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Research Article

Comparative Analysis of Seismic Performance of RC Buildings with Variation of Column Size and Orientation

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Abstract

Enhancement of the seismic performance of RC structures plays an essential role in a country like Bangladesh, which is among the world's most tectonically active regions. In this study, G+5 storey residential building is chosen, which is situated in Rangpur City. This structure is modified into four categories based on the column size and orientation like B1 for original building, B2 for all the column are of same dimension, B3 for orientation in X direction and B4 for orientation in Y direction. For simplification, linear time history analysis is considered in dynamic analysis for all the buildings where the ground motion is taken 'El Centro earthquake' from the PEER Ground Motion Database. The result is evaluated based on lateral displacement, storey drift and base shear. In terms of lateral displacement and storey drift, the building B3, showed the least value for the X component of both earthquake EQ_x and EQ_y. On the other hand, the same building B3 showed the largest value for the Y component, while building B2 showed the least. This can be because of the increased rigidity of all the columns for the highest dimension in building B2 in the Y direction. Also, the same response is observed in peak-to-peak displacement. But for the base shear, building B2 showed the highest value for all cases due to the increase in building weight by 2.64%. The research showed building B2 showing optimum seismic performance against earthquake force from any direction. Also increace in seismic weight for building B2 helps in earthquake resistivity.

Keywords

Seismic Performance, Ground Motion, Linear Time History Analysis, Peak-to-peak Displacement

1. Introduction

Bangladesh is being located in a seismically active region with a history of devastating earthquakes along the Bangladesh-India border. It is situated in a zone of low to moderate seismic hazards, with the risk increasing towards the north and east. It is also positioned on the boundary of the Indian plate, the Eurasian plate, and the Burmese plate, making it one of the world's most tectonically active locations. It is located in a zone with a moderate to high seismic risk, according to worldwide seismic hazard maps.

Bangladesh has a long history of seismic activity. The most noticeable example occurred in 2015 with the deadly Gorkha earthquake in neighbouring Nepal [1]. As a result, understanding and evaluating seismic performance in Bangladesh is critical. This seismic performance evaluation, which comprises a wide range of techniques, models, and analyses designed to assess how infrastructures and structures respond to

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seismic forces, is an important component of seismic risk reduction. It provides crucial insights into the susceptibility of existing infrastructure and buildings, as well as the effectiveness of mitigation strategies employed in the planning and creation of new buildings.

There are different kinds of mitigation strategies available, and this seismic analysis has been the subject of extensive research. The effect of column shape, size and orientation of rectangular columns was studied and the output was evaluated in terms of base shear, top storey displacement, storey drift and time period. The result was found satisfactory [2]. A similar type of research was conducted where the comparative seismic performance of rectangular-shaped columns and equivalent square-shaped columns using pushover analysis was studied [3]. With this pushover analysis, a comparison of improvement of revised BNBC 2020 [4] was done [5]. On the other hand, any potential weak spots were identified in the structures by applying the Egyptian code (ECP-201) to assess the possible structural inadequacies in the current frames caused by lateral loads [6]. To evaluate the stress behaviours of various RCC column cross-sections in framed structures, the Response Spectrum Method was used [7]. With disoriented columns, Zaid [8] examined the applicability of the Response Modification Factor (R) code-specified values for framed buildings. Zameeruddin and Sangle [9] attempted to evaluate the performance of fifteen-storey moment-resisting frames designed following the guidelines of Indian seismic codes. All the researches from above are showing common limitations in the aspect of comparative analysis on change in column shapes and orientations of a RC building. Also showing inability to evaluate comparative base shear and seismic weight performance.

This study aims to assess the seismic performance of a RC building constructed in accordance with BNBC 2020 provisions by investigating the structural response using dynamic analysis. Also, the seismic responses due to variation of column size and orientation changes are extensively observed.

2. Methodology

2.1. Building Description

A G+5 storey residential building of Height 23.16 m has been investigated for this study with different column sizes and orientations. This height was chosen because structures in this height range are so frequent in the research location (Rangpur). Rangpur City is located in Zone-III, a zone of severe seismic intensity, with a Z-value of 0.28. Buildings fall within the occupancy category II. As the soil in the study area is medium dense sand with gravel, based on BNBC 2020, the site class can be considered SC, which has a SPT Value, N (blows/30cm) is between 15 to 50. For a site class SC and Occupancy Category II, and seismic Zone-III, the seismic design category of the building is D and Importance factor, I = 1. The structural system of the study system is “Moment resisting frame systems with no shear wall” and designed as considering special reinforced concrete moment frames to provide ductile behaviour complying with the seismic requirements.

