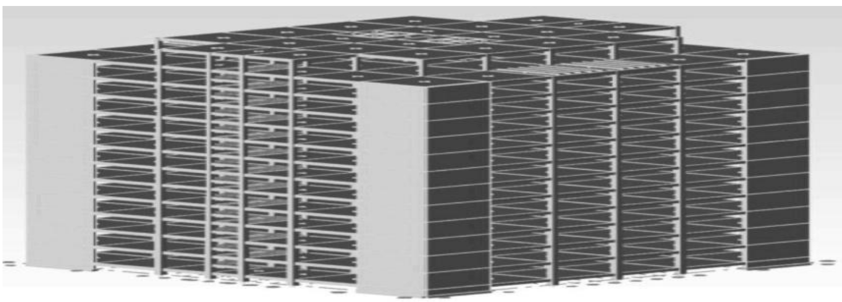

Figure 2: Generated 3D model of the whole structures

Table 1: Cross Section of Beam

Beam	Dimension (mm)
Beam	(250 x 500), (300 x 300)
	(250 x 500), (300 x 300)
Water Tank Beam	(300 x 700) mm, (350 x 800)

Table 2: Cross Section of Column

Beam	Dimension (mm)
C1	400 x 400
C2	450 x 450
C3	500 x 500
C4	550 x 550

Table 3: Cross Section of Wall

Beam	Dimension (mm)
Lift Core	300
Shear Walls	300

B. Phase 2: Analysis Seismic Design

In this phase, the 12-storey RC apartment building had been designed in accordance with Eurocode 8 (2004) and Malaysia National Annex using Tekla Structural Designer 2021 software with the method of design response spectrum [9,10]. The beam, column and walls were designed to fulfill the required steel reinforcement. Each designed model has different PGA values of 0.08g, 0.12g and 0.16g, covering soil type D in Sabah, Malaysia. The considered PGA and soil typeare in Ductility Class Medium (DCM). Concrete grade of C30/37 was considered in this research. Table 4 shows all models of the apartment building that had been considered in this study.

Table 4: Models of the RC apartment building

Model	Soil Type	PGA (g)
Non-seismic	-	-
D-0.08	D	0.08
D-0.12	D	0.12
D-0.16	D	0.16

C. Taking-off Process

The entire volume of concrete and total steel reinforcing weight of beams, columns and walls were measured in this process. Comparison of seismic and non-seismic models was carried out using the steel reinforcing weight per cubic meter of concrete.

IV. Results and Discussions

This section discussed the effect of different PGA magnitudes on the quantity of steel reinforcement based on the results of design generated bythe Tekla Structural Design 2021 software. The analysis was conducted utilizing a 12 storey

RC apartment building that has been developed based on Eurocode 8 (2004) [9]. All models had been designed concretecompressive strength of C30/37 (30 N/mm^2) and DCM.

A. Base Shear Force

Table 5 shows that three different values of PGA resulted in three different values of the design response spectrum, $_d(_1)$. The lowest $_d(_1)$ value was from α_{gR} = 0.08g meanwhile the highest was fromα_{gR} = 0.16g. As the value of α_{gR} increases, the value of $_d(_1)$ also increases. The model of D- 0.16g has the highest base shear force, $_{b(x)}$ = 15917.2 kN in x-direction and $_{b(y)}$ = 14272.7 kN in y-direction due to the highest α_{gR} and $_d(_1)$. This is due to the value of α_{gR} and $_d(_1)$ directly influence the magnitude of the base shear force, $_b$.

Table 5: Design Response Spectrum, $_d(_1)$ and Base Shear Force, $_b$ for each model

Model	Eff. Mass, *m* (ton)	$_{1(x)}$	$_{1(y)}$	$_d(_{1(x)})$	$_d(_{1(y)})$	$_{b(x)}$ (kN)	$_{b(y)}$ (kN)
NS	-	-	-	-	-	-	-
D-0.08	16445.23	1.686	1.599	0.483	0.510	7994.8	7123.5
D-0.12	16445.23	1.686	1.599	0.725	0.764	11917.2	10685.3
D-0.16	16466.16	1.686	1.598	0.967	1.020	15917.2	14272.7

B. Total Volume of Concrete

For the non-seismic and D-0.08 models total volume concrete for the RC beams, columns, walls and slabs is 4667.20 m^3. Meanwhile, for the D-0.12 model the volume of concrete is 4676.60 m^3. For the D-0.16 the total volume of concrete is 4669.70 m^3. The total volume of concrete for D-0.12 model is the highest due to the total volume of beam is higher compared to other models.

