INVESTIGATION ON STRUCTURAL PERFORMANCE OF HIGHRISE RC STRUCTURE IN DIFFERENT REGION OF BANGLADESH

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ABSTRACT

Construction of high-rise commercial and residential structures has increased at a rapid rate with the development of megacities. The structural design of these high-rise structures is sophisticated compared to other structures due to their structural complexity. The lateral load generated due to natural events like earthquakes or storms may pose major threats to high-rise structures. Introducing different structural systems and methods may enhance the structural integrity and performance of the structure. Selection of the location for the structure is another daunting task, as the perimeter of the structural design varies with different locations. Dynamic analysis is also vital to ensure the structural behavior of the high-rise structure. This study aims to analyze a 20-story high-rise reinforced concrete framed building with the ETABS software program using the response spectrum method in four different seismic zones as per BNBC (2020). For different seismic zones, the performances of structures are evaluated with the help of maximum displacement, storey drift, storey shear, base shear, ground motion acceleration, and overturning moment. The results showed that seismic zone 4 generally exhibited higher values in terms of storey drift, storey shear, base shear, ground motion acceleration, and overturning moment than seismic zones 1, 2, and 3, emphasizing the heightened seismic considerations needed for structures in Zone 4 compared to Zones 1 and 3.

Keywords: *High Rise Structure, RC Structure, Response Spectrum Analysis, Seismic Zone.*

1. INTRODUCTION

Bangladesh is a seismic-vulnerable country as it is surrounded by several active fault lines in different regions. An earthquake with a Richter scale magnitude of 6.0 striking Dhaka could result in the destruction of 78,323 urban structures and an overall financial loss of $1,075 million (Rahman et al., 2015). However, many of these buildings were not designed to withstand seismic forces. BNBC (2020) divides Bangladesh into four seismic zones, each with a different seismic zone coefficient. Seismic design should be tailored according to the zone and soil type (i.e., SC, SD). Therefore, a performance study of buildings under lateral load in different seismic zones is crucial to understand the variation in seismic vulnerability across zones.

Several seismic evaluation methods exist, and one of them is Response Spectrum Analysis. Response Spectrum Analysis (RSA) is a technique used to predict the maximum response of a structure (displacement, velocity, acceleration, or force) to a dynamic event like an earthquake. It achieves this by analyzing the response of simple, single-degree-of-freedom (SDOF) systems to the spectrum of frequencies and intensities of the event (Reitherman, 1997). Combining the responses of these SDOF systems allows engineers to understand the overall behaviour of complex structures efficiently. While RSA may not provide detailed information on localized damage, its ability to paint a clear picture of global behaviour makes it invaluable for engineers working within the time constraints of real-world projects.

Several previous studies have focused on evaluating the performance of buildings under different seismic conditions. Reddy and Kumar (2019) analyzed a 30-story building in different seismic zones. They found that the base shear of the building in Zone 5, which has the most significant zone coefficient, is 258.86% higher than that of Zone 2, which has a low zone coefficient. Rabbi and Sadik (2020) conducted an analysis on an 8-storied reinforced concrete building according to earthquake and wind provisions of BNBC (1993) and BNBC (2017). They observed that the base shear in BNBC (2017) increased due to the consideration of more zone coefficients and the self-weight of the building. Kale and Rasal (2017) evaluated the structural performance of 15, 30, and 45-storied buildings concerning story drift, story displacement, overturning moments, base shear, acceleration, and time period. They noted that seismic activity is significant at 15 and 30-story buildings, while wind effect is critical for 45-story buildings. Mahesh and Rao (2014) analyzed a G+11 multistorey building, taking into account various seismic zones. The behaviour of each zone was evaluated using three distinct types of soil: Hard, Medium, and Soft. They discovered that Zone 5, the region most susceptible to earthquakes, had a higher base shear value. Additionally, they found that the top story exhibited the most significant story drift. Tafheem et al. (2016) conducted a comparison of the response spectrum method and equivalent static force method loading circumstances on a multistorey RC structure after BNBC (2006). In comparison to dynamic response spectrum analysis, they found that static analysis produces larger maximum story displacement values in both directions. At the top story level, dynamic values for maximum lateral displacement are 78% of the static values. Furthermore, roughly 85% of the static analysis consists of dynamic base shear. However, these studies have often concentrated on comparing lateral behaviour based on base shear and storey drift. To comprehensively assess seismic evaluation, factors such as storey shear, overturning moment, and ground motion acceleration should also be considered. A study of the deviation of these values in different seismic zones is necessary for a comprehensive seismic study in Bangladesh.