2.2. Study Framework

First a building plan from Rangpur was taken for this study. Then the plan was modified based on the change in column size and orientation, as mentioned in Table 1. After that, all four buildings were modelled and analysed in both ETABS (v18.1.1) and SAP2000 (v23.2.0). The analysis was based on static and dynamic analysis. The static analysis consisted of linear static and pushover analysis, whereas dynamic analysis consisted of response spectrum analysis and linear time history analysis. All the static and dynamic analysis was done using ETABS (v18.1.1) except time history analysis was conducted on SAP2000 (v23.2.0). ACI-318 code was followed during the analysis. After that, the results were evaluated based on lateral displacement, storey drift ratio, and base shear. Study framework description is given in Figure 1.

***Table 1**. Building category and characteristics.*

Building Category Name	Building Characteristics
B1	Original Building with the same dimension that was approved by Rangpur City Corporation Authority
B2	Building with all the column of same size with highest dimension (C5)
B3	Building B1 with all the column oriented in X direction
B4	Building B1 with all the column oriented in Y direction

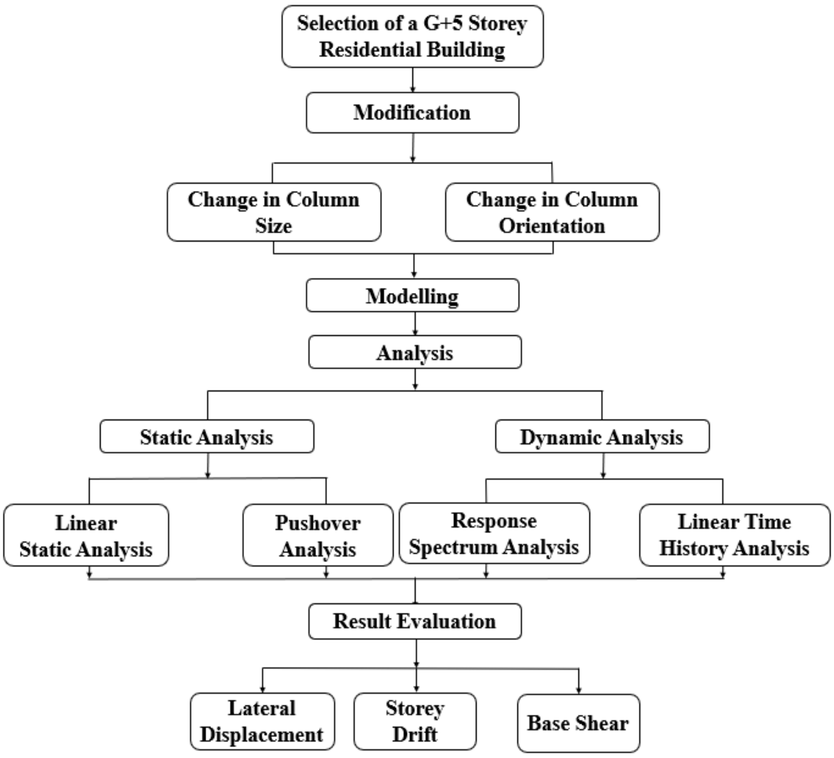


Figure 1. Study framework for seismic performance evaluation.

