Comparison of the performance of high-rise building based on various design code

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Abstract. The main purpose to conduct this research is to compare the performance of high-rise building based on design code BS 8110, EC 2 and the combination EC 2 and EC 8. 10-storey high-rise building was designed based on the 3 types of design codes. The design and analyses were used software method and manual calculation to define the detail of the structure. The software that was used to design is ETABS. The 3 main components that used to compare the structural and costs performance were beams, columns and slabs. As the results, the area of tension reinforcement provided for a column using the combination EC 2 and EC 8 design was required more rebar compared to another two codes. For the cost performance, BS 8110 required higher costs compared to Eurocode. This is because of the safety factor for the load analysis. For Eurocode, design with considers seismic effect had higher costs compared to design without considering the seismic effect but the cost difference between this two is about +1.46%. Therefore, by referring the result had been done, it can conclude that including of seismic effect did not affect too much on the cost performance.

1. Introduction
In this modern era, the development of a country is the most concern issue. As a country with a high population, the number of high-rise building increasing as much as possible to cover the factor of population increment. Most of the high-rise structures in Malaysia was design based on British Standard Code which is BS8110 [1,2]. The reinforced concrete design was not including the seismic design because Malaysia is not at the active fault area. But, in these few years, the earthquake occurred frequently. It brings some consequences to the building in that area which like building crack and others. But, due to the incrementation of cost, most of the companies in Malaysia are not ready to apply EC8 in designing structural for building [3]. The main thing that industries worry is the cost after applying the Eurocode 8 (EC8) will increases. Due to this event, the performance of high-rise building were studied in this research and comparison of the estimated cost of the high-rise building based on two building codes which are BS8110 [1] and Eurocodes are Eurocode 2 (EC2) [4] and Eurocode 8 (EC8) [5].

Existing knowledge based on British Standards was examined, as was the ability of Eurocodes to transfer technology in codes of practice and materials standards indirectly from one country to another [6]. Seismic forces were one of the major natural forces causing huge damage to lives and economy. So that it can understand the difference and can appropriate for the best guidelines for safety to lives and economy [7]. Therefore, seismic analysis and design is important and should be considered in Malaysia for the safety of structures. Most of Malaysia’s buildings were designed according to BS8110 [1] without any consideration of seismic effects. But, some of the buildings had been started to designed by European code for seismic design nowadays [8].
The shear performance that been showed stated that EC2 [4] design will have lower shear stress compare to BS8110 [1] design. Nevertheless, the EC2 [4] design also provided the lower punching shear stress than BS8110 [1] design [9]. The results show that the design of the columns of the building using BS 8110 [1] will require more area of reinforcement for both axial and un-axial load cases considered compared to EC2 [4] design. The reason was the partial safety factor for designing the strength for concrete. BS8110 [1] will use the lesser partial safety factor (0.67) compared to EC2 which is 0.85 at ultimate limit state for concrete [10].

From the previous research, it was conducted similar research to estimate construction cost for building with non-seismic design and seismic design with different ductility classes meanwhile focused on the cost impact on low ductility class building when they were subjected to different peak ground acceleration and behaviour factor. The results obtained were quite different even though a similar basis of design was used which using EC8 [5,11].

2. Materials and methods

Loading can be classified as many types which are self-weight of the structure, permanent load (Gk), variable load (Qk), wind load (Wk) and seismic action (AE) and others. In this research, the loads that was considered are self-weight, permanent load (Gk), variable load (Qk), wind load (Wk) and seismic action (AE). Different codes will have different safety factor for the calculation of the ultimate load (n). After calculate out the ultimate load, then manual calculation and software modelling and designing have been making. In the manual calculation, three main elements are taking to design which is the beam, column and slab. For the software, ETABS software is using to model and design for the building structure. When the calculation and modelling are done, the comparison of different type of code has been making to see the structural performance and the cost performance. Figure 1 shows the flow chart of this research.

