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Influence of the Malaysia's National Annex for Seismic Design on the Size and Reinforcement Weight of Low-rise Buildings

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Abstract. In early 2017, Malaysia's national annex for the seismic design of structures was published and led to some concerns regarding the increase in the construction cost of buildings. This study investigated the change in the reinforcement weights of beams and columns due to seismic design based on Malaysia's national annex. For this purpose, buildings with different numbers of stories (i.e., 3- and 6-storey), ductility classes (i.e., low and medium), and soil types (i.e., stiff and soft soil) were designed through two different methods. The first method followed the conventional design practice in Malaysia, in which the BS 8110 code was used to design structural elements only for gravity loads. However, the second design method was based on Malaysia's national annex and Eurocode 2, and buildings were designed for gravity loads and seismic actions. The results showed that buildings with low ductility class constructed on the soft soil had the largest increase in the reinforcement weights compared to the conventional design. On the other hand, the buildings with medium ductility class constructed on stiff soil had lesser reinforcement weights than the conventional design.

1. Introduction

The majority of buildings in Malaysia have not been designed against seismic actions mainly because the country is located in a low seismicity region. Therefore, since many buildings have been designed only for gravity loads, they have become vulnerable against ground motions [1–4]. For instance, on 5th June 2015, an earthquake with the magnitude of Mw 6 hit Sabah, Malaysia, and imposed significant damage to the public buildings of Ranau city [5]. Since then, many efforts were made to establish a local seismic design guideline. In early 2017, the Malaysia National Annex to Eurocode 8 [6] was released, and design engineers were asked to employ it for the seismic design of buildings in Malaysia.

Soon after the release of the national annex, some concerns arose regarding the increase in new buildings' construction costs due to the inclusion of seismic forces. In order to address this issue, some researchers worked on the construction cost of new buildings designed according to the Malaysia national annex. For example, Ramli et al. [7] compared the required reinforcement bars in beams and columns of 5- and 10-story buildings designed for gravity loads with buildings that designed for seismic actions according to Eurocode 8 [8]. They assumed that all buildings are constructed on soil type D. Besides, they altered the ductility class of buildings according to the assumed peak ground accelerations (PGA). The building subjected to the PGA of 0.06g had a low ductility class while the other buildings had the medium ductility class. They reported that compared to the gravity load-designed building, the reinforcement weight of the 5-story building showed up to 33% increase while that of the 10-story building exhibited up to 62% increase.

In another study, Adiyanto and Majid [9] compared the seismic response of 2-story reinforced concrete (RC) frames that were designed using behaviour factors (q) of 1 and 1.5 with RC frames that were only designed for gravity loads. They assumed that all buildings were constructed on soil type D. Besides, the design PGAs of RC frames ranged from 0.02g to 0.12g. They reported that when q=1, the increase in the construction cost of RC frames reached 270%. However, when q=1.5, the increase in the construction cost of RC frames was up to 72%. Hong et al. [10] worked on the cost analysis of 2- and 4-story school buildings in Sabah, Malaysia. They designed 14 school models according to Eurocode 2[11] and Eurocode 8 [8]. All school buildings were located in Ranau, Sabah, and their reference peak ground accretion was 0.16g. They employed the medium ductility class for the seismic design of all school buildings; however, the soil type varied from stiff soil to soft soil. They reported that the soil type had a significant influence on the construction cost of school buildings. Compared with gravity load-designed buildings the increase in the construction cost was up to 110% for the 2-story building and up to 55% for the 4-story building.

It should be mentioned that similar studies have been conducted in other countries to assess the increase in the construction cost of buildings when seismic design specifications are considered. For example, Rodrigues and Elawady [12] designed RC frames with different ductility classes according to the provisions of Eurocode 2 [11] and Eurocode 8 [8] and compared their seismic performance and construction costs. They concluded that the required materials for frames designed with medium and high ductility were close to each other in the high seismic zone. However, the construction cost of frames with high ductility was higher due to the higher workmanship cost needed for seismic detailing of high ductile frames. On the other hand, in the moderate seismic zone, the frames designed with medium ductility were more economical than other frames. They also found that the construction cost of frames designed with low ductility was less than other frames in the low seismic zone. Drivas [13] also found almost similar results for RC buildings constructed in Sweden. In their study, RC buildings with low and medium ductility classes were designed according to Eurocode 2 [11] and Eurocode 8 [8] for different PGAs of 0.10g, 0.16g, 0.22g, and 0.28g. Results indicated that the construction cost of buildings was lower when for large PGAs, high ductility class was used and for low PGAs, low ductility class was employed.

