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Original Article

Comparative analysis of seismic responses in multistoried residential buildings across seismic zones I and zone III in Bangladesh

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ABSTRACT

This study compares the seismic reactivity of multistory residential buildings in Seismic Zone I, which has low-to-moderate seismic activity, and Seismic Zone III, characterized by strong seismic activity. Structural engineering software (Extended Three-dimensional Analysis of Building Systems 2020) is used for computer modeling to examine how different building layouts respond to seismic loads specific to these zones. The results show that buildings in Seismic Zone III experience significantly higher base shear and lateral displacements than those in Zone I, necessitating stricter design and construction practices. Key response characteristics, such as interstudy drift and lateral displacement, are assessed to understand how structures behave under different seismic conditions. The research indicates that Zone III buildings require enhanced ductility and strengthening, as evidenced by variations in story drift ratios, to meet safety standards. The study highlights how varying seismic intensities lead to notable differences in building performance and underscores the importance of designing with each zone's unique seismic profile in mind. Buildings in Zone III exhibit greater base shear values and lateral displacements, demanding additional structural reinforcements and design considerations to ensure stability and safety. To improve the seismic resilience of multistory residential buildings in high-risk areas, the thesis concludes with recommendations for updates to construction codes and retrofitting techniques.

Keywords: Lateral displacement, lateral displacements, seismic zone I and III, story drift ratios

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INTRODUCTION

Bangladesh, located in a seismically active region, is increasingly vulnerable to earthquake-induced damage, especially in urban areas with multistory buildings. With a growing population and rapid urbanization, ensuring the structural safety of residential buildings has become a critical concern. Examined a G+13-story residential skyscraper. Extended Three-dimensional Analysis of Building Systems (ETABS) was used to evaluate the building's seismic loading. Both static and dynamic analyses were conducted under the assumption that the material qualities were linear. When doing these non-linear analyses, severe earthquake zones were taken into account, and the results were evaluated using the kind II soil condition. Various responses, such as base shear and displacement, were computed, and it was found that as building height increased, so did displacement.[1] Compared to static analysis, the dynamic evaluation demands more steel in the structure's bottom beam. From the evaluation of columns, it is found that the proportion and distance of steel are higher for the dynamic load aggregate compared to the static load combination. Design and analysis of "The Story Shear Force." The loaded irregular building was discovered to be longer and larger and have more base shear in comparison to the same standard building structure. When applied in the x-direction (parallel to a shorter span), the load was at its maximum. The deflection increased with building height, and the base shear was 5% higher in the structural analysis and design program (STAAD) Pro case than in the manual calculation. In contrast to earthquake loads, wind loads are more crucial for higher structures, and wind loads provide a greater deflection than non-wind load structures. Considering the steel quantity in the traditional design, there was a 1.517% increase.[2]

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The safe and economical method for constructing a building with floating columns is the main topic of the study. "The effect of a floating column under seismic excitation for varied soil conditions." For 2D buildings with multiple floors, frames with and without floating columns, and linear dynamic analysis are performed. To achieve this, the G+4 and G+6 building models were made, which altered the floating column's orientation. Both buildings are then subjected to response spectrum analysis. For both building models, dynamic response characteristics are derived, including base shear and moment for hard and medium soil conditions.[3] To compile different studies on seismic analysis of high-rise structures, enhance the system's lateral stiffness, and research earthquake-resistant constructions using a variety of techniques. The research was thoroughly examined and mentioned in several papers, theses, and research fragments. The purpose of the literature review was to gather information and develop knowledge of various techniques and strategies that might be used in a comparative analysis of this project. To establish comprehensive guidelines for the complete project research activity, a literature review was conducted.[4] Similarly, a 35-story multistory skyscraper underwent an analysis across various hard soil types and seismic zones. Software called SAP 2000 is used to analyze these building models. Among the three bracing systems, one infill system had the lowest displacement variation, according to the structural performance analysis. As the height of the structure increases, the base shear decreases because the bracings and infills increase the structure's stiffness. The concrete infills have a significant impact on the structural capacity. In terms of time, infill systems have smaller displacements.[5]