C. Influence of PGA Magitude on the Quality of Steel Reinforcement

The percentage difference in weight of steel needed for the whole building were 7.10%, 25.25% and 41.28% for αgR =

0.08g, 0.12g and 0.16g respectively compared to the non-seismic model as shown in Figure 3. There was a slight increment for weight of steel reinforcement required of the whole building for α_{gR} = 0.08g, 0.12g and 0.16g when compared to the non- seismic model. These were proved by [12] that a higher α_{gR}, a higher total weight of steel reinforcement per 1 m^3 concrete. Percentage difference will increase in the overall reinforcement's weight of the whole building between non-seismic and seismic designs [13].

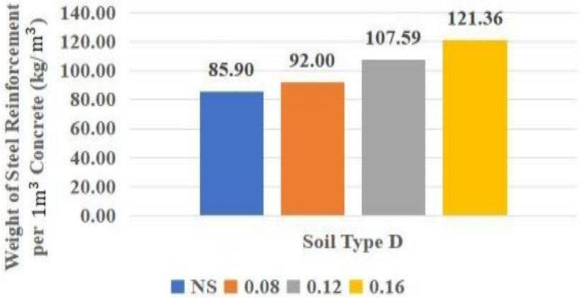

Figure 3: Total amount of steel required for 1 m^3 for the whole building

D. Total Steel Reinforcemet's Weight per Concreate Normalized to Model of Non-Seismic for Soil TypeD

As shown in Figure 4, the percentage of difference in weight of steel reinforcement per 1 m^3 concrete normalized to model of non-seismic for Soil Type D were 3%, 12% and 19% for αgR = 0.08g, 0.12g and 0.16g, respectively.

Based on the graph, it can be concluded that non- seismic model had the lowest amount of steel reinforcement required due to the lowest total steel reinforcement used for 1 m3 of concrete for beam and wall.

This result was proven by [5] that steel reinforcing increases for models with seismic design consideration. Model D-0.16 was the highest steel reinforcement's weight per 1 m^3 concrete normalized to themodel of non-seismic due to thehighest steel reinforcement usedfor 1 m^3 of concrete for beam, column and wall that resulted to the highest steel reinforcement used for 1 m^3 of concrete of the whole building.

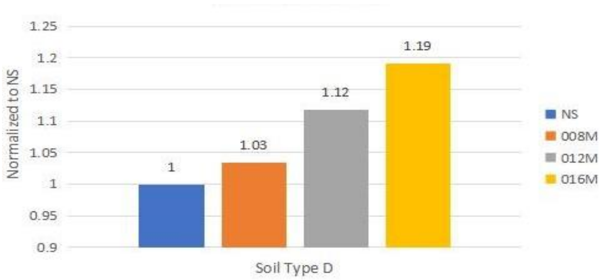

Figure 4: Total weight of steel reinforcement per 1 m^{3}concrete normalized to non-seismic model for Soil Type D

E. The Estimated Total Materials Cost for Soil Type D

Based on Malaysia's Standard Price (2021), the standardized concrete's price grade C30/37 per cubic meter is RM 370.90 while the standard price of steel bars per kilogram is around RM 4.00.

Figure 5 shows model D-0.16 had the highest cost estimation for structural work which was RM 3 945 982.72. This was due

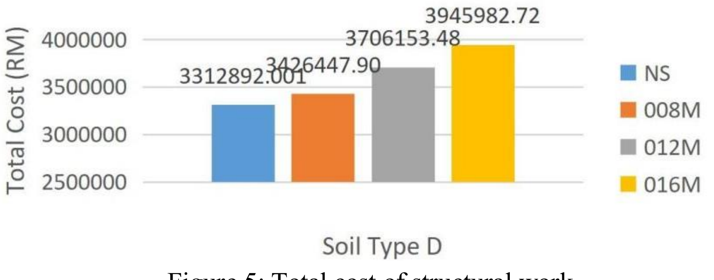

Figure 5: Total cost of structural work

to the highest total steel tonnage corresponds to model D-0.16.

As discussed by [3] previous work, the highest magnitude of base shear force, $_b$, highest total weight of steel reinforcement. Meanwhile, thelowest was non-seismic with total of RM 3 312 892.001 because the lowest total steel reinforcement required for the whole building. The percentage of difference in total cost of structural work were 3.43%, 11.87% and 19.11% when for αgR = 0.08g, 0.12g, and 0.16g accordingly.

V. Conclusion

For αgR = 0.08g, 0.12g and 0.16g the percentage difference total amount of steel required for 1 m^3 of concrete for the whole building when compared to non-seismic model was 7.10%, 25.25% and 41.28% for soil type D. Model D-0.16 had the highest total amount of steel required for 1 m^3 of concrete for the whole building to resist the seismic loading. Therefore, the result shows that level of seismicity has a big influenceon the amount of steel needed for overall beam, column and wall.

The amount of steel reinforcement required in a building was higher when it is subjected to a higher magnitude of PGA which was 0.16g compared to other models. Although, the total volume of concrete for D-016 is lower than D-0.12, the total cost (RM) for model D-0.16 is the highest total cost due to the total amount of steel required for the whole building is much higher compared to other models.

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