The primary objective of this paper is to analyze a high-rise 20-storied reinforced concrete framed building using the response spectrum method in different seismic zones as per BNBC (2020). The performance of the building will be evaluated based on maximum displacement, storey drift, storey shear, base shear, ground motion acceleration, and overturning moment for different seismic zones.

2. METHODOLOGY

In the present study, an analysis of 20-story reinforced concrete (RC) building has been conducted in four seismic zones, considering both wind and earthquake forces. A three-dimensional finite element model of the building has been prepared and analyzed by using ETABS v.17 (CSI, 2017).

3. Characteristics of modelled building

The modelled building is a 20 storied reinforced concrete (RC) building. The earthquake and wind load have been calculated according to provisions of BNBC (2020) for four different division of Bangladesh. The four seismic zones and their zone coefficients are shown in Figure 2. The zone coefficient and wind speed values have been used according to BNBC (2020). Soil type SD has been used for calculating vertical earthquake impact. The dimensions and sizes of columns, beams and slabs have been approximated. A typical floor plan of a floor of the building is shown in Figure 1(a) and three-dimensional view of the modelled building in ETABS is given in Figure 1(b).

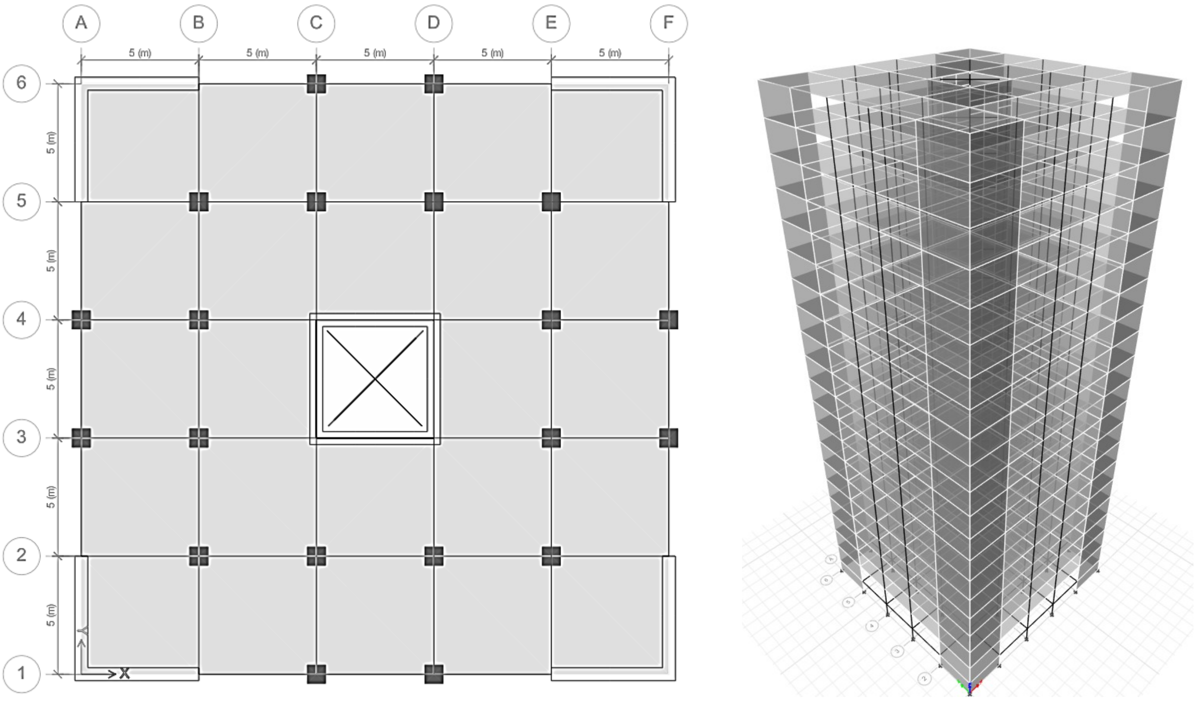


Figure 1: (a) Plan view of a typical floor and (b) Three-dimensional view of the modelled building