According to story stiffness statistics, the reinforced cement concrete (RCC) structure with a shear wall performed better in terms of stiffness than a column, as the shear wall captures both in-plane and out-of-plane stiffness. When considering the non-linear P-delta effect in both the composite and RCC structures with a shear wall, the P-delta effect will counteract the consequences, as it increases the additional moments where the extra displacement occurs. The results indicate that steel structures should perform better during earthquakes than traditional RCC structures due to their greater ductility. Since steel structures are lighter than RCC components, they experience lower axial forces. In RCC structures, the bending moment and shear force in the beams are higher than in steel structures.[6] The chosen building was modeled using the ETABS software. The software produced the structure's response spectrum and time history. Two models were created by the codes – the British code specification as well as the Indian code. Push analysis seismic forces and load combinations are calculated under BS 8110-1997 and IS 1893-2002. To determine their stability, the data models are represented.[7] The impact of reinforced concrete structures' bracing systems on sloping terrain when subjected to wind loads. The diagonal brace, X-brace, V-brace, and inverted V-brace are the primary bracings selected for the buildings. To comprehend the dynamic responses of the buildings, encompassing displacement, story drift, axial shear, shear force, and bending moments, among others, numerical seismic analysis has been done. According to the study, the inverted V-bracing and X-bracing performed better.[8]

Repeatedly, two G+ stories are selected for the research, and both computerized and manual analyses are performed.[9] Structures experience stresses and deformations as a result of ground vibrations during earthquakes. Seismic codes in several countries provide methods to assist configuration builders in organizing, planning, calculating, and creating structures.[10] There are several approaches accessible in earthquake engineering, including seismic analysis and building structure design. Evaluation of the lateral load distribution and global displacements of external activities in high-rise structures is required. A review is given of the analytical framework that looks at the structural behavior of tall structures supported by bracings of any sort. Frames and thin-walled shear walls with closed or open sections are specifically taken into consideration. To further illustrate the method's capabilities, curves corresponding to the internal actions of a generic bracing and the distribution of lateral loads among several structural typologies have been presented.[11]

Objective of the study "To analyze and compare the structural behavior of multistoried residential buildings when subjected to seismic forces typical of Seismic Zones I (low seismic activity) and III (moderate-to-high seismic activity)." "To study various responses such as base shear, shear force, bending moment, axial force, inter-story drift, and story shear of buildings, and compare these responses between Zone I and Zone III to know the rate of change in responses between these two zones.

METHODOLOGY

The methodology for this study involves several steps to analyze and compare the seismic responses of a multistoried residential building located in Seismic Zone I (low seismicity) and Seismic Zone III (high seismicity). The study includes building modeling, seismic load application, and evaluation of seismic responses such as displacement, acceleration, and stress within the structure. Below is the detailed methodology:

Two 10-storied residential building structures have been selected for Zone I and Zone III with the same properties and measurements. Standard modern facilities, such as lifts, stairs, and car parking, were provided. Material properties for concrete (compressive strength and density) and steel (yield strength and modulus of elasticity) are selected according to the standard Bangladesh National Building Code (BNBC) 2020 Code. The building is assumed to be centrally located within the seismic zones (Zone I and Zone III), with no irregularities in shape or mass distribution. The soil type is assumed to be medium (Type II) according to seismic zone parameters.

Basement Floor

The basement floor has a total area of approximately 7130 square feet, with a clear floor-to-ceiling height of 10 feet. It has been constructed at a depth of about 7 feet below the existing ground level (EGL), ensuring adequate structural design and accessibility. The basement is primarily designed to function as a parking facility, providing accommodation for up to 13 cars in an organized manner. In addition to parking, the floor is equipped with essential vertical transportation facilities, including a single escalator and a stairway that provide seamless access from the basement up to the ninth floor. For improved utility and convenience, a dedicated ramp is also available, facilitating smooth vehicle entry and exit.

Ground Floor (GF)

The GF occupies an area of approximately 7130 square feet with a floor-to-ceiling height of 10 feet. It has been constructed at an elevation of about 5 feet above the EGL, ensuring proper clearance and protection against surface water or flooding. The floor is designed to provide multiple functional spaces, including 16 designated parking spots for vehicles, a guard room to ensure security and supervision, one bathroom for convenience, and a dedicated generator room to accommodate essential backup power systems. Vertical circulation is well integrated within the floor, with a single escalator and a staircase providing uninterrupted access from the ground level up to the ninth floor. In addition, a dedicated ramp connects the GF to the basement level, ensuring smooth vehicular movement between floors.