This study evaluates the influence of Malaysia’s national annex for seismic design on the size and reinforcement weight of RC residential buildings. The effects of ductility class, soil type, and number of stories have been taken into account. Comparison has been made between the beam and column sizes and reinforcement weight of gravity load-designed buildings and those designed based on Malaysia’s national annex.

2. Investigated buildings

Figure 1 shows the plan of the selected buildings. In this study, 3- and 6-story residential RC buildings were designed once only for gravity loads using BS8110 [14], and then for gravity and seismic actions using Eurocode 2 [11] and Malaysian national annex [6]. The height of the first floor was 4 m and the other floors’ height was 3.0 m. The compressive strength of concrete and the yield stress of reinforcing bars were assumed 30 MPa and 400 MPa, respectively. The applied live and dead loads on floors were, respectively, 2 kN/m^2 and 5.3 kN/m^2. In the seismic design, two types of soil conditions were investigated; soft soil (i.e., soil type D of the Malaysia national annex) and stiff soil (i.e., soil type A of the Malaysia national annex). Besides, two types of ductility classes were used in the seismic design; ductility class low and ductility class high as per Malaysia’s national annex requirements.

The reference peak ground acceleration (a_{gR}) was assumed to be constant for all buildings and equalled 0.1g. As shown in table 1, ten buildings were designed for different soil conditions and ductility classes. The values for the seismic design parameters in table 1 have been selected based on the Malaysia National annex [6]. The buildings were named based on their number of stories (i.e., N3 and N6 in table 1), ductility classes (i.e., L for low and H for high), and soil conditions (i.e., A for stiff soil and D for soft soil). In table 1, the N3-G and N6-G are the 3-story and 6-story buildings designed only for gravity loads. As shown by equation 1, the lateral force method of analysis was used to determine the base shear of buildings. In this equation, S_d (T1) is the ordinate of the design spectrum at the fundamental period (i.e., T_1) of the building, m is the seismic mass of a building, and λ is the correction factor. Besides, the fundamental period of buildings was estimated by equation (2) based on Malaysia's national annex. In this equation, H is the height of the building, and C_t is a coefficient that equals 0.075 for moment resistance concrete frames. The load combination for buildings designed only for gravity loads was based on BS8110 [14], as shown in equation (3). However, as shown in equations (4) and (5), the load combinations for buildings designed for gravity and seismic actions were based on Eurocode 8[8]. In these equations G_k and Q_k represent the dead and live loads, respectively, and EQ shows the earthquake force.