3. Detail of Models

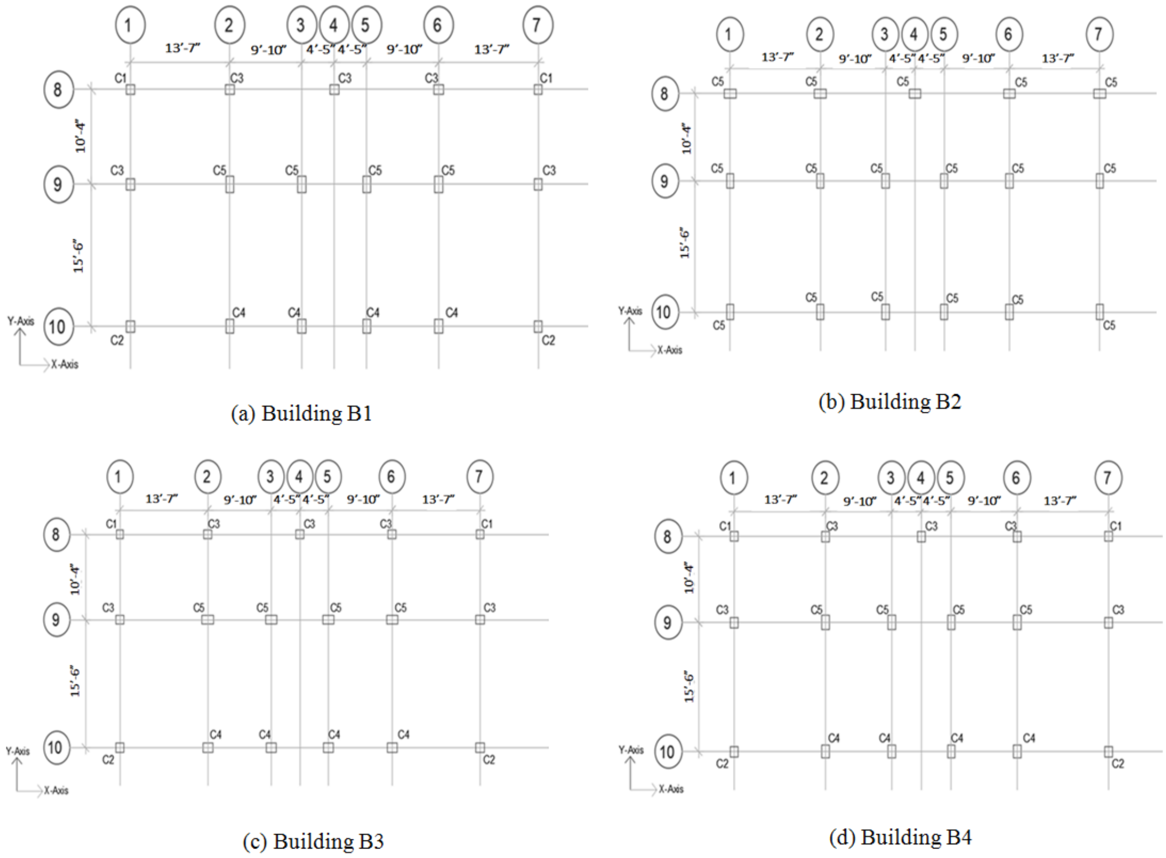


Figure 2. Column layout of the buildings.

Table 2. *Column dimensions with reinforcement and Building Category with their characteristics.*

Column	Dimension	Reinforcement	Building Category	Building Characteristics
C1	330.2 mm × 330.2 mm	6–16 mm dia	B1	Original Building
C2	330.2 mm × 381 mm	6–16 mm dia	B2	All the column of same size with highest dimension (C5)
C3	330.2 mm × 381 mm	8–16 mm dia	B3	Building B1 with all the column oriented in X direction
C4	330.2 mm × 457.2 mm	10–16 mm dia	B4	Building B1 with all the column oriented in Y direction
C5	330.2 mm × 533.4 mm	6-20 mm dia 4–16 mm dia		

In figure 2(a), the original building plan is shown without any modification. In original building plan column dimensions and reinforcement details are shown in table 2. Replacing all the column with C5 which has the highest dimension is shown in figure 2(b). Here, the orientation is same as B1. In figures 2(c) and 2(d), the column orientation of buildings B3 and B4 are shown. All of the columns in B3 are orientated in the X direction, whereas in B4, the same columns are oriented in the Y direction. The reinforcement of the columns is maintained according to the design approved by the Rangpur City Corporation authority.

4. Analysis

4.1. Equivalent Static Analysis

Equivalent linear static methods are allowed to analyse regular, low- to medium-rise buildings in most codes. ETABS v18.1.1 was used to do this static analysis for the investigation. Table 3 contains the data that were used in this investigation. In this study, the EQ_x stands for the earthquake applied in X direction whereas the EQ_y stands for the earthquake applied in Y direction.

Table 3. *Necessary data for static load analysis.*

Parameters	Value
Seismic Zone Coefficient	Z = 0.28
Response Reduction Factor	R = 8
Structural Importance Factor	I = 1
Soil Profile Type	S = 1.15

4.2. Time History Analysis (THA)

A useful method for studying structure seismic response is time history analysis. It is an examination of the structure's dynamic response at each time step when its base is exposed to a certain ground motion time series. SAP 2000 software is used in this study to analyse time histories. For this study, one of the main concerns from THA was evaluating the peak-to-peak displacement comparison. The details of this seismic data are provided in Table 4. As the earthquake data for Bangladesh is not available, Imperial Valley earthquake at El-Centro station was taken which is shown in figure 3.

