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Comparison in terms of Material Quantity Between Non-Seismic and Seismic Design for Selected Buildings in Malaysia

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ABSTRACT

Almost all buildings in Malaysia were previously designed for non-seismic loading. As such, the need to consider seismic load poses challenges for the engineers and project owners. In order to enlighten the stakeholders on the effect of adopting seismic design, the impact on building material cost and quantities must be investigated in advance. Although many studies have been conducted, the use of hypothetical building models and not considering the actual soil factors in Malaysia may yield unrealistic results. As such, this study is conducted with the aim to evaluate the change in the material quantities of the main frame members using six existing building models subjected to peak ground acceleration of 0.16g and situated on soil type D. The analysis, design and taking-off were conducted with the aid of Tekla Structural Designer software. The results showed significant increase in terms of the material quantity required for the main frame members when seismic design was considered. The increase in the concrete volume and reinforcement tonnage was calculated to be in the range of 6.92% to 404.86% and 3.23% to 563.94%, respectively. The development of high base shear force, the amplification of the seismic force by the soft soil, and relatively stringent detailing in DCM were identified as the contributing factors. With a broader spectrum of results, the stakeholder can anticipate the increase in the material cost for adopting seismic design that can be useful for design submission and project cost estimation.

Keywords: Seismic design; conventional design; concrete volume; steel reinforcement; ductility level

INTRODUCTION

Earthquakes are one of the natural disasters that cause widespread damage and claim the most lives. Although Malaysia is resided away from the 'Ring of Fire', past records have shown that Malaysia is susceptible to the long-distant Sumatran earthquake and local earthquakes. As an example, an earthquake with a magnitude of 6.0 Mw hit Ranau and Kundasang in June 2015, resulting in physical damage to public and private buildings. Recent geological activity in Malaysia suggests that the region is no longer immune to seismic events and is affected by both regional and local earthquakes (Tongkul 2021). The post-earthquake damage assessment in Ranau found that some reinforced concrete (RC) buildings are vulnerable to further structural deterioration (Marto et al. 2013). Consequently, the Malaysian Ministry of Public Works has reached a consensus that the seismic design review is critical for newly built structures in Malaysia (Adiyanto and Majid 2014) especially with the establishment of MS EN 1998-1: 2015 (National Annex 2017) that reflect the design requirements for Malaysia. However, the need to incorporate seismic design has raised concern to the local agencies and construction players particularly on the design submission and the potential increase in the construction, respectively. A significant amount of research has been conducted in Malaysia, concentrated on evaluating the concrete and reinforcing requirements for buildings subjected to non-seismic and seismic design (Adiyanto et al. 2019; Azman et al. 2019; Hong et al. 2020; Mustafa et al. 2019; Ramli et al. 2017; Roslan et al. 2019; Ghorbani, 2023). The findings showed that the concrete volume and steel reinforcement tonnage were highly dependent on various considerations such as ductility class, seismicity level and soil type. Nevertheless, these studies used fictitious and hypothetical building models that may not be realistic. In addition, the analysis was performed solely based on EC 8 before the establishment of Malaysia National Annex (NA) to Eurocode 8 (EC8). In this case, the soil factors that were used did not adequately represent the soil condition that was designated for Malaysia. Therefore, this study is conducted with the aim to compare the required amount of concrete and steel reinforcement between non-seismic and seismic design utilizing actual reinforced concrete (RC) building drawings. In addition, soil type D (soft soil) was adopted with soil factors that represent the soil condition for Malaysia. This study not only broadened the spectrum of results but most importantly yielded a more reliable and accurate results.

METHODOLOGY

In the modelling phase, a total of six existing RC building models with different building heights were generated using Tekla Structural Designer software as shown in Figure 1. The details of the buildings is presented in Table 1.