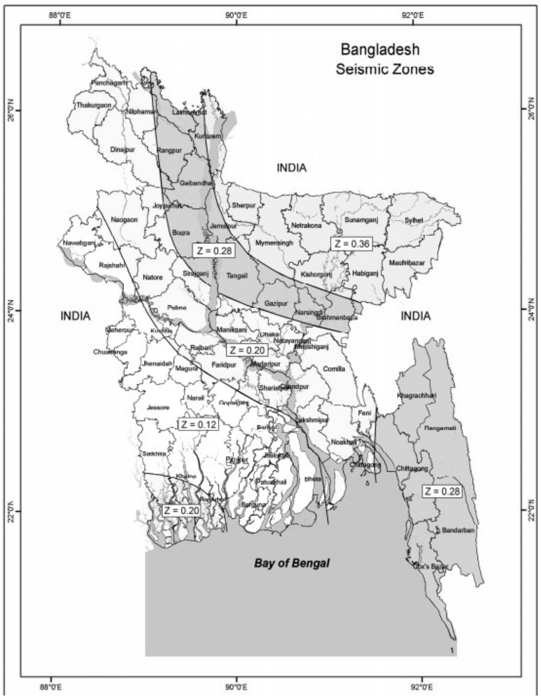


Figure 2: Seismic zoning map of Bangladesh (BNBC 2020)

The support condition of building is considered as fixed at column and shear wall base. For the purpose of lateral load transfer, a diaphragm has been assigned at each floor slab. Basic model information of the building is given in Table 1. Design specification for the structure for different seismic zone is given in Table 2.

Table 1: Basic information of the modelled building

Information	Corresponding data
Structure type	reinforced concrete residential building structure
No. of floor	20 story
Elevation of the building	62 meters
Base height	2 meters
Typical stories height	3 meters

Table 2: Design specification

Specification types	Dhaka	Chattograg	Khulna	Sylhet
Zone co-efficient	0.20	0.28	0.12	0.36
Seismic design category	D	D	C	D
Basic wind speed	65.7 m/s	80.0 m/s	73.3 m/s	61.1 m/s
Response reduction factor	7	7	7	7
Importance factor	1	1	1	1
Exposer Category	A	A	A	A

4. Material Properties

The material specifications for steel and concrete utilized in the modelled building is given in Table 3.

Table 3: Material properties of the modelled building

Material properties	Corresponding data
Concrete strength (shear wall and column)	30.00 MPa
Concrete strength (slab and beam)	28.00 MPa
Yield strength of reinforcement	500.00 MPa

5. Modelling of structural members

The columns and beam sizes have been assumed which is given in Table 4. The earthquake and wind load in both orthogonal directions have been calculated according to BNBC (2020). The gravity loads have also been assigned according to (BNBC 2020). Load combination for strength design and serviceability has been assigned according to BNBC (2020).

Table 4: Dimensions of structural members

Components	Corresponding dimension (mm)
Column	(800×800)
Beam	(300×825)
Slab thickness	150
Shear wall thickness	550

6. Response spectrum analysis

The response spectrum of a building predicts peak responses by analyzing simple oscillators vibrating to the same event, providing a quick way to estimate the behaviour of any linear system at its natural frequency. To select responses in each mode from the response spectrum, modal analysis must first be completed to identify the modes. The estimated total response is then obtained by summing the peak responses. Response spectrum analysis has been conducted in various locations, considering

Bangladesh's four seismic zones. Modal selection for response spectrum analysis should prioritize modes contributing at least 90% of the total effective mass, ensuring a comprehensive capture of the structural response (BNBC 2020). To capture the dominant dynamic behaviour of the structure, a set of 60 mode shapes (two translational and one rotational per story) has been selected, resulting in a cumulative modal mass participation ratio of 98%. The P-Δ effect and a damping ratio of 2% have been considered for this study.

Types of primary types of loads that are used in the analysis:

- I. Dead load (self weight of structure)
- II. Live load (for residential building)
- III. Wind load (in both X and Y directions)
- IV. Response spectrum function (in both X and Y directions)

The load cases used in this study shown in Table 5. The basic load combinations with appropriate safety factor have been used for this study as per BNBC-2020, shown in Table 6.