From a structural safety perspective, special consideration has been given to seismic conditions prevalent in Bangladesh. The country is known to have significant earthquake risks, particularly in high-risk zones such as Dhaka, Chittagong, and Sylhet, due to their proximity to active fault lines. This makes earthquake-resistant design a crucial factor in modern construction practices. Adhering to the BNBC, structural systems are engineered to withstand seismic forces, which are typically measured in terms of ground acceleration relative to gravity (g). The BNBC's seismic zoning classifications guide engineers in determining appropriate design parameters for different locations, ensuring resilience against different levels of seismic activity. Beyond structural compliance, ongoing improvements in earthquake preparedness, public awareness, and resilient infrastructure development remain critical in minimizing risks and protecting human life.

First Floor to Ninth Floor

The design adopts a symmetrical layout, comprising four independent residential units on each floor. Each unit incorporates a dining space measuring 22'-0" × 13'-5", a living room of 15'-10" × 12'-0", and one or more bedrooms of 16'-0" × 12'-0". Kitchens are dimensioned at 10'-0" × 8'-0", with attached toilets measuring 10'-0" × 5'-0". Every unit is provided with a balcony of 4'-0" × 11'-0", ensuring adequate ventilation and outdoor space. The vertical circulation core, centrally located, consists of a staircase and a lift, ensuring efficient movement between floors. The plan is designed to maintain uniformity, functionality, and structural balance across all levels of the building.

Data Analysis

The structural analysis of the multistoried residential building was conducted using ETABS software, following the provisions of BNBC 2020. A comprehensive three-dimensional model of the structure was developed, incorporating the architectural layout, column positioning, beam configurations, and slab systems. Material properties such as concrete grade, reinforcement strength, and sectional dimensions were carefully defined. Various loads, including dead load, live load, finishes, wall loads, and lateral forces, were assigned as per code requirements. Special attention was given to seismic loading, where the building model was analyzed separately for Seismic Zone I and Seismic Zone III, as classified in BNBC 2020. Appropriate load combinations were applied to capture the building's behavior under different loading conditions. The primary objective of this study was the comparison of seismic responses of multistoried residential buildings in Seismic Zones I and III, focusing on parameters such as story displacement, inter-story drift, base shear, and overall stability. The analysis results provided valuable insights into the performance variation of the same structural system under different seismic intensities, ensuring a deeper understanding of safety and serviceability requirements.

Lateral Load

Seismic load data

Seismic load refers to the forces or stresses that a structure experiences due to earthquakes or ground motion. These loads are generated by the shaking of the ground caused by seismic waves during an earthquake and are a critical consideration in the design and construction of buildings, bridges, dams, and other infrastructure, especially in earthquake-prone areas.

Wind load data

(Zone I)	(Zone III)
Wind pressure, V_b=44.44 m/s Importance factor, I=1.0 Topographical factor, k_{zt}=1.0 Gust factor, G=0.875 Wind directionality factor, k_d=0.85 Exposure height (Base to overhead water tank, including parapet height=3 ft)	Wind pressure, V_b=55.56 m/s Importance factor, I=1.0 Topographical factor, k_{zt}=1.0 Gust factor, G=0.875 Wind directionality factor, k_d=0.85 Exposure height (Base to overhead water tank, including parapet height=3 ft)

(Zone I)	(Zone III)
Height of building (Base to Roof), h_n=232 ft (70.72 m) Length of building, L=105 ft (y direction) Width of building, B=73.5 ft (X direction) Seismic zone coefficient, Z=0.12 Site class=SB Soil factor, S=1.15 Response reduction factor, R=6.5 System overstrength factor, Ω_0=2.5 Deflection amplification factor, C_d=5 Importance factor, I=1.0 Time period, T=1.278 s 0.2 s. spectral acceleration, S_s=0.3 1 sec spectral acceleration, S_1=0.2 Long period transition period=2 s Site coefficient, F_a=1.2 Site coefficient, F_v=1.5	Height of building (Base to Roof), h_n=232 ft (70.72 m) Length of building, L=105 ft (y direction) Width of building, B=73.5 ft (X direction) Seismic zone coefficient, Z=0.28 Site class=SC Soil factor, S=1.15 Response reduction factor, R=6.5 System overstrength factor, Ω_0=2.5 Deflection amplification factor, C_d=5 Importance factor, I=1.0 Time period, T=1.278 s 0.2 s. spectral acceleration, S_s=0.7 1 sec spectral acceleration, S_1=0.36 Long period transition period=2 s Site coefficient, F_a=1.15 Site coefficient, F_v=1.725