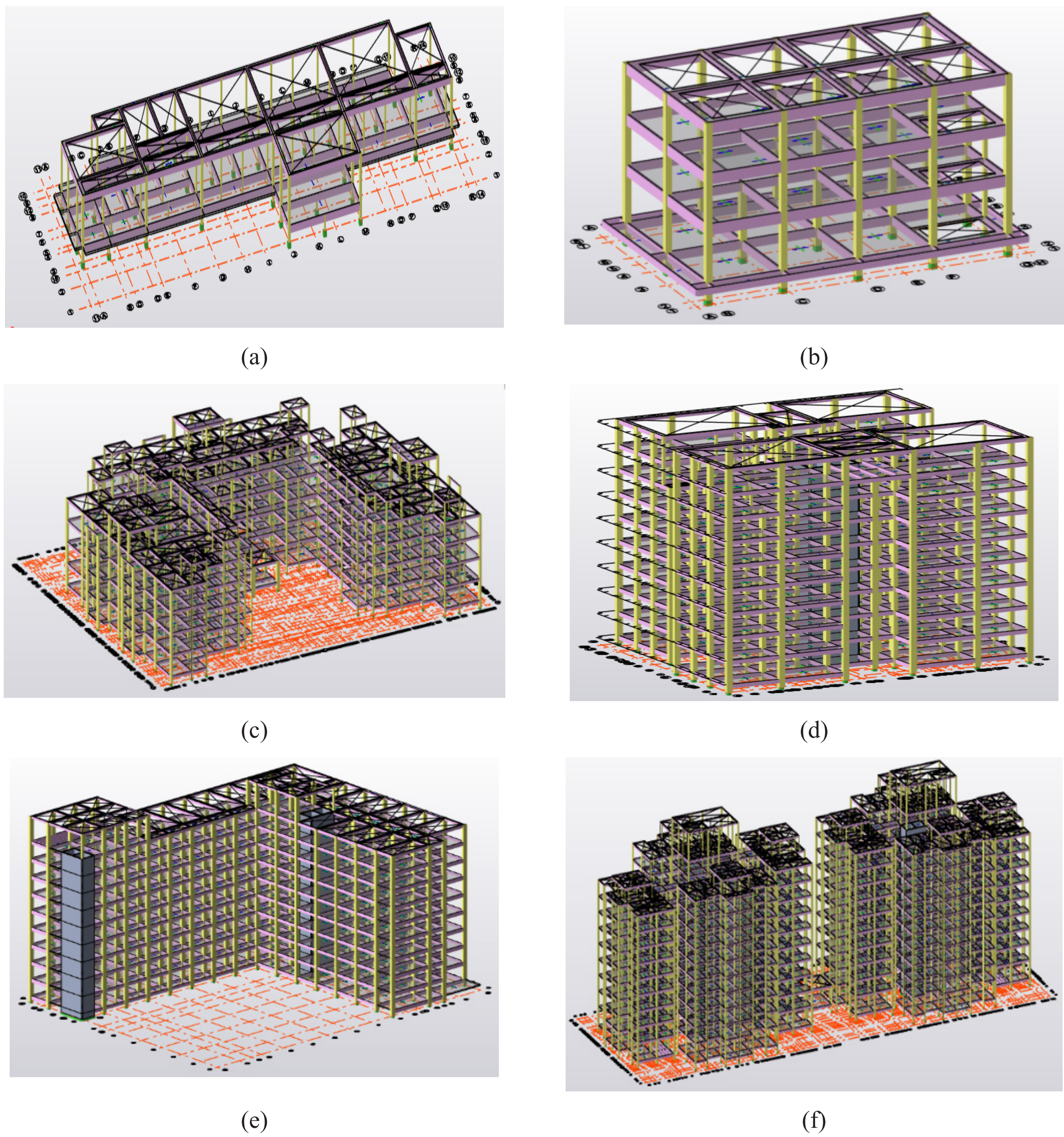

FIGURE 1. The 3D view of building models (a) Model N1 (b) Model N2 (c) Model N3 (d) Model N4 (e) Model N5 (f) Model N6

TABLE 1. Selected RC building models

Model	No. of Storey	Height (m)	Building Category	Concrete Compressive Strength, f_{ck}
N1	1	4.8	School	25 MPa
N2	3	12.2	Office	35 MPa
N3	5	19.2	Residential	30 MPa
N4	9	33.7	Residential	35 MPa
N5	10	38.9	School	35 MPa
N6	12	40.1	Residential	35 MPa