Table 4. *Data for time history analysis.*

Parameters	Value
Earthquake Name	Imperial Valley
Station Name	El Centro
Magnitude	6.9
Time interval	0.01 s
Distance from Epicenter	8 km
Year	1940

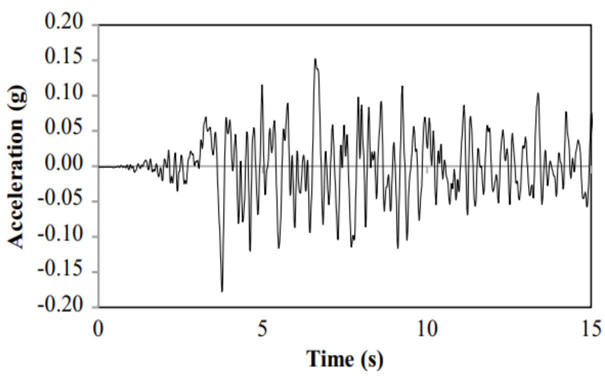


Figure 3. *The 1940 Imperial Valley earthquake at El-Centro station [10].*

4.3. Response Spectrum Analysis (RSA)

According to BNBC-2020, a site-specific response spectrum is needed, which takes into account the geology, tectonics, seismology, and soil properties related to that particular location. The normalized response spectra for a damping ratio of 5% will be used in the dynamic analysis if there isn't a response spectrum particular to the site. The BNBC response spectrum curve used in this investigation is shown in Figure 4.