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

$$T_1 = C_t \, H^{3/4} \tag{2}$$

$$1.4 \, G_k + 1.6 \, Q_k \tag{3}$$

$$1.35 \, G_k + 1.5 \, Q_k \tag{4}$$

$$1.0 \, G_k + 0.3 \, Q_k + 1.0 \, EQ \tag{5}$$

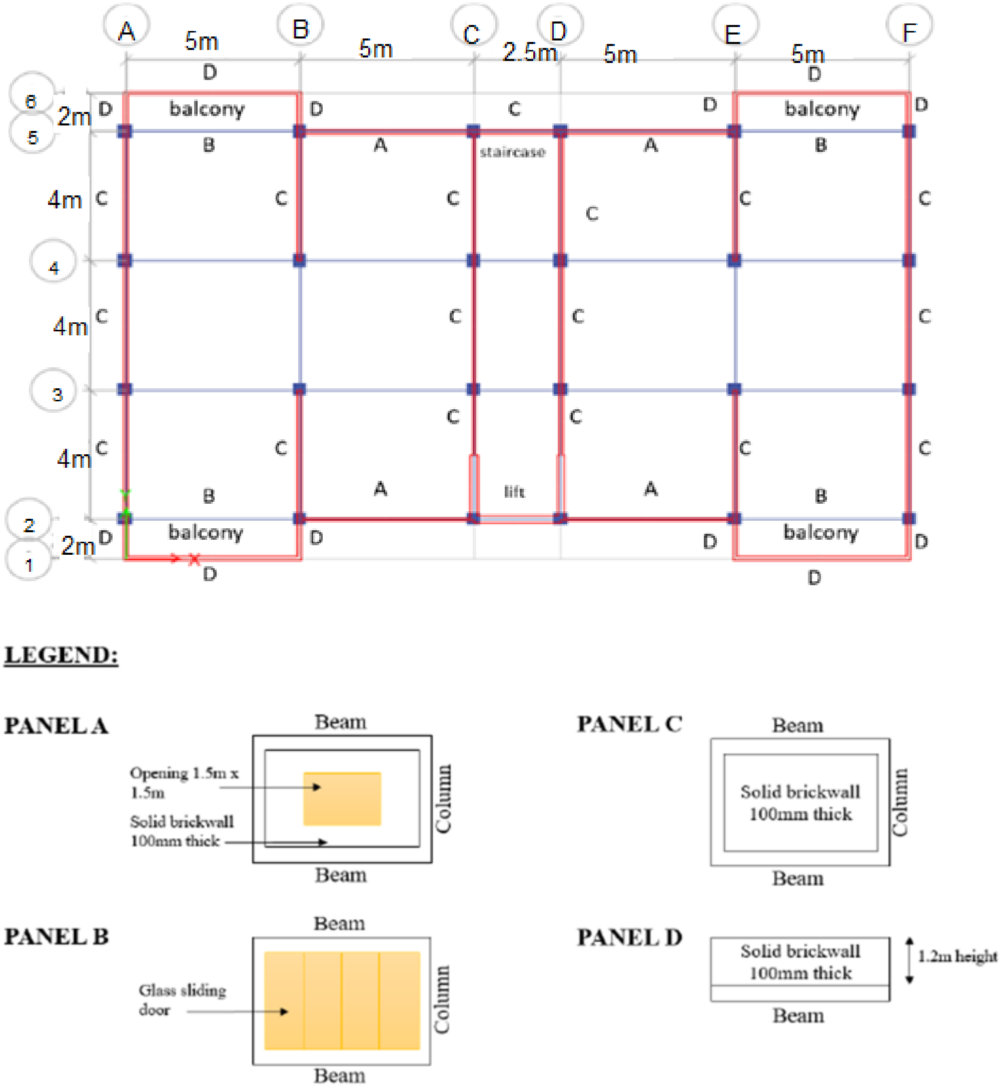


Figure 1. Schematic view of the plan of selected structures.

Table 1. Considered parameters in the seismic design of buildings.

Building name	H (m)	C_t	T_1	S	T_B	T_C	T_D	ß	q	a_g (m/s^2)	$S_d(T_1)$
N3-G	10	-	-	-	-	-	-	-	-	-	-
N3-LA	10	0.075	0.42	1.0	0.05	0.2	2.2	0.2	1.5	1.0	0.78
N3-LD	10	0.075	0.42	1.35	0.3	0.8	2.2	0.2	1.5	0.85	2.21
N3-MA	10	0.075	0.42	1.0	0.05	0.2	2.2	0.2	3.9	1.0	0.30
N3-MD	10	0.075	0.42	1.35	0.3	0.8	2.2	0.2	3.9	0.85	0.72
N6-G	19	-	-	-	-	-	-	-	-	-	
N6-LA	19	0.075	0.68	1.0	0.05	0.2	2.2	0.2	1.5	1.0	0.48
N6-LD	19	0.075	0.68	1.35	0.3	0.8	2.2	0.2	1.5	0.85	1.88
N6-MA	19	0.075	0.68	1.0	0.05	0.2	2.2	0.2	3.9	1.0	0.18
N6-MD	19	0.075	0.68	1.35	0.3	0.8	2.2	0.2	3.9	0.85	0.72

3. Results and discussions

The cross-section sizes of beams and columns for 3- and 6-story buildings have been compared in tables 2, 3 and 4. As can be seen from these tables, the ductility class and soil type of buildings have affected the column sizes more than the beam sizes. The maximum increase in the cross-section size of beams and columns has occurred when buildings have been constructed on soft soil with low ductility (i.e., N3-LD and N6-LD). On the other hand, compared with the gravity load-designed buildings (i.e., N3-G and N6-G), the sizes of beams and columns have remained almost unchanged when buildings have been constructed on the stiff soil with low or medium ductility. Besides, buildings constructed on soft soil with medium ductility have shown a small increase in their beams and columns sizes. It is also noteworthy that the ground floor has shown more changes in the sizes of beams and columns compared with upper floors.