These existing buildings were previously designed based on BS8110 (BS, 1997) without the consideration of seismic loading. The RC building models were then analysed and designed according to EC8 (EC8, 2004) and Malaysia NA to EC8 (Malaysia NA, 2017). In this study, a reference peak ground acceleration (PGA) of 0.16g was chosen to represent a moderate seismicity region located in East Malaysia. Ductility class medium (DCM) was taken into consideration for seismic design and detailing. In addition, this study only considers soft soil type D as this type of soil can amplify seismic force (Ozmen 2023) and is also a type of soil defined under Malaysia condition. The design response spectrum followed the newly determined seismic parameters for Malaysia that includes soil factor and period parameters. Linear modal response spectrum analysis was performed with the aid of Tekla Structural Designer software package.

In all cases, the yield strength of the longitudinal and transverse reinforcement was set at 500N/mm^2 and 250N/mm^2, respectively. In addition, the base of the building was assumed to be rigidly fixed. The quantity of the main material of the actual buildings (previously designed without seismic provision) were determined via manual taking-off exercise from the drawings.

RESULTS AND DISCUSSION

The results and discussions on the influence of seismic design consideration with regards to the amount of concrete volume and steel tonnage for beams, columns and shear walls of the RC buildings are presented in the following sections.

CONCRETE QUANTITY FOR BEAMS

Figure 2 shows the comparison between the non-seismic and seismic design of the RC building models with regard to the amount of concrete volume required for beams. By setting the non-seismic design as the base line, the incorporation of seismic design, the volume of concrete for the beams in building models N1, N2, N3, N4, N5, and

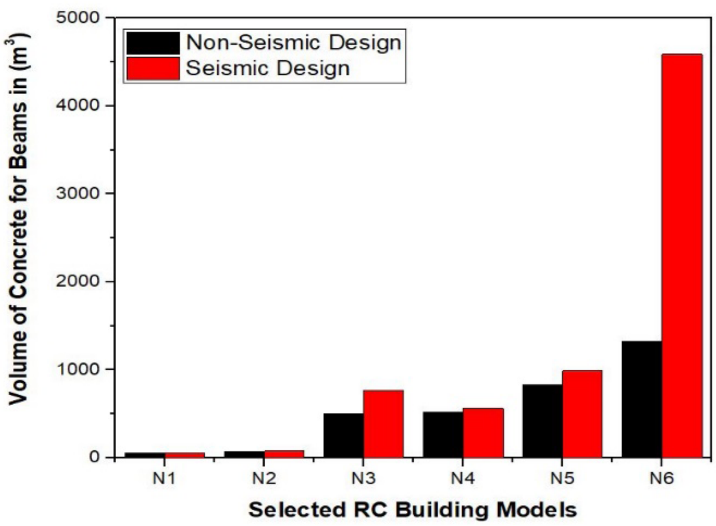

FIGURE 2. The quantity of concrete volume for beams with and without seismic design consideration

N6 increases by 0%, 12.35%, 53.02%, 9.62%, 19.14%, and 246.24%, respectively.

In the case of model N1, the amount of concrete for beams was not impacted by the seismic load and DCM detailing. This study suggests that the initial cross-sections of the concrete beams that were used in the non-seismic design can yield satisfactory results under seismic requirements.

As the seismic design is based on the DCM, the increase in the concrete volume for other models can be associated with the requirement of the internal force and ductility class. As an example, the magnitude of maximum bending moment, and the ductile detailing of DCM provision governed the amount of longitudinal steel reinforcement to be provided at each relevant section of the beam. The increase in the magnitude of maximum moment at a certain region of the beam, increases the steel reinforcement demand that led to the member enlargement.

In addition, the detailing part for DCM in EC8 requires that the reinforcement ratio at the tension zone of the beam, ρ shall not exceed the maximum reinforcement ratio of the tension zone, ρ_{max} (Malaysia NA, 2010; Fardis et al. 2015).