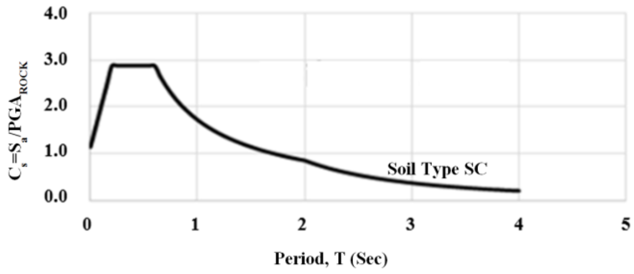


Figure 4. *BNBC response spectrum curve for 5% damping ratio [11].*

5. Results and Discussions

5.1. Lateral Displacement

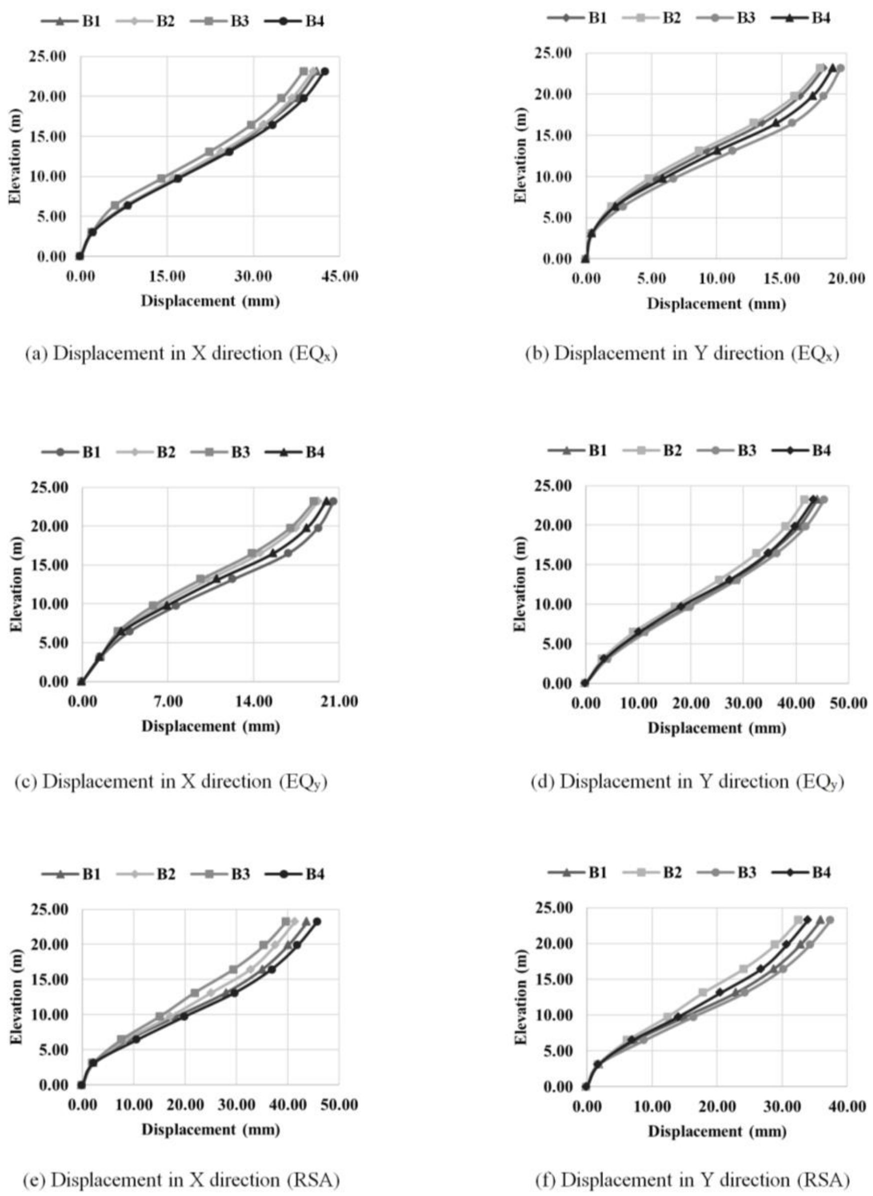


Figure 5. *Lateral displacement for various criteria.*

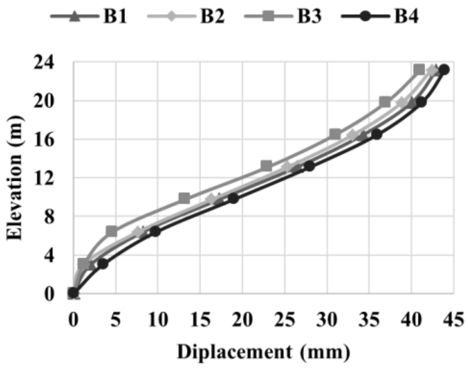


Figure 6. Peak to Peak Displacement in X direction (THA).

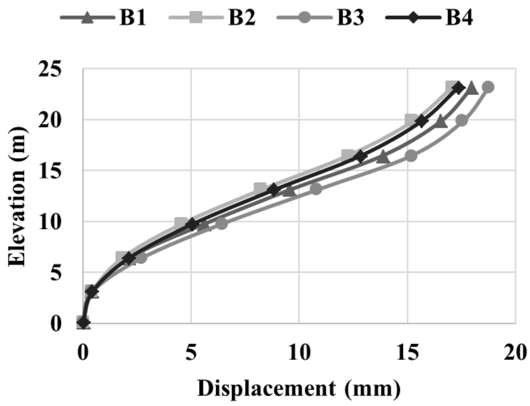


Figure 7. Peak to Peak Displacement in Y direction (THA).

Figure 5(a) illustrates the static analysis that shows maximum elastic displacement was found 42.37 mm for B4 model and the minimum value of 38.69 mm was observed from B3 model. These values are within the limit of 1/500 times of the building height which satisfies the criteria provided by BNBC. The displacement is significantly lower in the Y direction which is also within the permissible limit of BNBC 2020 which is shown in figure 5(b). From figure 5(c), it can be concluded that applying earthquake load in the y direction results in a greater displacement than executing it in the x direction. The maximum displacement for the component along x direction in this case was 20.54 mm for building B1, while the minimum value that was seen was 18.97 mm for building B3.

The maximum displacement for the y component of the earthquake along the y axis was found to be 45.37 mm, which is the highest displacement. This value was found in structure B3. Building B2 displayed the least amount of displacement which is 8.13% less than the building B3 shown in figure 5(d).

Figure 5(e) illustrates the displacement caused by RSA in which the building B4 showed the maximum displacement of 45.65 mm. According to the BNBC code, this figure is within the permitted range of 1/500 times the building height. Building B3 shows minimal displacement of 39.67 mm. In the Y direction, the maximum displacement is 37.43 mm for building B3 and the building B2 shows minimum displacement of 32.53 mm which is illustrated in figure 5(f).