![Flowchart of research](image-url)
2.1 Wind loads

When the wind blows towards the building, the lateral load acting on the elevation is called "wind load". The structural design of the building must absorb the wind load safely and effectively and pass it to the foundation to avoid the collapse of the structure. According to the MS 1553 [12], the Analytical procedure (for the height of the building is lesser than 200 m) was used to calculate the wind pressure on the reinforced concrete building. Equation (1) shows the equation for designing wind pressure. Below is the step for calculating the wind pressure:

\[
P = 0.613 \left[V_{\text{des}}\right]^2 C_{\text{fig}} C_{\text{dyn}}
\]

Where,
- \(V_{\text{des}}\) = Design wind speed = \(V_{\text{sit}} I\)
- \(I\) = Importance factor
- \(V_{\text{sit}}\) = wind speed at Site = \(V_s M_d M_{z,\text{cat}} M_s M_h\)
  - \(V_s\) = Basic wind speed
  - \(M_d\) = multiplier for Wind direction
  - \(M_{z,\text{cat}}\) = multiplier for terrain height
  - \(M_s\) = Shielding multiplier
  - \(M_h\) = Hill shape multiplier
- \(C_{\text{fig}}\) = shape factor for Aerodynamic = \(C_{p,e} K_a K_c K_l K_p\)
  - \(C_{p,e}\) = External pressure coefficient
  - \(K_a\) = Area reduction factor
  - \(K_c\) = Combination factor
  - \(K_l\) = Local pressure factor
  - \(K_p\) = Porous cladding reduction factor
- \(C_{\text{dyn}}\) = Dynamic response factor

2.2 Seismic action

Seismic action can be called as earthquake load which need to consider when earthquake event has occurred and also the seismic action is represented by the elastic response spectrum [13]. Calculate the total dead load and imposed load for the whole building first. Then, calculate the seismic mass by using the load combination which is \(G + \Psi_{E,i} Q\). After finish the calculation for seismic mass, seismic base shear is calculated by using the equation \(F_b = \lambda m_s q\). Then, the seismic load was divided by behaviour factor \(q\) to get the actual seismic load acting on the building. To get the seismic load for each floor, \(F_k = \text{seismic load multiple with } z_k m_k\) and divided by the total of \(z_k m_k\). \(z_k\) has represented the height of building level and \(m_k\) is represent the mass [14].

2.3 ETABS

ETABS software [15] was used in the analysis and design stage. Three conditions that was used for comparison which are design based on BS8110 [1], EC2 [4], and the combination EC2 [4] and EC8 [5]. ETABS [15] can handle the largest and most complex building models, including a wide range of nonlinear behaviours, making it the tool of choice for structural engineers in the building industry. In this project, the 10-storey high-rise building had been designed. Figure 2 shows the structural model in the 3D view using ETABS software [15].
2.4. Manual design calculation using Microsoft excel

The manual calculation also is done for countercheck the data from the ETABS [15] to ensure that all the data is correct. There was three sets of calculation which are using BS8110 [2], EC2 [4] and another set using EC2 [4] design inclusive of EC8 [5]. The calculation was made through the Microsoft Excel. In the design phase, there was few elements taken to be designed which are beam, column and slab. Each element has a different equation, different factors used and others. In the design phase, there was few elements taken to be designed which are beam, column and slab.

3. RESULTS AND DISCUSSION

3.1. Seismic load analysis

The seismic load is analysing out and the value for the seismic load that acting to the whole building was shown in table form. Table 1 shows the detail of the seismic load, $A_E$.

| Level $k$ | Height, $z_k$ (m) | Mass, $m_k$ (t) | $z_km_k$ (m.t) | Force $A_E$ (kN) | Moment $= A_Ez_k$ (kNm) |
|----------|------------------|-----------------|----------------|-----------------|-------------------------|
| 10       | 35.0             | 277.1           | 9699.6         | 102.1           | 3573.1                  |
| 9        | 31.5             | 1014.3          | 31950.1        | 336.3           | 10592.7                 |
| 8        | 28.0             | 1014.3          | 28400.1        | 298.9           | 8369.5                  |
| 7        | 24.5             | 1014.3          | 24850.1        | 261.5           | 6407.9                  |
| 6        | 21.0             | 1014.3          | 21300.1        | 224.2           | 4707.8                  |
| 5        | 17.5             | 1014.3          | 17750.1        | 186.8           | 3269.3                  |
| 4        | 14.0             | 1014.3          | 14200.1        | 149.5           | 2092.4                  |
| 3        | 10.5             | 1014.3          | 10650.0        | 112.1           | 1177.0                  |
| 2        | 7.0              | 1014.3          | 7100.0         | 74.7            | 523.1                   |
| 1        | 3.5              | 1014.3          | 3550.0         | 37.4            | 130.8                   |
| Totals   | -                |                 | 169450.2       | 1783.46         | 40843.5                 |