In addition, the increase in the concrete volume for beams shown by all models (except for model N1) are related to the critical region requirement of the structural members. Under the seismic loading, the beam-end regions are dominated by flexure where plastic hinges are likely to take place. Consequently, the steel reinforcement demand at the critical regions tends to increase the cross-section and concrete volume of the beams.

CONCRETE QUANTITY FOR COLUMNS

Figure 3 shows the percentage difference between non-seismic and seismic design requirements for columns. It can be seen that the incorporation of seismic design causes the concrete volume to escalate. In the case, the increase was calculated to be 403.86%, 44.47%, 119.93%, 23.57%, 27.02%, and 134.17%, for building models N1, N2, N3, N4, N5, and N6, respectively. As such, the seismic design considerations appear to have a significant impact on the column. This is particularly true due to the fact that the columns act as vertical member that need to resist lateral load.

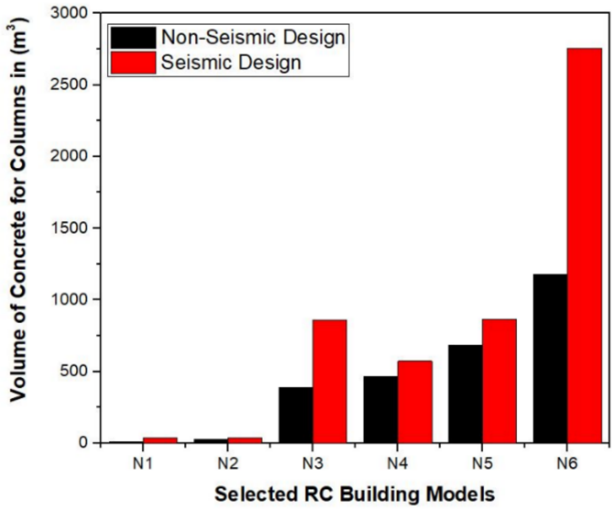

FIGURE 3. The quantity of concrete volume for columns with and without seismic design consideration

In the case of DCM detailing, the presence of critical regions in the primary columns leads to an increase in the volume of concrete for columns in the frame building via the additional detailing requirements. The critical regions are considered up to a distance l_{cr} which is adjacent to both end of a primary column. In the case where $l_{cr}/h_c < 3$, the whole height of the column between floors is taken as being the critical region.

These findings can be associated to the selection of the column cross-sectional dimensions as a necessary input to the analysis of the structural system which in turn governs the design. In this case, dimensioning of a column depends on the amount of the steel reinforcement in the column. In this study, enlargements of the cross-sections tend to increase the volume of concrete when the minimum dimension of 200 mm cannot accommodate the steel reinforcement required in the primary seismically designed columns.

The enlargement of the column size has resulted in the increase of the effective seismic building mass, m and reduces fundamental period of vibration T1. As a result, the building become stiff and generated high base shear.

Moreover, the concrete demand was also affected by the detailing requirement of the primary columns in DCM as specified in EC8. The ratio of longitudinal reinforcement in the columns was limited up to 4% for sufficient resistance and stiffness under seismic considerations. Moreover, this requirement also avoids the over-congested reinforcement conditions in the undersized columns.

For RC building models that are subjected to seismic loads, the significant concrete demand in the structural columns relative to the beams can be attributed to the unique capacity design principles (the strong column – weak beam concept). In this study, the column design is strongly related to the beam where the design moments of resistance of the columns framing the joint, M_{Rc} is derived to be greater than or equal to 1.3 times the design moments of resistance of the beams, M_{Rb} framing the same joint as stated by Fardis et al. (2015). In this study, the strong column – weak beam concept shows to be more profound on the concrete demand for columns in the lower building compared to the taller building. As such, the highest percentage increase in the volume of concrete for columns is reflected for the case of single storey building model N1 compared to other models.

CONCRETE QUANTITY FOR WALLS

The difference in concrete demand for seismic and non-seismic design for wall is shown in Figure 4. The concrete volume of the walls for building model N4, N5, and N6 was found to be higher by approximately 66.49%, 68.76%, and 173.73%, respectively than that of the non-seismic design.