Figure 6 illustrates that the building B4 has a maximum peak to peak displacement of 43.95 mm for THA in X direction. The difference between this result and the one obtained from RSA is 3.72%. On the other hand, in figure 7, the same building has the maximum displacement of 18.76 mm which is 49.9% smaller than RSA in the Y direction. The total peak to peak displacement is the summation of positive and negative peak along the direction of propagation of the seismic wave.

5.2. Storey Drift

Figure 8 depicts that the maximum inter-storey drift ratio is 0.00296 observed in building B4. This value is less than the limit of 0.02 suggested by BNBC 2020. Also, the storey drift for building B3 in the X direction is the lowest which is 1.49% less than the peak value. On the other hand, the same building showed maximum value for $EQ_{y,}$ shown in Figure 9.

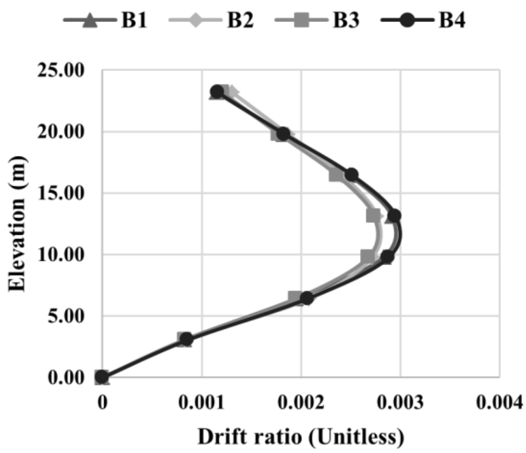


Figure 8. Storey drift in X direction (EQx).

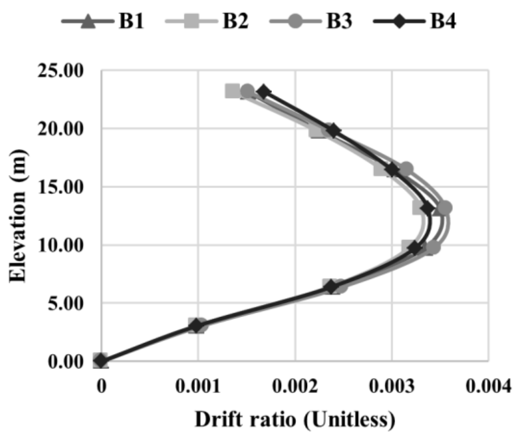
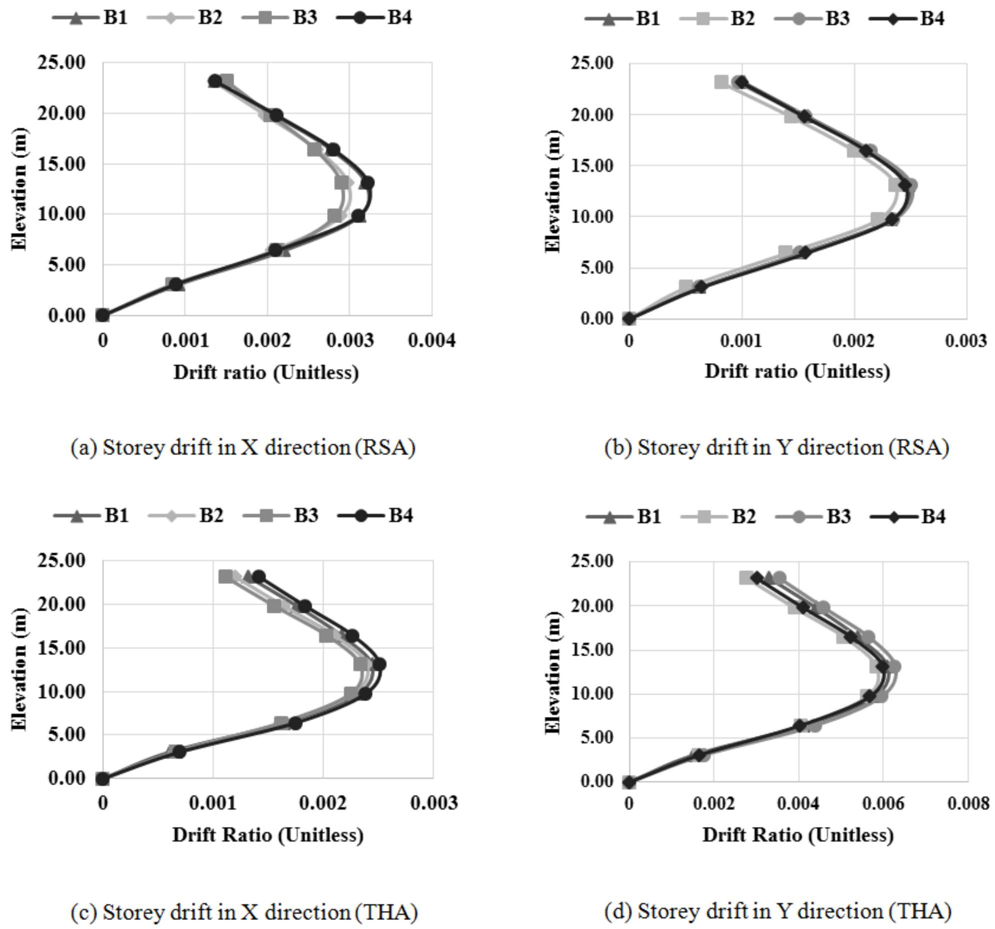