Figures 2 and 3 compare the obtained reinforcement weights for the gravity load-designed buildings with that of seismic load-designed buildings. In order to calculate these weights, at first, the construction drawings of beams and columns were prepared using the calculated reinforcement areas by the ETABS software. Then, manually, the weight of reinforcing bars in each beam and column was obtained and combined. It is evident from these figures that the soil type and ductility class of buildings have had a great effect on the calculated reinforcement weights. As shown in figure 2, the beams and columns' reinforcement weights in the building with medium ductility constructed on stiff soil (N3-MA) are, respectively, 15.5% and 35.8% less than the gravity load-designed building (i.e., N3-G). Similarly, the obtained reinforcement weights for the beams and columns of N6-MA are, respectively, 9.5% and 11.3% less than that of the gravity load-designed building (i.e., N6-G).

The reason for the decrease in the reinforcement weights relies on the employed load combination factors. As shown in equations (3) to (5), the gravity load-designed buildings employ the proposed load combination factor by BS8110, which has been the practice design code before the publication of Malaysia's national annex. In this load combination, the dead and live loads are multiplied, respectively, by 1.4 and 1.6. On the other hand, the dead and live load factors for buildings designed for seismic actions according to Eurocode 8 are, respectively, 1.35 and 1.5 that are smaller than that of the BS8110 code. Furthermore, since buildings designed based on the medium ductility class on the stiff soil have an insignificant seismic force, the calculated axial force, bending moment, and shear force based on equations (3) and (4) become smaller than that of equation (3). Consequently, the reinforcement weights also become less than the gravity load-designed buildings.

It can be seen from figures 2 and 3 that the maximum increase in the reinforcement weights occurs when buildings are constructed on soft soil and with low ductility. For example, for the low ductile 3-story building (i.e., N3-LD), the increase in the reinforcement weights of beams and columns are, respectively, 37.8% and 59.5%. Similarly, compared with the gravity load-designed building, the low ductile 6-story building constructed on the soft soil (i.e., N6-LD) has shown 62.6% and 63.8% increase in beams and columns' reinforcement weights. It is also noteworthy that the N3-LA and N6-LA buildings have shown, respectively, 4.5% and 0.8% decrease in their beams' reinforcement weights compared with the gravity load-designed buildings. On the other hand, compared with the gravity load-designed buildings, the N3-MD and N6-MD have shown, respectively, a 7.4% and 19.3% increase in their beams' reinforcement weights. This observation implies that the effect of soil type on the beams' reinforcement weight has been more than the employed ductility classes.

The change in the total reinforcement weights (i.e., beams and columns) compared with the gravity load- designed buildings have been shown in table 5. The negative sign shows an increase in the reinforcement weight in this table, while a positive sign indicates a decrease in the total reinforcement weight. It is evident that in both 3-and 6-story buildings, the maximum increase in the reinforcement weights has occurred when they have been constructed on the soft soil and with low ductility. Besides, when buildings have been constructed on stiff soil and with medium ductility the reinforcement weights have been less than the gravity load designed buildings. It can also be seen that the use of medium ductility class has resulted in the least increase in the reinforcement weights on both stiff and soft soils.

Table 2. Obtained sizes for the beams and columns of 3-story buildings.