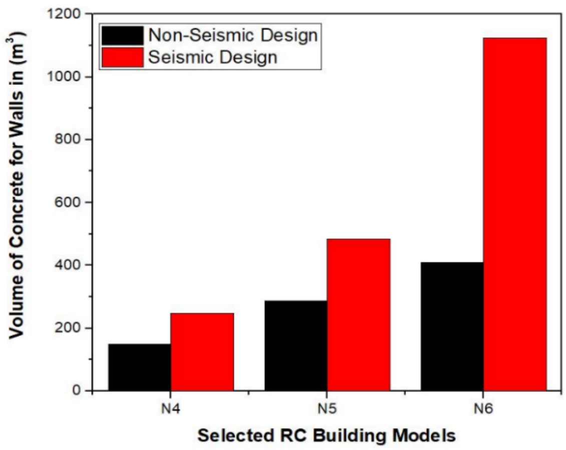

FIGURE 4. The quantity of concrete volume for walls with and without seismic design consideration

The additional demand in the concrete volume for adopting seismic design can be associated to the provision of the critical regions of the walls dominated by flexure deformation under seismic loading. In this case, the maximum value of the seismic moments occurred at the end sections namely, the base of the wall, at the connection to the foundation and the top of a rigid basement in the case of frame equivalent dual system (as reflected in model N4, N5 and N6). This requirement resulted in a heavily reinforced section that requires enlargement of the wall thickness.

Furthermore, the seismic design in DCM for walls is also affected by the requirement of the confining reinforcement inside the region of the boundary elements. This is due to the fact that seismic forces tend to concentrate near boundary elements. It is important to note that this area is also extensively reinforced, and that the distance between the vertical reinforcements is not allowed to exceed 200mm. As a result, when the reinforcement ratio at the boundary element is more than 4%, the thickness of the wall is increased.

WEIGHT OF THE LONGITUDNAL REINFORCEMENT FOR BEAMS

Figure 5 shows that the longitudinal reinforcement tonnage for beams in the building models N1, N2, N3, N4, N5, and N6 increases up to 18.57%, 26.64%, 402.72%, 563.94%, 180.22%, and 828.16%, respectively.

The concept of capacity design and the DCM provisions of seismic reinforcement detailing incorporated in the RC framed building play a large part in influencing these findings. The high demand of longitudinal reinforcement for beams is likely due to the presence of high bending moment generated by the high base shear force for adopting seismic loading. These findings can also be associated to the specific requirements on the longitudinal reinforcement for the detailing of the primary beams in DCM. In this case, the increase in the amount of longitudinal reinforcement is influenced by the provision of minimum reinforcement ratio at the tension zone.

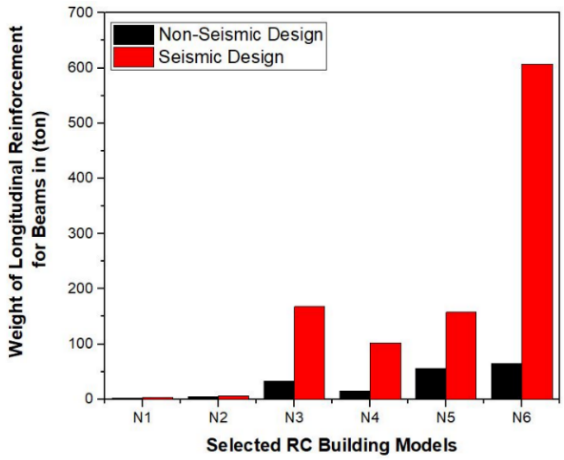

FIGURE 5. The weight of longitudinal reinforcement for beams with and without seismic design consideration

WEIGHT OF THE TRANSVERSE REINFORCEMENT FOR BEAMS

The comparison between the non-seismic and seismic consideration for the transverse reinforcement of beam is shown in Figure 6. It can be seen that the reinforcement demand for incorporating seismic design significantly increase the quantity, and particularly true model N3, N4, N5 and N6. The increase was calculated to be 12.5%, 3.23%, 272.14%, 240.63%, 193.02% and 296.63% for model N1, N2, N3, N4, N5 and N6, respectively.