Figure 9. Storey drift in Y direction (EQ_y).

Figure 10 displays the distribution of the inter-storey drift ratio for RSA and THA. The maximum inter-storey drift ratio obtained in both X and Y direction is less than the prescribed limit of 0.02 (BNBC 2020), which is 0.00136 (RSA) and 0.00142 (THA) in the X direction and 0.000997 (RSA) and 0.0035 (THA) in the Y direction. Figure 10(d) shows that the drift ratio along Y direction for THA is greater than the drift ratio along X direction.



(a) Storey drift in X direction (RSA)

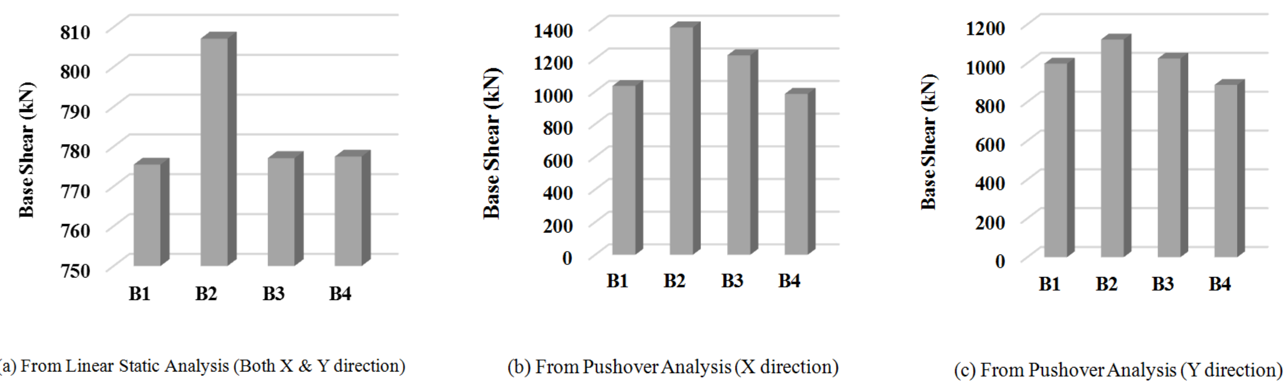
(b) Storey drift in Y direction (RSA)

(c) Storey drift in X direction (THA)

(d) Storey drift in Y direction (THA)

Figure 10. *Storey Drift from RSA and THA.*

5.3. Base Shear



(a) From Linear Static Analysis (Both X & Y direction)

(b) From Pushover Analysis (X direction)

(c) From Pushover Analysis (Y direction)

Figure 11. *Base Shear Comparison for Static Analysis.*

Figure 11 illustrates the base shear for various building models. Among all building types, building B2 has the largest base shear of 807.12 kN in both directions. The lowest base shear is visible in building B1 which is 775.46 kN. Both values fall within the permitted range established by BNBC 2020. In linear static analysis (LSA), the base shear value is the same for both X and Y directions.

In case of pushover analysis, the base shear was maximum in B2 model in X direction which is 41.3% higher than the least base shear of building B4. Also, in Y direction, B2 showed the maximum shear which is 26.4% higher than the minimum value of 887.6 kN in B4.