Table 5: Load cases consideration of building design

Types of loads	**Corresponding value (KN/m^2)**
Live load	2
Floor finish	1
Roof live load	1

Table 6: Basic load combinations

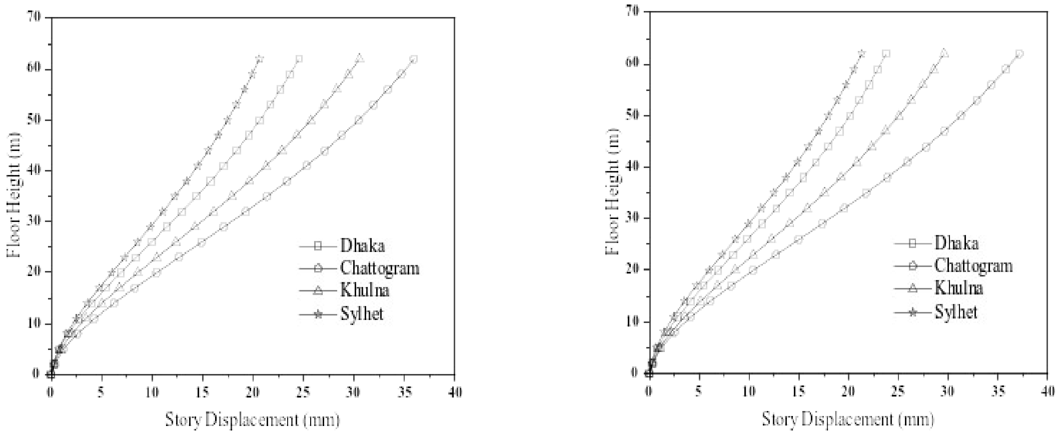
Sl no.	**Load combinations**
1	1.4(D+L)
2	1.2(D+L+T)+1.6(L+H) +0.5R
3	1.2D+1.6R+(L or 0.8W)
4	1.2D+1.6W+L+0.5R
5	1.2D+E+L
6	0.9D+1.6W+1.6H
7	0.9D+E+1.6H

Where, D= dead load, L= live load, W= wind load, E= earthquake load, T= temperature load, R= roof live load

7. ILLUSTRATION

8. Maximum displacement

A structure experiences maximum displacement in a direction of lower stiffness when assessing structural response and potential damage to infrastructure. Maximum and minimum roof displacements have observed in Chittagong and Sylhet, respectively, as shown in Figure 3. The maximum allowable displacement limit according to BNBC (2020) has found to be 0.002h mm, which amounts to 124 mm for the study under sway in-service conditions.

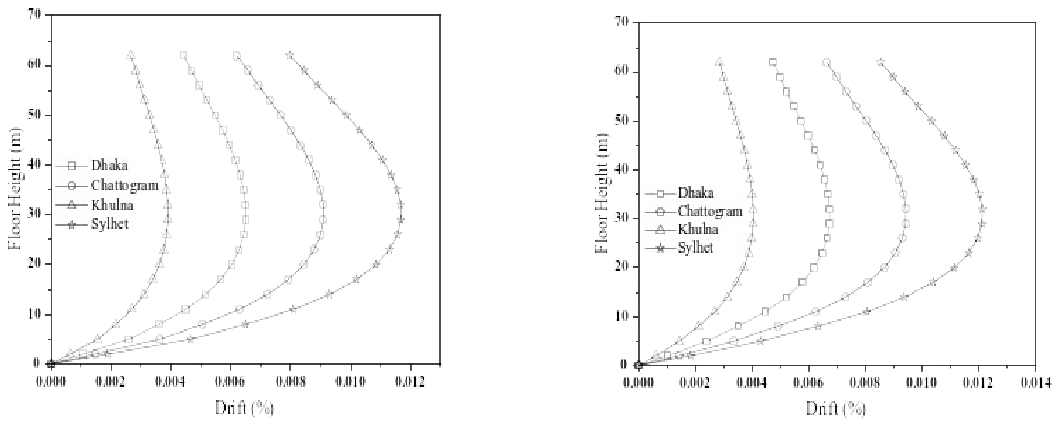


(a) (b)

Figure 3: Floor height vs story displacement for response spectrum analysis for four different seismic zone in (a) X-direction (b) Y-direction

9. Storey Drift

The maximum storey drift is a parameter based on the demand of strong earthquake acceleration on a structure, representing the ratio of adjacent storey displacement. Minimum and maximum drift have observed in Khulna and Sylhet, respectively, within the allowable limit of 0.02, as shown in Figure 4.