The finding is particularly true due to the compliance requirements of the design shear with based on the capacity design rule. As specified in EC8, the design shear force of the primary beams is determined on the equilibrium of the beam under the transverse load acting and the end moments M_{id}. Two values of the shear force namely, the maximum, $V_{Edmax,i}$ and minimum, $V_{Ed,min,i}$ corresponding to the maximum positive and maximum negative end moment need to be determined . Ultimately, the prevention of the shear failure under the capacity design principles controls the required amount of the transverse reinforcement in the seismically designed beams.

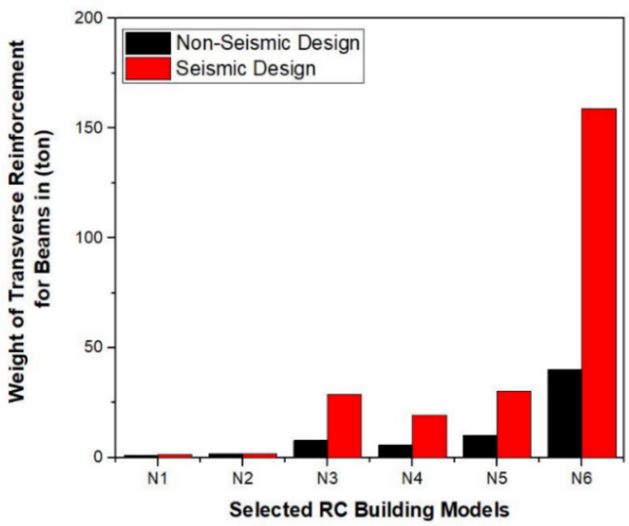

FIGURE 6. The weight of transverse reinforcement for beams with and without seismic design consideration

Furthermore, the increase in the usage of the transverse reinforcement for the RC beams can be associated to the requirements of the minimum diameter of the hoops, d_{bw} of 6 mm as prescribed in EC8 to accommodate the design shear forces in the beams. Moreover, the additional amount of reinforcement required causes an increase in the transverse reinforcement for the beams as the placement of the hoops was limited up to the maximum spacing. The DCM provision in EC 8 stated that the spacing of hoops should be designed based on the minimum value between the quarter of the beam depth, h_w, the 24 times diameter d_{bw} of the hoops and the 8 times the minimum diameter of the longitudinal reinforcement, d_{bL}. Nevertheless, the maximum spacing between hoops, s_{max} is restricted to 225 mm within the critical regions of the primary beams.

WEIGHT OF THE LONGITUDINAL REINFORCEMENT FOR COLUMNS

Figure 7 shows the reinforcement tonnage for columns. Tt can be seen that the increase of longitudinal reinforcement embedded in the seismically designed RC columns differ substantially from the non-seismic designed and particularly true for all cases. The increase calculated to be 262.34%, 154.46%, 119.87%, 156.77%, 114.77% and 180.41% for model for model N1, N2, N3, N4, N5 and N6, respectively.

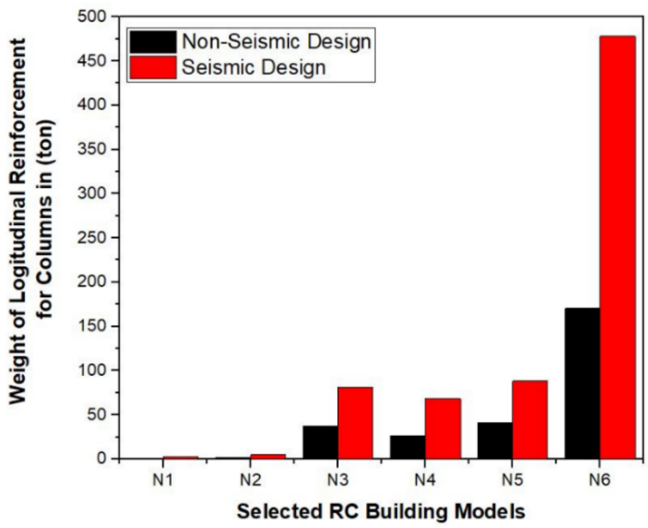

FIGURE 7. The weight of longitudinal reinforcement for columns with and without seismic design consideration