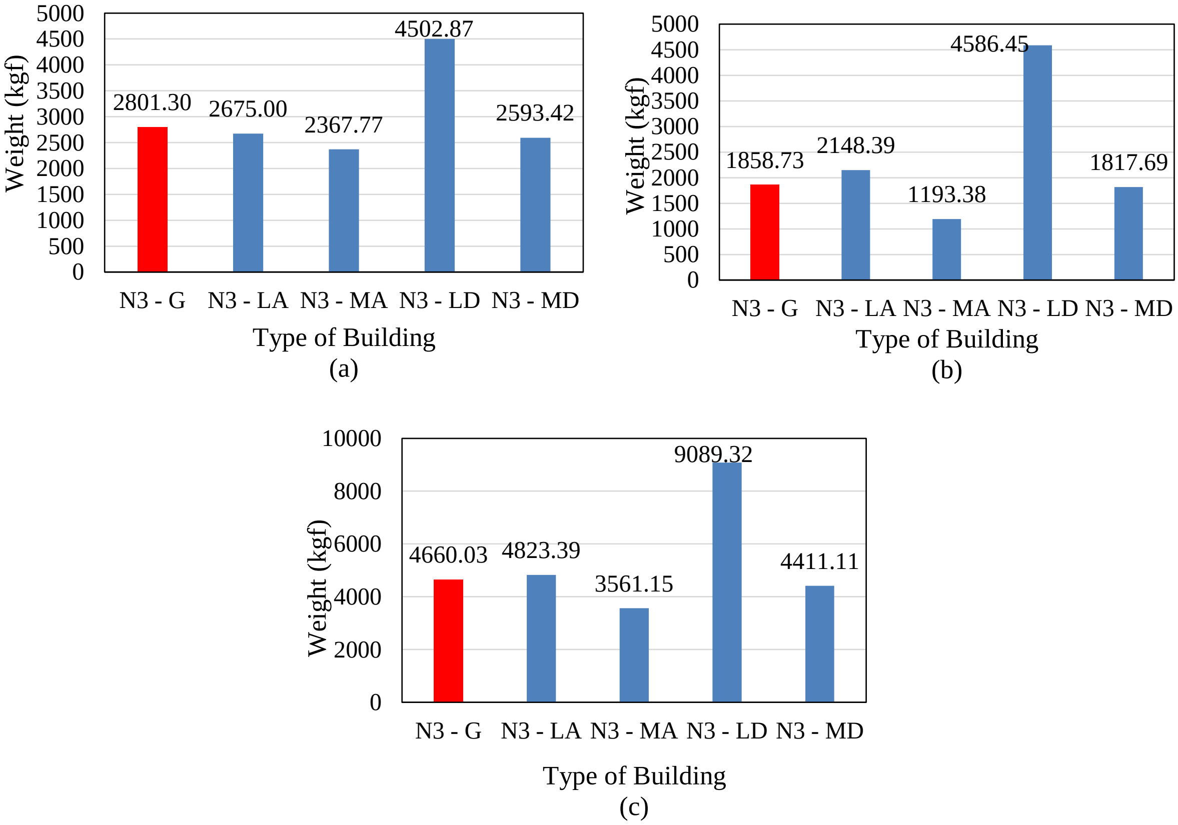
Building Name	**Column size (mm)**			**Beam Size (mm)**		
	Story 1	**Story 2**	**Story 3**	**Story 1**	**Story 2**	**Story 3**
N3-G	300x300 250x250	250x250 200x200	200x200	300x250	300x200	300x200
N3-LA	300x300	250x250	200x200	300x250	300x200	300x200
N3-MA	250x250	200x200	200x200	300x250	300x200	300x200
N3-LD	400x400	300x300	300x300	400x300	300x300	300x250
N3-MD	300x300	250x250	200x200	300x250	300x200	300x200

Table 3. Obtained sizes for the columns of 6-story buildings.

Building Name	**Column size (mm)**					
	Story 1	**Story 2**	**Story 3**	**Story 4**	**Story 5**	**Story 6**
N6-G	350x350 300x300	350x350 300x300 250x250	300x300 250x250	250x250 200x200	250x250 200x200	250x250 200x200
N6-LA	350x350 300x300	300x300 250x250	300x300 250x250	250x250 200x200	250x250 200x200	200x200
N6-MA	350x350 300x300 250x250	300x300 250x250	250x250 200x200	250x250 200x200	200x200	200x200
N6-LD	650x650	600x600	550x550	400x400	350x350	350x350
N6-MD	400x400 350x350 300x200	350x350 300x300	300x300	300x300 250x250	300x300 250x250 200x200	300x300 250x250 200x200

Table 4. Obtained sizes for the beams 6-story buildings.

Building Name	Beam Size (mm)					
	Story 1	Story 2	Story 3	Story 4	Story 5	Story 6
N6-G	300x250	300x250	300x200	300x200	300x200	300x200
N6-LA	300x250	300x250	300x250	300x200	300x200	300x200
N6-MA	300x250	300x250	300x200	300x200	300x200	300x200
N6-LD	500x450	450x450	450x400	400x350	400x300	400x300
N6-MD	350x300	350x300	300x300	300x250	300x200	300x200