RESULT AND DISCUSSION

Check Torsional Irregularity

The results for torsional irregularity ratio in seismic Zones I and III, as shown in Figure 1, indicate the building's response to seismic forces in the X direction. Torsional Irregularity refers to the twisting or rotational movement of a building due to an asymmetrical distribution of mass or stiffness. The torsional irregularity ratio is calculated by dividing the maximum displacement of a floor by its average displacement, and a ratio near 1.0 suggests a regular response. In Zone I, the ratios range from 1.003 at the overhead water tank (OHWT) to 1.199 at the GF, with most floors showing regular behavior. In Zone III, the ratios are similar, ranging from 1.004 at the OHWT to 1.168 at the GF [Figure 1]. The highest torsional irregularity is observed at the GF in both zones, but overall, the building maintains a uniform response to seismic forces, with the ratios remaining close to 1.0 throughout the structure.

Check for Story Drift (Earthquake)

The story drift results for Seismic Zones I and III, as shown in Table 1, indicate the relative horizontal displacement between consecutive floors due to earthquake forces in the X direction. Story drift is calculated as the difference in displacement between two adjacent floors, divided by the height between them. In Zone I, the drift values increase with height, ranging from 0.354 at the GF to 0.761 at the ninth floor, indicating a moderate response to seismic forces. In Zone III, the drift values are higher, with the GF experiencing 0.552 and the fourth floor reaching 1.454, reflecting the stronger seismic activity in this zone [Table 1]. Overall, the results suggest that the building exhibits acceptable lateral displacement, with no critical drift that would compromise its stability under seismic loading in both zones.

Table 1: Story drift due to earthquake in X direction

Story No.	Elevation	Zone I	Zone III
	ft	Story drift	Story drift
OHWT	123	0.289	0.314
Stair case	112	0.383	0.396
Machine room	106.167	−0.114	−0.362
Roof	103	0.668	0.723
9th	93	0.761	0.876
8th	83	0.862	1.043
7th	73	0.959	1.202
6th	63	1.036	1.331
5th	53	1.081	1.419
4th	43	1.085	1.454
3rd	33	1.033	1.420
2nd	23	0.906	1.280
1st	13	0.693	1.014
GF	3	0.354	0.552

OHWT: Overhead water tank, GF: Ground floor

Table 2: Sway limitation due to lateral displacement

Building height, ft	Load combination	Zone I	Zone III
		Lateral displacement	Lateral displacement
130	D+0.5L+0.7Wx	1.061	0.391
130	D+0.5L−0.7Wx	1.505	0.414
130	D+0.5L+0.7Wy	1.059	0.467
130	D+0.5L−0.7Wy	0.962	0.445

Check Sway Limitation

The results for sway limitation due to lateral displacement, as shown in Table 2, present the building's response to lateral forces in Seismic Zones I and III under various

Table 3: Modal participating mass ratio

Structure type	Modal mass participation				
	Sum UX	Sum UZ	Sum RX	Sum RY	Sum RZ
For Zone I model	99.99%>91%	99.99%>91%	99.99%>91%	99.99%>91%	99.99%>91%
For Zone III model	99.99%>91%	99.99%>91%	99.99%>91%	99.99%>91%	99.99%>91%