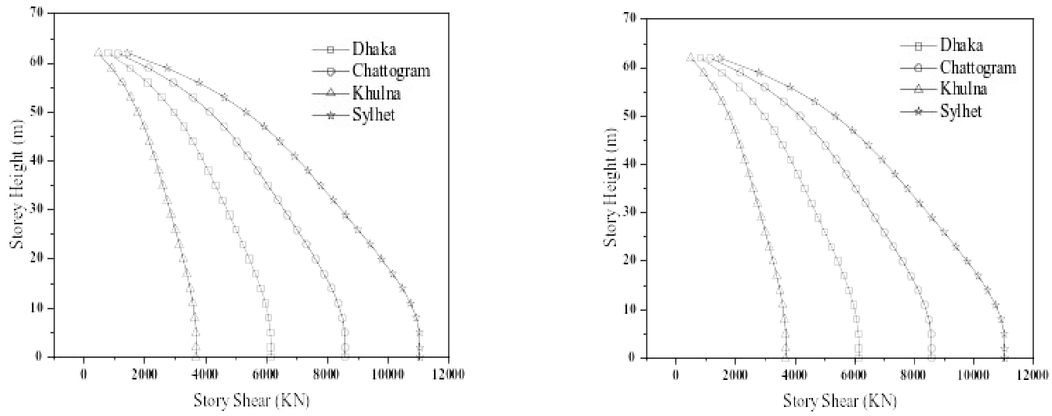


(a) (b)

Figure 4: Floor height vs drift for response spectrum analysis for four different seismic zone in (a) X-direction (b) Y-direction

10. Storey Shear

Storey shear depends on several factors, including building height, soil classification, and structural geometric shape, due to the reaction to lateral load. The values displayed in Khulna and Sylhet correspond to the minimum and maximum values, as shown in Figure 5.



(a) (b)

Figure 5: Story height vs story shear for response spectrum analysis for four different seismic zone in (a) X-direction (b) Y-direction

11. Base Shear

The force exerted on the base of a structure due to seismic activity is crucial to ensuring the stability and integrity of the structure. Zone 1 in Khulna and Zone 4 in Sylhet have displayed the minimum and maximum bar data, respectively, as illustrated in Figure 6**.**

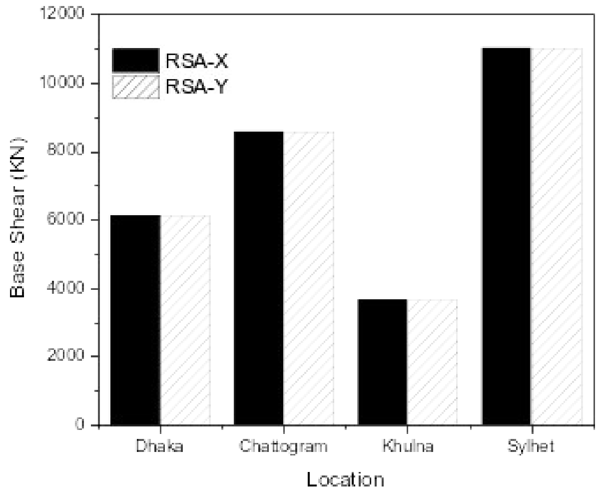
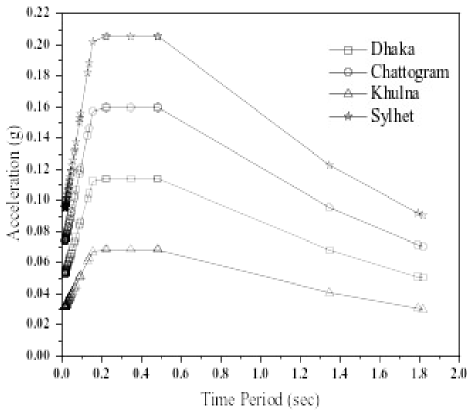
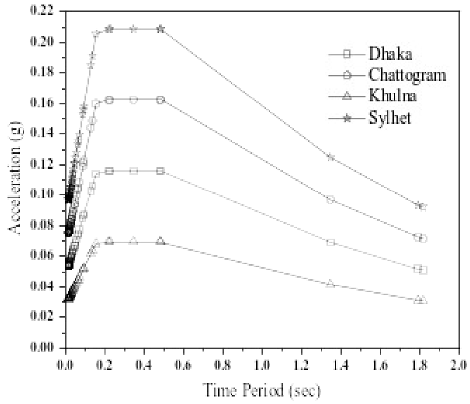