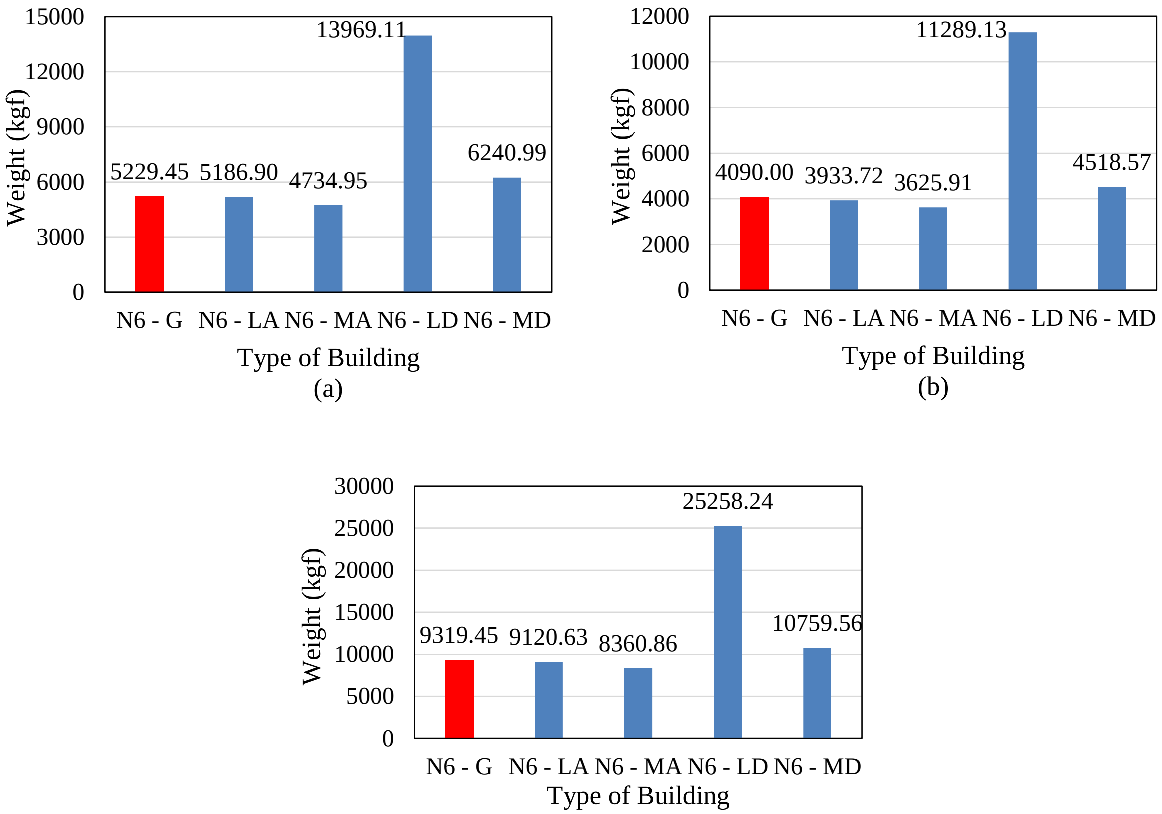


(a)

(b)

(c)

Figure 2. Obtained reinforcement weights for the beams and columns of 3-story buildings (a) beams (b) columns (c) summation of beams and columns.



(a) (b)

(c)

Figure 3. Obtained reinforcement weights for the beams and columns of 6-story buildings (a) beams (b) columns (c) summation of beams and columns.

Table 5. Change in the total weight of reinforcements.

Building Name	Reinforcement weight change (%)
N3-LA	-3.5
N3-MA	+23.6
N3-LD	-95.1
N3-MD	+5.3
N6-LA	+2.4
N6-MA	+10.1
N6-LD	-172.5
N6-MD	-16

4. Conclusions

The main focus of this study was on the cost analysis of buildings that have been designed for seismic actions according to Malaysia's national annex. For this purpose, ten typical reinforced concrete residential buildings were designed for gravity loads based on the BS8110 code and the combination of gravity loads and seismic actions based on Malaysia's national annex. The selected buildings had three and six stories with two different ductility classes (i.e., low and medium). Besides, two different soil types were considered in the seismic design of buildings. The obtained results indicated that the soil type and ductility class significantly influenced the cross-section sizes of beams and columns, especially at the ground level. Buildings constructed on the soft soil and with a low ductility exhibited significantly larger cross-section sizes for beams and columns when compared with the gravity load-designed buildings. However, the effect of seismic actions on beams and columns' cross-section size was insignificant when buildings were constructed on stiff soil with a low or moderate ductility level. The increase in the reinforcement weights of beams and columns was up to 95.1% for the 3-story building and up to 172.5% for the 6-story buildings. Such an increase in the reinforcement weight occurred when buildings were constructed on soft soil and with a low ductility level. It was also found that, regardless of the soil type, when buildings were constructed with a medium ductility level, their reinforcement weights were less than the low ductile buildings.

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