The analysis and design carried out in this study showed that the amount of longitudinal reinforcement for the detailing purpose of primary columns is mainly controlled by the additional requirements of local ductility demand as stated in EC 8. It is interesting to note that the longitudinal reinforcement with a minimum ratio of 1% is provided in the column has resulted in the increase of the steel tonnage compared to only 0.4% minimum requirement set by Table 3.25 of BS 8110. In order to ensure the integrity of the beam-column joints, the number of provided steel reinforcement is increased due to the requirement of at least one intermediate bar between corner bars for each side of the column according to Clause 5.4.3.2.2 (2)P of EC8. Consequently, a minimum of 8 longitudinal bars is required in a rectangle shaped-column to meet this requirement.

WEIGHT OF THE TRANSVERSE REINFORCEMENT FOR COLUMNS

Figure 8 shows the difference between non-seismic and seismic design for the transverse reinforcement in columns. The increase in the transverse reinforcement of columns for model N1, N3, N5, N9, N10, and N12 was calculated to be 42.76%, 18.75%, 31.88%, 29.75%, 26.32%, and 140.4%, respectively.

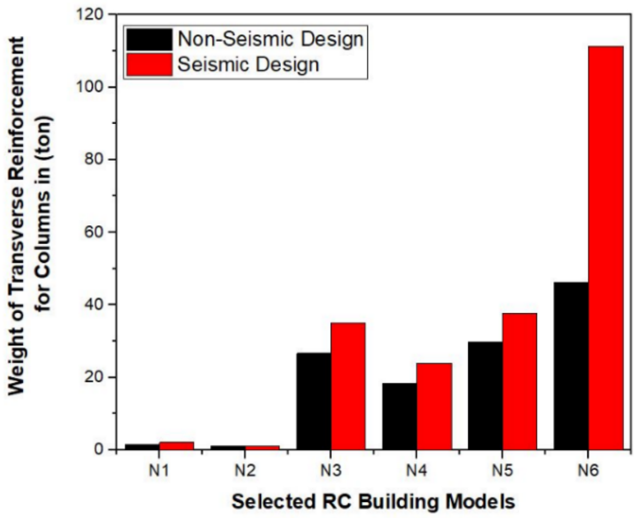

FIGURE 8. The weight of transverse reinforcement for columns with and without seismic design consideration

The increase in the weight of the transverse reinforcement for columns can be associated with the prevention of shear failure in the column design that is required to resist the earthquake forces. Concrete is known to be a quasi-brittle material (Bazant 2019); therefore, the concrete columns are inherently brittle in shear under monotonic or cyclic loading. The brittle shear failure of the column prior the occurrence of flexural yielding can be prevented by enforcing the capacity design rule in accordance with EC8. The capacity design shear in the columns is based on the flexural capacities of the most critical members around a joint. If the plastic hinges formed first at the ends of the beams connected to the joints into where the column end frames, the capacity design shear of the column is based upon the beam flexural capacities. Otherwise, the plastic hinges are taken to form at the ends of the columns. The flexural ductility of the columns is improved by using closed stirrups to confine the concrete and prevent the longitudinal reinforcements from buckling.