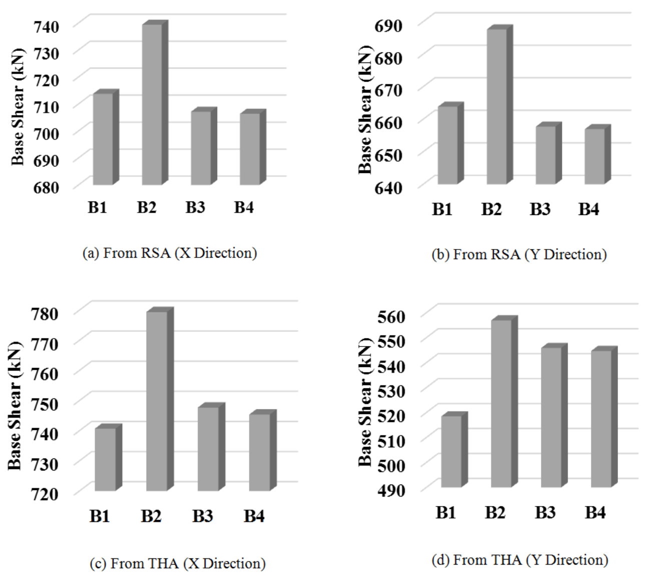


Figure 12*. Base Shear Comparison for Dynamic Analysis.*

Figure 12 shows that the base shear for dynamic analysis is 8.39% less than the value obtained from linear static analysis. Building B2 has the largest base shear in all the analysis. In RSA, the building B4 holds the lowest base shear value of 656.93 kN in Y direction whereas in THA, the building B1 holds the place.

6. Conclusion

In this study, it was found that the value of lateral displacement and the storey drift was the lowest in building B3 which was 8.69% less than the maximum value of 42.37 mm in B4. On the other hand, for the seismic load in Y direction, B2 showed the least displacement and storey drift because of the rigidity of the columns for highest dimension. In terms of base shear, building B2 displayed the greatest value of 807.12 kN. This might be as a result of the increased building weight by 2.64% due to larger column cross sections. According to the investigation, building B2 exhibits the best seismic performance against seismic force coming from any direction. Building B2's increased seismic weight also contributes to its earthquake resistance. This work might be expended to analyse and evaluate the structural responses with more representative earthquake data.

Abbreviations

RC	Reinforced Concrete
BNBC	Bangladesh National Building Code
THA	Time History Analysis
PEER	Pacific Earthquake Engineering Research

Author Contributions

Abu Huraira Mohammed Adyeel: Formal Analysis, Investigation, Resources, Software, Validation, Writing – original draft

Md. Robiul Awall: Conceptualization, Methodology, Project administration, Supervision

Noor-E Zami: Investigation, Resources, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Abu Huraira Mohammed Adyeel recently finished his undergraduate studies at Rajshahi University of Engineering & Technology in the Civil Engineering Department. In 2023, he graduated from Rajshahi University of Engineering & Technology with a B. Sc. in Civil Engineering. In recent years, he has published a number of research studies and conference proceedings.

Md. Robiul Awall began working at RUET as a lecturer in the Department of Civil Engineering in 2002. Under the guidance of Professor Hiroki Yamaguchi, he completed his master's degree in engineering from Saitama University in Japan in 2008 with a dissertation titled "Gust response analysis of transmission lines for interpretation of wind-induced vibrations measured in the field." Additionally, he received a Japanese Government Scholarship (MEXT) in 2009, which allowed him to pursue a doctorate in Japan. Under the guidance of Professor Toshiro Hayashikawa, he completed a dissertation titled "Dynamic behavior of horizontally curved twin I-girder bridges under moving vehicles" that earned him a PhD from Hokkaido University in Japan in 2012.

Noor-E Zami recently completed his undergraduate studies in the Civil Engineering Department at Rajshahi University of Engineering & Technology. He earned a B. Sc. in Civil Engineering from Rajshahi University of Engineering & Technology in 2023.

Research Fields

Abu Huraira Mohammed Adyeel: Earthquake Engineering, Structural Engineering, Linear Time History Analysis, Dynamic Analysis, ETABS, Construction Materials

Md. Robiul Awall: Structural Dynamics & Control, Earthquake Engineering, Wind Engineering, Cable Supported Structures, Horizontally Curved Bridge, Bridge-vehicle interaction, Structural Strengthening and Rehabilitation

Noor-E Zami: Structural Analysis, Earthquake Engineering, ETABS