Figure 6: Base shear of four seismic zone for response spectrum analysis in orthogonal direction

12. Ground Motion Acceleration

The acceleration of the response spectrum is utilized to predict how structures respond to ground motions during the formation of an earthquake wave, considering factors such as shaking duration and amplitude of the wave (Lin & Jiang, 2018). Minimum and maximum accelerations have observed in Khulna and Sylhet, respectively, as depicted in Figure 7.



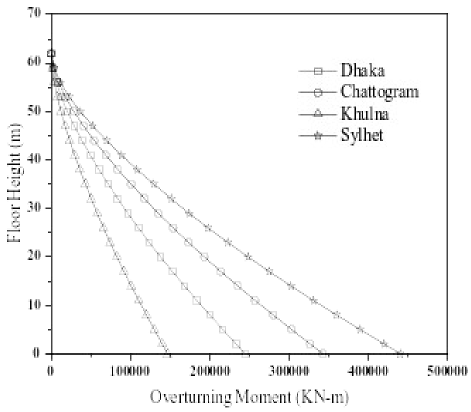


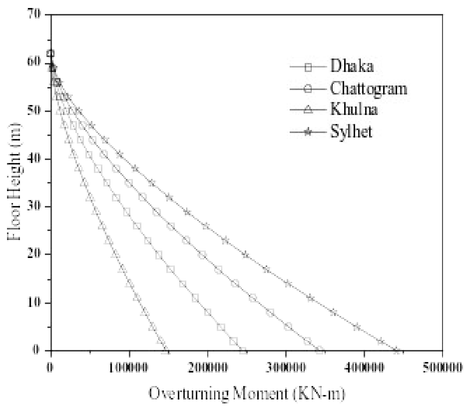
(a) (b)

Figure 7: Acceleration vs time period for response spectrum analysis for four different seismic zone in (a) X-direction (b) Y-direction

13. Overturning Moment

A structure may tip or rotate as a result of lateral forces, such as wind and tectonic plate activity, causing overturning movement. Sylhet has exhibited the largest overturning moment in both directions compared to other seismic zones, as shown in Figure 8.





(a) **(b)**

Figure 8: Floor height vs overturning moment for response spectrum analysis for four different seismic zone in (a) X-direction (b) Y-direction

14.CONCLUSIONS

In this study, the lateral capacity of an RC building was evaluated for four different seismic zones according to BNBC (2020). Four numerical model representing four different zone was developed in FEM software ETABS. The following key observations were made:

- The building experienced maximum displacement in Chattogram (Zone 3) and minimum in Sylhet (Zone 4).
- The building exhibited maximum drift in Sylhet (Zone 4) and minimum in Khulna (Zone 1).

- Khulna (Zone 1) and Sylhet (Zone 4) displayed minimum and maximum storey shear values, respectively.
- The base shear was minimum in Khulna (Zone 1) and maximum in Sylhet (Zone 4).
- Minimum and maximum acceleration were observed in Khulna (Zone 1) and Sylhet (Zone 4).
- Sylhet (Zone 4) demonstrated the largest overturning moment on the other hands Khulna (Zone 1) demonstrated the smallest overturning moment.

In the study four different high-rise FEM model representing four seismic zone was analyzed for response spectrum analysis to evaluate the structural integrity particularly for lateral load. The study exerts the structural permittivity of construction of high-rise structure to be lenient respectively for Khulna (Zone-1), Dhaka (Zone-2), Chattogram (Zone-3) and Sylhet (Zone-4). However, the structural design of a high-rise structure involves various factor, seismic zone must be considered earnestly.

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