In addition, the amount of transverse reinforcement of the columns is obtained based on the minimum requirements for the seismic detailing in DCM. The cross-sectional area of providing the transverse reinforcement is directly influenced by the selection of its size, spacing and number. The hoops and cross-ties of at least 6 mm in diameter are provided in the columns at the designated spacing to ensure the minimum ductility and prevent the local buckling of the longitudinal reinforcements. The spacing of hoops is determined according to the minimum value between the half of the confined core width, b_o in a column and the 8 times diameter of the longitudinal reinforcement, d_{bL}. However, the maximum permissible distance between the hoops within column's critical regions is limited up to 175 mm in accordance with Clause 5.4.3.2.2(11) of EC8. Hence, the small spacing requirement has resulted in the higher number of hoops in the critical regions compared to the other regions. Moreover, the provision of extra confining hoops (for an adequate confinement around the perimeter of the column core) also contributes to the increase in the transverse reinforcement. In seismic design, the mechanical volumetric ratio of the confining hoops at a minimum value of 0.08 is required within the critical region at the base of the primary seismic columns in DCM as stated in Clause 5.4.3.2.2(9) of EC8. Besides decreasing the spacing, adjustments were made on the hoops by increasing the number and/or diameter to meet this requirement which in fact, added the total transverse reinforcement tonnage for the columns.

TOTAL WEIGHT OF REINFORCEMENT FOR WALLS

As shown in Figure 9, the incorporation of seismic design significantly affects the longitudinal reinforcement demand in shear walls. In this case, the increase was calculated to be up to 238.56%, 267.65%, and 275.66% for model N4, N5, and N6, respectively.

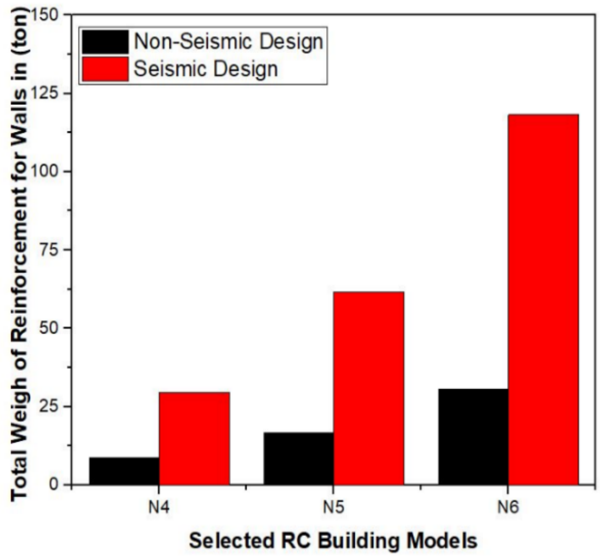

FIGURE 9. Total weigh reinforcement for walls

The increase in the demand of the longitudinal reinforcement can be associated to the magnitude of the base shear forces generated from the seismic force. Based on Tekla design output, it was noted that the value of the base shear force for model N4, N5 and N6 showed to be 9442.1 kN, 15494.9 kN and 51690.7 kN, respectively. It can be expected that these base shear forces that are distributed along the building height (in the form of storey shear) exceeded the corresponding lateral force generated by the wind load. In addition, the use of soil type D that is able to amplify the seismic force towards the building also contributes to this phenomenon.

In addition, the seismic detailing specifications of the vertical bars in the boundary elements and web, govern the amount of the longitudinal reinforcement for the walls. With emphasis on achieving a moderately ductile behavior for RC walls in DCM, the longitudinal bars were chosen on the basis of the prescriptive minimum requirement, particularly in term of the reinforcement ratio. The minimum vertical reinforcement ratio over cross-sectional area of the confined boundary element is extended up to 0.5% to ensure the moderate ductile response of the RC shear walls during seismic loading.

CONCLUSIONS

The increase in terms of the material quantity, both concrete and steel reinforcement of the main frame members can be significantly affected by the incorporation of seismic load. The trend became more apparent for column and wall, and particularly true with the increase in the building height. The main reason for these findings was associated to the development of high base shear force, the amplification of the seismic force by the characteristics of the soft soil, and relatively stringent detailing in DCM in the form of the local ductility and the limit of the reinforcement ratio. As such, the local agencies and the construction players can anticipate the increase in the material cost for adopting seismic design. However, since the PGA in this study was set to be 0.16g and the use of DCM detailing, the results are not applicable to low seismicity region such as 0.09g in Kuala Lumpur and 0.5g in Penang.

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DECLARATION OF COMPETING INTEREST

None

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