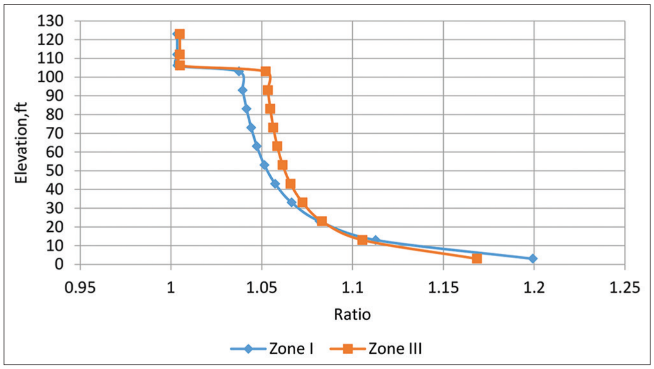

Figure 1: Torsional irregularity ratio due to earthquake in X direction

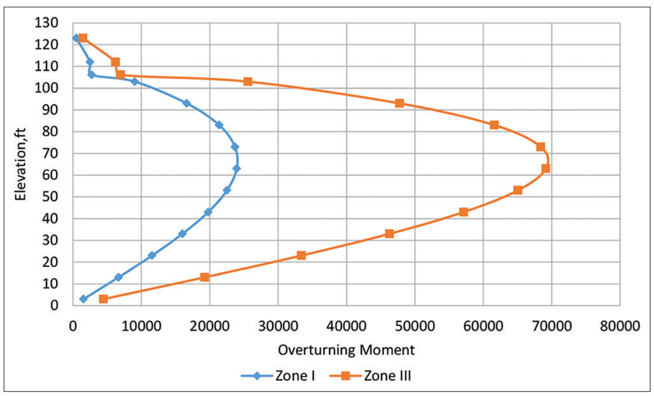

Figure 2: Story overturning due to an earthquake

load combinations. Sway limitation refers to the maximum allowable lateral displacement of a building, ensuring that it does not undergo excessive swaying or horizontal movement that could compromise its stability or functionality. This displacement is calculated by evaluating the horizontal movement of the building's top relative to the base, considering various loads, including dead load (D), live load (L), and lateral wind or seismic forces (Wx, Wy). The values provided in the table for Zone I and Zone III show lateral displacements for different load combinations. In Zone I, lateral displacements range from 1.061 ft under the D+0.5L+0.7Wx combination to 1.505 ft under the D+0.5L–0.7Wx combination. In Zone III, displacements are generally lower, with values ranging from 0.391 ft under D+0.5L+0.7Wx to 0.467 ft under D+0.5L+0.7Wy [Table 2]. These results demonstrate that the building remains within acceptable sway limits in both zones, ensuring its stability and serviceability under seismic and wind forces.

Story Overturning due to Earthquake

The story overturning results for Seismic Zones I and III, as shown in Figure 2, represent the overturning moment at each floor due to earthquake forces applied in the X direction. Story Overturning refers to the rotational effect or moment experienced by each floor of a building when subjected to lateral seismic forces, which can lead to the building overturning or tipping over if the moments exceed the structure's stability limits. The overturning moment is calculated by multiplying the applied lateral force by the distance from the center of mass (typically the building's base or center of gravity) to the point of application of the force. The results show that in Zone I, the overturning moments range from 1547.478 ft-lbs at the GF to 16636.677 ft-lbs at the ninth floor. In Zone III, the moments are significantly higher, ranging from 4470.582 ft-lbs at the GF to 47763.777 ft-lbs at the ninth floor, reflecting the higher seismic forces in this zone [Figure 2]. These values help in understanding the building's response to lateral seismic forces and the potential risk of overturning due to excessive seismic moments at higher floors.

Check for Modal Participating Mass Ratio

The modal participating mass ratio for both Zone I and Zone III is shown in Table 3. The analysis shall include a sufficient number of modes to obtain a combined modal mass participation of at least 91% of the actual mass in each of two orthogonal directions. After 91 number of modals, the modal mass participation ratios are as follows:

CONCLUSIONS

- The study confirms that a multistory residential building behaves significantly differently in Seismic Zones I and III. In Seismic Zone I (low seismic risk), the building experiences lower base shear, lateral displacements, and accelerations. These lower values suggest that the building's existing design is sufficient to withstand the seismic forces in this zone, and no significant structural modifications are necessary
- In contrast, Seismic Zone III (high seismic risk) results in much higher seismic forces. The base shear, lateral displacements, and accelerations increase substantially, indicating that the building faces significantly more stress and potential damage during an earthquake. The increased forces lead to higher demands on the structural elements, which could cause failure or severe damage to the building unless reinforced

- For both Zone I and Zone III, the story has no exhibit mass irregularity, torsional irregularity, re-entrant corners, or diaphragm discontinuity
- Both structures have the same value of modal participating mass ratio in both X and Y directions, which is 99.99%
- The value of story drift for earthquakes was less than allowable drift; hence, for both zones, the structures are stable
- In Seismic Zone III, the top floors experience much larger lateral displacements and accelerations compared to Zone II. This suggests that without proper seismic reinforcement, the building could experience uncomfortable shaking for occupants, and its structural integrity could be compromised under strong seismic events.

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