Based on Table 1, the seismic load that acting on the building is increasing with the height of the building except for the roof floor. The maximum seismic load is 336.3 kN which is acting on the second-highest storey. From the first floor, the seismic load acting on that storey is 37.4 kN which is the lowest seismic
load act to the building. Then, for the second storey, the seismic load increase from 37.4 kN to 74.7 kN which increase about 37.3 kN. For the third storey, the seismic load continue increases from 74.7 kN to 112.1 kN. After that, the seismic load increases from 112.1 kN to 149.5 kN at the fourth storey. For the fifth storey, the wind load keep increases from 224.2 kN to 261.5 kN. For the eighth storey, the wind load keep increases from 261.5 kN to 298.9 kN. For the ninth storey, the wind load increases from 298.9 kN to 336.3 kN which is the highest seismic load compare to others storey. Then, it occurs a sudden decrease from 336.3 kN to 102.1 kN on the top floor. Hence, can conclude that the seismic load depends on the mass of each floor. The higher the building height, the stronger the wind load acting horizontally on the building structure. But, for the top storey, the seismic load occurs a sudden drop because of the mass for the top floor is lesser compare with other storeys.

3.2. Cost performance

In this section, the cost performance is made for comparing between 3 types of codes. In this comparison, the price for steel and concrete [16] was used. For beam, column and slab that use how many quantities of reinforcement bar, how much volume for concrete used in this project. All was calculating and show in a table form. Table 2 shows the cost performance for the beam, column and slab.

| Component       | Material | BS 8110 [1] | EC 2 [4] | EC 2[4] + EC 8[5] |
|-----------------|----------|-------------|----------|------------------|
| Beam (300 x 300 mm) | Steel    | 93,740.00   | 69,760.00 | 69,760.00        |
|                 | Concrete | 86,757.42   | 86,757.42 | 86,757.42        |
| Column (600 x 600 mm) | Steel    | 52,320.00   | 52,320.00 | 69,760.00        |
|                 | Concrete | 129,118.32  | 129,118.32 | 129,118.32       |
| Slab (thickness =150 mm) | Steel    | 676,880.32  | 676,880.32 | 676,880.32       |
|                 | Concrete | 175,968.12  | 175,968.12 | 175,968.12       |
| Total Price     |          | 1,214,784.18 | 1,190,804.18 | 1,208,244.18   |

Based on Table 2, by comparing the cost performance for the 3 components with 3 different design codes, BS 8110 is the most expensive cost in this project. It uses RM 1,214,784.18 for the beam, column and slab of the whole building. The second highest cost is using EC 2 + EC 8 for designing. By comparing the EC 2 and EC 2 + EC 8, when seismic action is included in the design, the cost for the project is increased in just RM 17,440 extra (+1.46%). The lowest cost performance is using EC 2 which is RM 1,190,804.18. In the beam section, it shows that the cost for rebar used in BS 8110 has a huge difference compared to other 2 design codes. The difference is about +34.375%. For the column section, EC 2 + EC 8 also has more costs for rebar used compared to BS 8110 and EC 2. It is due to the seismic load acting on the building and need to make the column to be stronger to resist the seismic load. Therefore, the EC 2 + EC 8 design need to increase the number of rebars to resist the load.

4. Conclusion
The cost performance was developed and showed that BS 8110 required the highest cost compared to another 2 design codes because of the safety factor for British Standard which is using 1.4 \( G_k + 1.6 Q_k \) but for Eurocode is using 1.35 \( G_k + 1.5 Q_k \). The second highest cost is EC 2 inclusive of EC 8 which is higher than EC 2. It is due to the seismic load and needs to make the column to be stronger to resist the seismic load. Although EC 2 + EC 8 has a higher cost than EC 2, the difference between this two is just around RM 17,440 (about +1.46%). Therefore, the incrementation of cost is not so much by comparing the cost performance for both cases. So, consider the seismic load into the structure design does not cost too much compared to the design code without considering the seismic load.
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